Evaluation of Optical Radiation Hazards from Plasma Arc Cutting Operations

Eric Glassford, MS, CIH
Gregory Burr, CIH

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a steel building materials manufacturer who was concerned about optical radiation hazards from a plasma arc cutting system and eye protection requirements for plasma operators, other employees, and visitors. We visited the company in February and April 2016.

What We Did

- We observed employees performing plasma arc cutting.
- We measured the strength of the ultraviolet, visible, and infrared light the plasma arc cutter generated at various distances from the source. We also measured it at different amperages.

What We Found

- We measured optical radiation above safe levels for the unprotected eye in the ultraviolet-C, ultraviolet-B, and visible light ranges.
- Infrared and ultraviolet-A radiation levels during plasma arc cutting were similar to background levels when no cutting was done.
- The welding curtain surrounding the plasma arc cutter reduced optical radiation exposures to the operator and other employees in the area.
- The small (1 inch) gap between the welding curtain and the steel being cut allowed some optical radiation to be visible at the safe walkway area due to the viewing angle.

We evaluated the ultraviolet, visible, and infrared light hazards generated from a plasma arc cutter. We measured visible and ultraviolet light levels above safe limits for unprotected eyes. We recommended using the welding curtain as much as possible and modifying the curtain to further reduce or eliminate accidental viewing of the plasma arc. Employees should wear welding eye protection of shades 4, 5, or 8, depending on the plasma arc cutting task and amperages.

What the Employer Can Do

- Require a shade 8 welding lens for the plasma operators when performing a zero-zero alignment and rip cutting regardless of amperage.
- Require a shade 8 welding lens for activities that require removing or altering the welding curtain.
- Require a shade 4 welding lens for the plasma arc operators when running the plasma arc cutter at 130 amperes.
- Require a shade 5 welding lens for the plasma arc operators when running at 260 amperes.
- Require visitors and other employees in the safe walkway area to wear at least shade 3 welding lenses when the plasma arc cutter is in operation.
- Evaluate ways to reduce or eliminate the gap between the welding curtain and the steel

slab being cut.

- Require the plasma operator to wear welding shade protection that covers the entire face.
- Post signs that warn employees and visitors of the optical radiation hazard and the requirement for PPE during plasma arc cutting.
- Revise training and hazard communication procedures to reflect changes implemented on the basis of our recommendations.

What Employees Can Do

- Use the plasma arc cutter welding curtain whenever possible.
- Wear required eye protection.
- Report eye injuries or symptoms of exposure from optical radiation to the employer and your doctor.

Abbreviations

μW/cm^2	Microwatts per square centimeter
ACGIH®	American Conference of Governmental Industrial Hygienists
amps	Amperes
ANSI	American National Standards Institute
cd/cm^2	Candelas per square centimeter
cd/m^2	Candelas per square meter
CFR	Code of Federal Regulations
HHE	Health hazard evaluation
IR	Infrared
mW/cm^2	Milliwatts per square centimeter
nm	Nanometer
nW/cm^2	Nanowatts per square centimeter
NIOSH	National Institute for Occupational Safety and Health
OD	Optical density
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PAC	Plasma arc cutting
PPE	Personal protective equipment
REL	Recommended exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
UV	Ultraviolet
W/cm^2	Watts per square centimeter

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Introduction

The Health Hazard Evaluation (HHE) Program received a request from a steel building materials manufacturer concerning exposures to optical radiation hazards during plasma arc cutting (PAC). The company asked for guidance on the appropriate shaded protective eyewear for employees during PAC operations. We visited the company in February 2016 to observe work activities and processes, measure optical radiation levels during PAC, and assess potential controls. We returned to the facility in April 2016 to perform additional measurements for visible light radiation.

Background

An Occupational Safety and Health Administration (OSHA) compliance officer had inspected the facility and cited the company for employees not wearing the correct shade number during PAC. The compliance officer based the citation on 29 Code of Federal Regulations (CFR) Part 1910.133(a)(5), which stipulates a welding lens shade 8 on the basis of the amperages used during the PAC [CFR]. The OSHA inspector also suggested the company contact the HHE Program for an optical radiation evaluation.

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 3 welding glasses, while the plasma arc cutter operators were required to wear shade 5 welding glasses. The company reported no eye injuries from welding, cutting, or brazing activities. The company was concerned that requiring employees in the vicinity of a plasma arc cutter to wear the darker shade 8 welding glasses would create safety hazards, for example not clearly seeing overhead cranes moving unfinished and finished materials.

Nonionizing Radiation

Welding, cutting (e.g., PAC), and brazing emit nonionizing radiation energy over a broad range of wavelengths, typically from 100 nanometers (nm) to 10,000 nm. This range includes ultraviolet (UV) radiation from 200–400 nm, visible light radiation from 400–760 nm, and infrared (IR) light 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) [Plog 2001]. Eye exposures to UV, high intensity visible, and IR light can cause thermal and photochemical eye injuries [Anna 2011].

Plasma is an electrically conductive, ionized gas. Plasma arc cutting is the process of cutting electrically conductive materials using a jet of hot plasma [Messer 2016]. 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.

Process Description

At the time of this evaluation the company had approximately 253 employees on-site, and work occurred over three, 8-hour shifts. Typically three PAC operators worked per shift, and cutting occurred for about 2.5 hours of an 8-hour shift. The PAC operators spent their remaining time moving unfinished and finished materials into and out of the PACs and adjusting the computer-controlled PAC systems for the desired cutting design. Other employees worked in adjacent areas moving materials or in product finishing. The company had marked safe walking paths for employees and visitors and areas where forklift traffic and overhead crane work intersected the walking path.

The company used two identical Messer Cutting Systems computer-controlled PAC systems to cut sheets of carbon steel to desired shapes. The PAC systems had light barrier sensors that shut the PAC systems off if employees entered restricted areas with moving parts. The PAC systems, designated as north PAC and south PAC, operated at 130 amperes (amps) 95% of the time. For thicker steel sheets cutting was performed at 260 amps.

Following the OSHA inspection the company installed a 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. During our February 2016 site visit a company designed welding curtain was installed on the north PAC and a factory designed curtain on the south PAC. The company was determining which curtain design was more durable and easier for the PAC operators to use. By the time of our April site visit the company was using the PAC manufacturer-designed curtain for both systems. The welding curtain design blocked the plasma arc over a 180-degree viewing range.

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

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 curtain had to be opened to allow the PAC operator to precisely see the starting point for the cut. The PAC operator wore shade 8 protective eyewear that consisted of a flip-down tinted lens mounted to his hard hat. The zero-zero alignment occurred about 3 to 4 feet from the plasma arc head. Once the arc was struck the PAC operator closed the curtain and let the computer guide the remaining cutting. The PAC operators also had the option to use joysticks to manually guide the cutting.

Occasionally, the PAC operator performed a "rip cut" that was perpendicular to the cuts on the metal sheet. Because a rip cut may only be a few inches in length the PAC operator opened the curtain and stood within 3–4 feet of the plasma arc to have a clearer view. However, the welding curtain remained attached to the plasma cutting head to shield viewing by other PAC operators and nearby employees.

The PAC operator performed other tasks in the immediate area that did not require direct viewing of the ongoing PAC operations. These tasks included off-bearing of metal pieces and working on paperwork at a computer station and standing desk. The computer station was between the two PAC systems, close to the off-bearing end.

During operation, the distance between the operator and the arc generated from the PAC system varied as the head of the system moved to complete the cut design on the metal slab. The distance from the cutting head to the PAC operators typically ranged from 10 feet up to 45 feet, but could be longer. Figure 2 shows 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 other company employees not involved in the operation could stand in the safe walkway with a direct view of the PAC systems approximately 35–70 feet away.

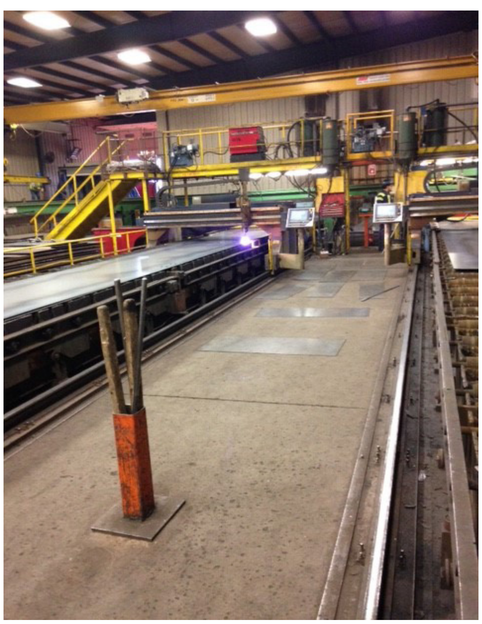

Figure 2. View of the intense visible light generated from an operating PAC without attached welding curtains at a typical distance an employee may stand. Photo by NIOSH.

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.

Methods

Our objectives 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 may come into the viewing area of the PAC systems.

Direct-Reading Measurement

During our first visit we measured UV, visible, and IR radiation levels using an International Light Technologies ILT1700 research radiometer/photometer with four different detectors. The detectors measured different wavelength bands of light and had different units of measurement; some detectors had filters to further narrow down the wavelengths of light that we wanted to measure. On the basis of our professional judgement we did not consider the visible light measurements obtained during our February 2016 visit to be accurate, and thus they are not presented. During our return visit in April 2016, we used a Konica Minolta LS-110 luminance meter to reassess the visible light levels. Table 1 is a summary of the direct reading instruments we used.

Table 1. Summary of direct-reading instruments used

Detector/Instrument	Instrument unit of measurement	Light wavelength band measured (nm)
SED240*	Effective‡ W/cm^2	200–315
SED033*	W/cm^2	315–400
LS-110†	cd/m^2	400–760
SED033*	cd/m^2	400–760
SED623*	W/cm^2	760–10,000

W/cm^2 = watts per square centimeter

cd/m^2 = candelas per square meter

*Used with ILT1700 radiometer/photometer instrument

†Konica Minolta luminance meter

‡Biological effective units

We measured the UV-A, UV-B, UV-C, visible, and IR energy emitted from the PAC systems under two power levels: 130 amps and 260 amps. We also measured these nonionizing radiation levels at varying distances from the PAC systems to determine nearby employees' and visitors' potential exposures. We measured distances to the PAC head during sampling using a laser distance meter. We also measured nonionizing radiation with and without the welding curtains in place.

Calculating Optical Density

To compare our nonionizing radiation measurements to applicable occupational exposure limits (OELs) for eye exposure based on the wavelength of light, we had to convert our field measurements to the same units as the OELs. Once the measurement units were converted, we calculated the optical density (OD), a measure of the effectiveness of a filter, like the filtered lenses worn for lasers, welding, or PAC operations [Stewart et al. 2005]. As part of the OD calculation, we input the value we wanted to compare with our measurement. We set this value to our chosen OEL for the portion of radiant light energy we were measuring. For additional information on OELs, see Appendix B.

Once we calculated the OD, we determined what the equivalent shade number would be for each of the radiant energy types. The shade number is a function of the OD and is used to describe welding eye protection [Stewart et al. 2005]. The shade number calculation reflects broadband attenuation of optical radiation energy and includes protection to visible, UV, and IR radiation [Anna 2011].

The formulas to calculate the OD and shade number are listed below:

$OD = [\log \frac{Measurement}{OEL}]$; where the OEL is the level at which one can be exposed to without adverse eye effects from the optical radiation energy

$$\text{Shade number} = \left[\frac{7}{3} \times OD\right] + 1$$

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 for that portion of radiant energy and thus no protective shaded eyewear is required. In our recommendations for appropriate safety eyewear to bring eye exposure levels to safe levels, we chose the highest shade number calculated for each scenario and spectral region evaluated.

Results and Discussion

Our results are presented in Tables 2–3 by type of radiant energy measured, sample location, approximate distance from the PAC systems, and the OD and protective shade number. For unadjusted and negative values, see Table A1–A4 in Appendix A. Background readings (not shown) were collected prior to the operation of the PAC systems.

In this evaluation interpreting results obtained from fixed measuring locations was challenging because the PAC head was constantly moving toward or away from where the measurement was being made (either the location of the PAC operator or nearby employees). Additionally, the plasma arc became visible at certain points, particularly during edge cuts, where the plasma torch head was cutting near the edges of the metal sheets and the arc was fully penetrating (blowing through) the metal being cut. We also noticed that our radiation measurements fluctuated and depended on the sensor's focal point relative to the plasma arc. Compared to ILT1700, the focal point was easier to control with the LS-110 luminance meter because it had a targeting icon in the focal lens. As a result, we used the peak values recorded for our sample result.

Visible Light

Our visible light measurements are presented in Table 2. The American Conference of Governmental Industrial Hygienists (ACGIH) has threshold limit values (TLVs) for specific wavelengths of visible light, for example light in the blue spectrum or intense visible light causing retinal thermal damage for unprotected eyes [ACGIH 2016]. However, calculating specific TLVs on the basis of spectral data of a visible light source is required only if the luminance (intensity) of the source exceeds 1 candela per square centimeter (cd/cm^2) [ACGIH 2016]. Therefore, we used a value of 1 cd/cm^2 as our threshold OEL to indicate whether exposure to the eye was above safe levels and to determine an appropriate protective shade. Please see Appendix B for more information on nonionizing radiation OELs.

Table 2. Summary results of visible light (400–760 nm) measurements

Location description	PAC amperage	Result (cd/cm^2)	Calculated OD* (unitless)	Shade number*† (unitless)
3–4 feet from arc during zero-zero task, with curtain, plasma arc partially visible	130	8	1	4
3–4 feet from arc, with curtain, no visible plasma arc	130	1	0	1
3–4 feet from arc, rip cutting, no curtain, direct view of plasma arc	130	23	2	5
10 feet from arc, edge cutting, with curtain, direct arc view, some metal reflectance	130	9	1	4
10–15 feet from arc, with curtain, sparks and some metal reflectance	130	3	1	2
12 feet from arc, no curtain, direct arc view	260	87	2	6
5 feet from arc, no curtain, direct arc view	260	99‡	—	8‡
10 feet from arc, no curtain, direct arc view	260	57	2	6
18 feet from arc, no curtain, direct arc view	260	16	2	4
34 feet from arc, no curtain, direct arc view	260	5	1	3
46 feet from arc, no curtain, in safe walkway	260	3	1	2

*OD and shade number values are rounded up to the nearest whole number.

†A shade number 1 or less means no shaded protective eyewear is needed.

‡Visible light measurement exceeded the instruments' range of detection.

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. This meant that the visible light intensities exceeded the instrument's detection limit of 99 cd/cm^2. Because we could not measure above this level, we used the OSHA Filter Lenses for Protection Against Radiant Energy table in 29 CFR 1910.133(a)(5), which recommends a shade 8 welding lens for PAC below 300 amps.

Our measurements showed that the PAC curtain greatly reduced the visible light reaching the operator and nearby employees, regardless of the amperage, meaning that eye protection for visible light radiant energy would not be needed. However, we observed reflectance on the metal slab being cut and occasional periods where part of the plasma arc was visible, even with the welding curtains in place. During these instances we measured visible light intensities that resulted in welding shade lens numbers above 1. At lower amperages (130 amps), with the welding curtain in place, and at locations roughly 10 feet away, our measurements indicate that a welding shade protection of at least 4 should be used to protect eyes from viewing edge cuts and reflectance off metal.

At the safe walkway area (at least 35 feet from the PAC systems) part of the plasma arc could still be seen. This was because the welding curtain did not fully contact the metal slab being cut, and distance increased from the PAC system, the plasma arc became visible. At 35 feet from the PAC systems, we measured visible light energies (at 260 amp operation) that would require welding shade lenses of 3. At 130 amp operation, we did not measure visible light energies that would require eye protection. However, as discussed in the following section, UV light levels were high enough to require welding shade lenses of 3, or alternative eyewear designed specifically for UV protection.

Ultraviolet-C and Ultraviolet-B Light

Our UV-C and UV-B measurements are summarized in Table 3. 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 feet from the arc.

Table 3. Summary results of UV-C and UV-B (200–315 nm) measurements during PAC

Location description	PAC amperage	Result (effective μW/cm^2)	Calculated OD* (unitless)	Shade number*† (unitless)
10 feet, without welding curtain	260	6	2	5
10 feet, with welding curtain	260	0.5	1	3
35 feet, with welding curtain	260	0.5	1	3
10–15 feet, with welding curtain	130	0.02	−1	0
10–15 feet, without welding curtain	130	0.1	−1	1
35–40 feet, with welding curtain	130	0.4	1	3
35–40 feet, without welding curtain	130	0.3	1	3

μW/cm^2 = microwatts per square centimeter

*OD and shade numbers are rounded up to the nearest whole number.

†A shade number 1 or less means no shaded protective eyewear is needed.

At 130 amps and with a welding curtain in place, our measurements determined that welding shade numbers were below 1, indicating that the welding curtains were effective at controlling UV-C and UV-B exposures. However, when we recorded measurements during operations at 260 amps at the same distance and with welding curtains in place, we measured levels that indicate a welding lens shade 3 would be needed to bring eye exposures to safe levels. This increased exposure at 260 amps is likely caused by the plasma arc reflecting off the sheet metal surface, and from edge cuts.

We also measured levels of UV-C and UV-B approximately 35–40 feet from PAC operations, the location of the safe walkway area where visitors or employees could stand. At this distance, we calculated a welding shade lens of 3 was needed, even with welding curtains in place and at 130 amps.

Because we measured UV-C and UV-B light intensities that exceeded safe levels in locations where the visible light intensity was not above safe levels for the unprotected eye, we looked into specific eyewear for only UV protection. In these instances, eye protection that meets the American National Standards Institute (ANSI) standard for eye protection can be worn. This standard, ANSI Z87.1-2015, provides requirements for safety eyewear that is protective against UV light. These eyewear have a "U" marking with a number rating from 2 to 6 which indicates the degree to which UV light is reduced. This 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 safe walkway during PAC operations at 130 amps. This is the amperage that the PAC systems operate at 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.

Ultraviolet-A and Infrared Light

The UV-A and IR measurement results are shown in Appendix A. The levels were similar to background levels in the work area without the PAC systems operating. 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. National Institute for Occupational Safety and Health (NIOSH) investigators reached similar conclusions in a 1996 HHE at another facility where similar PAC systems and amperages were evaluated [NIOSH 1996].

Workplace Observations

We observed employees wearing the required PPE in the PAC area, as well as other areas of the facility. We did not see signs in the PAC areas warning employees and visitors of the potential for optical radiation hazards. We did not see welding curtains or panels around the PAC system area. These engineering controls are used commonly to protect employees and bystanders from optical radiation [Plog 2001]. However, because employees frequently used overhead cranes in this area to move raw and finished metal stock, panels and curtains may create obstacles in safely using overhead cranes.

Conclusions

Optical radiation hazards from UV-C, UV-B, 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 our measurements PAC operators should wear at least shade 5 eye protection for distances greater than 5 feet from the PAC head and when using a curtain. For tasks that require the PAC operators to be within 5 feet of the arc, and when a welding curtain cannot be used, PAC operators should use shade 8 eye protection. Modifying the PAC curtain design to further reduce or eliminate the gap between the curtain and the steel stock being cut will reduce the chance that employees and visitors in the surrounding areas inadvertently view the PAC arc.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the steel building materials manufacturer to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the company.

Our recommendations are based on an approach known as the hierarchy of controls (Appendix B). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Evaluate extending the PAC welding curtain further out from the plasma arc head or installing a welding curtain that drapes onto the metal. These changes will further reduce exposures and eliminate accidental viewing of the plasma arc in the safe walkway area.

Administrative

The term administrative controls refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently.

1. Post optical radiation hazard warning signs in the PAC operation area and the safe

walkway. The signs should indicate the required PPE for PAC operators, other employees, and visitors.

2. Routinely inspect and, as needed, replace welding curtains.
3. Revise training and hazard communication procedures to reflect changes implemented on the basis of our recommendations.
4. Consider audible or visual warning cues to indicate when 260 amp PAC work is performed if untinted eyewear that meets ANSI Z87.1-2015 with at least a U2 rating is implemented as PPE.

Personal Protective Equipment

Personal protective equipment is the least effective means for controlling hazardous exposures. Proper use of PPE requires a comprehensive program and a high level of employee involvement and commitment. The right PPE must be chosen for each hazard. Supporting programs such as training, change-out schedules, and medical assessment may be needed. Personal protective equipment should not be the sole method for controlling hazardous exposures. Rather, PPE should be used until effective engineering and administrative controls are in place.

1. Instruct PAC operators performing rip cutting or zero-zero alignment to wear at least shade number 8 during operation, regardless of the amperage. During all other PAC tasks, such as off-loading or working at the desk, the PAC operator should wear a minimum shade number of at least 4 during 130 amp cuts and at least 5 during 260 amp cuts.
2. Instruct employees or visitors using the safe walkway in the vicinity of the PAC to wear at least a welding lens shade 3 to protect their eyes from UV and high intensity visible light. For PAC tasks at 130 amps, clear (untinted) eye protection that meets ANSI Z87.1-2015 requirements with a rating of at least U2 (for UV radiation) could be worn in place of a shade 3 lens.
3. Re-evaluate the optical radiation hazards for PAC operating amperages above 260 amps, or refer to the OSHA *Filter Lenses for Protection Against Radiant Energy* table in 29 CFR 1910.133a(5) for the proper filter lens shade number.
4. Use welding shades that cover the entire face to protect exposed skin from UV radiation hazards.

Appendix A: Tables

Table A1. Results of visible light (400–760 nm) measurements at different locations, controls, and operating parameters

Location description	PAC amperage	Result (cd/cm^2)	Calculated OD (unitless)	Shade number* (unitless)
3–4 feet from arc, at PAC computer during zero-zero task, with curtain, plasma arc partially visible	130	7.8	0.89	3.1
3–4 feet from arc, at PAC computer, with curtain, no visible plasma arc	130	0.51	−0.29	0.3
3–4 feet from arc, PAC computer, rip cutting, no curtain, direct view of plasma arc	130	22.7	1.35	4.16
10 feet from arc, PAC operator desk, edge cutting, with curtain, direct arc view, some metal reflectance	130	8.7	0.93	3.18
10–15 feet from arc, PAC desk, with curtain, sparks and some metal reflectance	130	2.67	0.16	1.36
10 feet from arc, with curtain	130	0.0005	−3.31	−6.7
31 feet from arc, with curtain, sparks and reflections on metal	130	0.086	−1.06	−1.4
63 feet from arc, with curtain, sparks and reflections on metal	130	0.066	−1.18	−1.75
45 feet from arc, with curtain, in safe walkway, sparks and reflections on metal	130	0.079	−1.1	−1.56
40 feet from arc, no curtain, in safe walkway	130	0.51	−0.29	0.31
10 feet from arc, PAC operator desk, sparks and metal reflectance, with curtain	260	0.49	−0.30	0.29
35–40 feet from arc, in safe walkway, sparks and metal reflectance, with curtain	260	0.22	−0.64	−0.5
12 feet from arc, no curtain, direct arc view	260	87.3	1.94	5.5
5 feet from arc, no curtain, direct arc view	260	99†	1.99	5.6
10 feet from arc, no curtain, direct arc view	260	57	1.75	5.09
18 feet from arc, no curtain, direct arc view	260	16.1	1.21	3.81
34 feet from arc, no curtain, direct arc view	260	4.9	0.69	2.61
15 feet from arc, at PAC desk, with curtain, no direct arc view but some sparks	260	0.2	−0.68	−0.59
35–40 feet from arc, with curtain, some sparks and metal reflectance	260	0.77	−0.1	0.74
46 feet from arc, no curtain, in safe walkway	260	2.6	0.4	1.99

*A shade number 1 or less means no shaded protective eyewear is needed.

†Measurement was at the instrument's maximum response level.

Table A2. Results of UV-C and UV-B light (200–315 nm) measurements at different locations, controls, and operating parameters

Location description	PAC amperage	Result (effective μW/cm²)	Calculated OD (unitless)	Shade number* (unitless)
10 feet, without welding curtain	260	6	1.7	5.1
10 feet, with welding curtain	260	0.5	0.69	2.6
35 feet, with welding curtain	260	0.5	0.69	2.6
10–15 feet, with welding curtain	130	0.02	−0.82	−0.92
10–15 feet, without welding curtain	130	0.09	−0.046	0.89
35–40 feet, with welding curtain	130	0.4	0.60	2.4
35–40 feet, without welding curtain	130	0.3	0.53	2.2

*A shade number 1 or less means no shaded protective eyewear is needed.

Table A3. Results of UV-A light (315–400 nm) measurements at different locations, controls, and operating parameters

Measurement location description	Amperage of cutter	Result range (effective μW/cm²)	Optical density (unitless)	Shade number* (unitless)
3–4 feet, without welding curtain	260 amps	40	−1.4	−2.3
3–4 feet, with welding curtain	260 amps	1.3	−2.8	−5.7
10 feet, with welding curtain	130 amps	0.5	−3.3	−6.7
10 feet, without welding curtain	130 amps	0.28	−3.6	−7.3
35–40 feet, with welding curtain	130 amps	0.5	−3.3	−6.7
35–40 feet, without welding curtain	130 amps	0.3	−3.5	−7.2

*A shade number 1 or less means no shaded protective eyewear is needed.

Table A4. Results of IR light (760–10,000 nm) measurements at different locations, controls, and operating parameters

Measurement location description	Amperage of cutter	Result range (nW/cm²)†	Optical density (unitless)	Shade number* (unitless)
3 feet, without welding curtain	260 amps	0.015	−9.3	−20.7
3 feet, with welding curtain	260 amps	0.030	−8.5	−18.8
3 feet, without curtain up	130 amps	0.0030	−9.5	−21.2

*A shade number 1 or less means no shaded protective eyewear is needed.

†Result shown in nanowatts per square centimeter (nW/cm²), which were converted from the instrument readout in W/cm².

Appendix B: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a pre-existing medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short term exposure limit or ceiling values. Unless otherwise noted, the short term exposure limit is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH recommended exposure limits (RELs) are recommendations based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Other OELs commonly used and cited in the United States include TLVs, which are recommended by the ACGIH, a professional organization, and workplace environmental exposure levels, which are recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and workplace environmental exposure levels are developed by committee members of these associations from a review of the published, peer-reviewed literature. These OELs are not consensus standards. TLVs are considered voluntary exposure guidelines for use

by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2016]. Workplace environmental exposure levels have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2016].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/gestis/gestis-internationale-grenzwerte-fuer-chemische-substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

Table B1 is a summary of applicable OELs that apply to ocular hazards from nonionizing radiation, as well as the primary health effects from exposures above OELs for the wavelength band of light. In our evaluation, we used the lowest OELs as the basis for our OD calculation and shade number determinations [ACGIH 2016; NIOSH 1972]. It should be noted that for visible radiation, ACGIH has more specific TLVs than are in the table. We chose to use the threshold criteria of 1 candela per square centimeter criteria for determining the OD and shade number, as values under 1 candela per square centimeter do not require eye protection or further OEL determination according to Figure 1 of the optical radiation section in the ACGIH TLV booklet [ACGIH 2016].

Table B1. Occupational exposure levels used to determine effective eye protection

Physical agent	ACGIH TLV	NIOSH REL	OSHA PEL	Primary health effect
UV-C and UV-B (200–315 nm)	0.1 μW/cm² (effective)*†	0.1 μW/cm² (effective)*†	None	Photokeratitis and erythema
UV-A (315–400 nm)	1.0 mW/cm²‡	1.0 mW/cm²‡	None	Erythema
Visible (400–760 nm)	1.0 cd/cm²§	None	None	Retinal burns
IR (760 nm–1,000,000 nm)	10 mW/cm²‡	None	None	Cataracts, dry eyes and skin

mW/cm² = Milliwatts per square centimeter

*Biological effective units

†These values represent 8-hour exposures, but higher exposures are permitted in certain cases for shorter time periods.

‡These values are based on 17 minute exposures or greater.

§For any viewing duration

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Copies of this report have been sent to the employer and employees, and union at the facility. The state and local health department and the Occupational Safety and Health Administration Regional Office have also received a copy. This report is not copyrighted and may be freely reproduced.

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