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UV and Blue-Light Exposures in an Aluminum Shipbuilding Environment

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Abstract

Arc welding and flame cutting are sources of intense emissions in the ultra-violet (UV), visible, and infra-red (IR) regions of the electromagnetic spectrum. Reports about the level of these emissions rarely appear in published literature. This study reports on exposure to UV and blue-light emissions during fabrication of ship structures from uncoated aluminum. .Relative magnitude of UV emissions depends on the process in the sequence MIG (Metal Inert Gas) > TIG (Tungsten Inert Gas) > plasma arc cutting > flame cutting (oxyacetylene torch). Relative magnitude of blue-light emissions also depends on the process in the sequence MIG > TIG > plasma arc cutting > flame cutting (oxyacetylene torch). Flame cutting using oxyacetylene produced no emissions. MIG (Metal Inert Gas) welding produced very high emissions. Blue-light emissions exceeded UV emissions during plasma arc cutting and TIG welding. Relative production of UV versus blue-light emissions within a process depends on the actions of the welder.

Keywords: aluminum, blue-light exposure, UV exposure, welding

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I. INTRODUCTION

One of the realities of life on Earth is exposure to energy in the electromagnetic spectrum that irradiates the planet. The most common source of this energy is the Sun because of proximity to the Earth [1]. Two important regions of the non-ionizing part of the electromagnetic spectrum of concern to human health are the ultra-violet and the blue-light region of the visible spectrum [2]. Ultra-violet energy and energy in the blue-light region of the visible spectrum are prominent in emissions from the electric arc created during welding and similar processes. These emissions are also present in the arc flash created during separation of electrical conductors under load.

Ultra-violet energy is commonly applied in industrial processes. Usually and especially when high levels are present, the process is completely enclosed or at the least partly shielded in order to prevent exposure of workers and bystanders in the area.

Ultra-violet energy is also a product of some industrial processes. Again, usually and especially when high levels are present, the process is often completely enclosed or at the least partly shielded in order to prevent exposure of workers and bystanders in the area.

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This report focuses on measurement of ultra-violet and blue-light emissions from welding and cutting processes used in a shipyard engaging in aluminum fabrication. Arc welding processes employed in this shipyard included argon- and helium/argon-shielded metal inert gas (MIG) welding and tungsten-inert-gas-shielded (TIG) welding. Cutting processes included plasma-arc cutting and oxyacetylene cutting.

The welding arc is a widely recognized source of intense emission of visible and nonvisible (ultra-violet and infra-red) radiant energy [3]. Impenetrable fabrics and materials in clothing and protective equipment are the main line of defense against these emissions. Despite widespread recognition of the hazard (welder's flash and skin burns) posed by acute exposure to radiant emissions from welding arcs and ready availability of protective equipment, some workers failed to utilize full protective measures.

This was especially true of fitters, production welders who operated automatic welding machines, and other workers whose jobs required them to come into close proximity with the arc. (Fitters hold pieces of metal in position during initial welds to immobilize them.). Many of the fitters did not use eye or skin protection or used inappropriate equipment. They turned their heads to face away from the arc. This action may block exposure to the eyes, but leaves the skin of the face and neck unprotected from exposure. Some operators of automatic welding machines did not wear gloves. The need for dexterity in making adjustments to control and positional settings motivated this decision. As well, operators of this equipment must flip up the tinted shield or outer visor of the welding helmet in order to be able to see the controls.

While the fume collector hood on automatic welding machines has curtains for shielding the arc, some of these were routinely flipped up out of position. This was intended to provide an unshielded view of the arc. The frequent raising and lowering of the protective shield or visor during operation of this equipment increases the risk of unprotected exposure to the arc. This point is important, since this exposure occurs at close proximity, less than l m from the arc. Noninvolved bystanders also are at risk from exposure to welding arcs. A noninvolved bystander unprepared for the striking of the arc and startled by it could react in an uncontrolled manner that leads to injury.

An important consideration in this discussion is voluntary, deliberate suppression of the avoidance response. This is especially the case with fitters who adopted a heroic posture of avoidance to the extent permitted by the requirement to hold the work in a particular position.

While there is general recognition among the workforce about the acute hazard posed by exposure to welding arcs, there is little awareness about the hazard from chronic (long-term) exposure.

Surfaces of uncoated aluminum are highly reflective compared to coated steel. As well, arc welding and cutting processes involved in aluminum fabrication produce small amounts of fume compared to other types of welding and welding on coated surfaces. As a result, radiant emissions from the arc during work on aluminum are more of a concern than those from other metals. Structures in aluminum vessels contain large reflective surfaces that can reflect emissions from welding arcs in an unpredictable manner.

Radiant emissions produced by welding arcs generally occur in the ultra-violet, visible, and infra-red regions of the non-ionizing part of the electromagnetic spectrum:.Wavelengths in the ultra-violet region of the electromagnetic spectrum range from 180 to 400 nm (nanometres). (One nanometre is one billionth of a metre.) Wavelengths in the visible region range from 380-400 to 760-780 nm. Wavelengths in the infra-red region range from 760-780 nm to 1 mm. The eye and skin are the organs of concern for interaction with these types of radiant energy.

Radiant energy in the ultra-violet (UV) region is subdivided into three subregions: UVC, 100 to 280 nm; UVB, 280 to 315-320 nm; UVA, 315-320 nm to 380-400 nm [4]. The hazard is related to the region of the UV in which the energy occurs. The organs of concern are the eye and the skin [5]. Sources emitting UV energy at wavelengths below 250 nm produce ozone. The presence of ozone around welding operations is an indicator that these wavelengths are present.

The cornea (outer layer of the eye) and conjunctiva (membranes of the eyelids) strongly absorb UVB and UVC. The result from unprotected exposure is welder's flash (keratoconjunctivitis) [6]. Reddening of the skin (erythema) near the eyes also may occur. Only rarely does an exposure that causes welder's flash result in permanent eye injury. Wavelengths above 295 nm pass through the cornea and are absorbed by the lens. Cataracts result in laboratory animals from exposure to energy in the range, 295 to 320 nm.

Skin absorption of UVB and UVC causes reddening (erythema) or burning. Absorption of UVA can cause the same effect, but only at much higher levels. Maximum sensitivity of the skin to this type of injury occurs in the UVB region [5]. Chronic exposure to UVB also contributes to premature aging and wrinkling of the skin and skin cancers. Chronic exposure to UVA contributes to premature aging and wrinkling of the skin, photosensitizing reactions when certain drugs are used and development of certain forms of cancer.

Radiant energy in the visible region of the electromagnetic spectrum enters the cornea (outer layer of the eye) and is focused by the lens onto the retina. Very high exposures can cause thermal or photochemical injury [7].

Thermal injury results from a rapid rise in temperature in the retina. The retina cannot regenerate and therefore is highly at risk from this type of injury. According to some researchers, visible emissions in welding arcs are sufficiently intense to produce thermal retinal injury. High levels of exposure can cause permanent and irreversible defects in the visual field, as well as visual impairment. There is some controversy about this. This view is not universally accepted.

Photochemical injury is a chronic condition associated with premature aging of the retina. Photochemical injury results from absorption of radiant energy in the blue region (400 to 500 nm), the so-called blue-light region, by the retina. Welding arcs emit considerable energy in the blue region of the visible spectrum. Photochemical injury results from effects on pigments in the visual receptor cells in the retina [6] .

Radiant energy in the infra-red region of the electromagnetic spectrum is divided into three subregions: IRA, 760-780 to 1400 nm; IRB, 1400 nm to 3 µm; IRC, 3 µm to 1 mm [7].

Excessive exposures in the IRA region produce thermal damage in the retina. The eye focuses IRA energy onto the retina almost as effectively as visible light. IRB and IRC are absorbed in the water-containing regions of the eye. This absorption causes heating and thermal damage.

High levels of radiant energy trigger the aversion response of the eye. This results in involuntary blinking or deliberate closing of the eye. The aversion response substantially reduces the potential for hazardous exposure. Thermal discomfort sensed by the skin and cornea (outer transparent layer of the eye) will trigger an aversion.

II. MEASUREMENT OF ULTRA-VIOLET AND BLUE-LIGHT VISIBLE EMISSIONS

Ultra-violet and blue-hazard visible emissions were measured using a Solar Light PMA2100 datalogging unit connected to individual detectors (Solar Light PMA2120 for UV radiation) and PMA2121 for blue-light, respectively). The detectors were calibrated by the manufacturer. Both detectors are cosine corrected. The detectors were positioned and oriented to measure emissions in locations accessible to fitters and welders, as well as bystanders.

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The potential for damage to the detectors from metal spatter and projectiles precluded their use in personal dosimetry. Hence, the display of the PMA2100 datalogging unit was programmed to read instantaneous values

The detectors provide a single number output of the respective spectral region weighted according to hazard curves published by ACGIH (American Conference of Governmental Industrial Hygienists). There are hazard curves for the UV and blue-light regions, respectively [8], [9]. For broad-spectral sources the hazard curves weigh the impact of the exposure relative to damage produced at 270 nm for UV and 435 nm to 440 nm for blue light, respectively.

III. RESULTS AND DISCUSSION

Table I provides results from measurements of emissions from arc welding operations.

TABLE I. RADIANT EMISSIONS FROM WELDING OPERATIONS

Location/Description	**Distance** m	**Blue Hazard** µW/cm²	**Ultra-Violet** µW/cm²
Oxyfuel cutting torch			
cutting steel, helper position	1.5	0	0
Plasma arc cutting machine			
operator position, cutting aluminum	3 1.5	25 20 40	2 1.3 4.5
operator chair, maximum level	5		0.9
Argon-shielded metal inert gas (MIG)			
manual production welding on frames			
peak, beginning of weld typical	1 1	160 125	900 700
peak, beginning of weld typical	1.5 1.5	135 90	406 200
peak, beginning of weld typical	2 2	54 34	249 160
build-up welding on hull at keel (He/Ar mixture)			

closest helper position, obstructed path	1 1	73 52	249 311
	2 2 2	175 175 245	700 842 992
	3 3	41 41	103 133
A2, automated welding machine			
closest operator approach to arc for inspection, unshielded by curtains, path obstructed by torso	0.5	204 249 218 205	716 615
closest operator approach to arc for inspection, unshielded by curtains, unobstructed path	0.5	340 434 398 353 353 480 480 580	1141 1230 1010 1034 1273 1132
Bug, automated welding machine			
closest operator approach to arc for inspection, unshielded by curtains, path obstructed by torso	0.5	495 683 683 641	>1280 820
closest operator approach to arc for inspection, unshielded by curtains, unobstructed path	0.5	803 742 770 890 661 772 885 910	>1280 >1280 >1280 >1280 >1280 >1280 1070 >1280
	1.5	274 312 211 191 144 108 157 164	152 129 159 127 121 126 138

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	3	54 51 46 49 47 33 33 36 41 35 41	116 101 112 93 85
Tungsten inert gas (TIG) welding			
· touch-up work in frames, path obstructed by torso	1	2.1 2.2 2.5 2.8	0.7 0.8 0.8 0.8 0.8
· touch-up work in frames, unobstructed path	0.5	101 73 80 61 43	53 45 51
	1	28 30 24 43 37 51 31	17 22 18 17 16 18 17 20 18 18
Threshold Limit Value - Blue-Hazard Visible Radiation			
small angle (<2° at measurement position), duration <100 s/day		10,000/(seconds)	
small angle (<2° at measurement position), duration >100 s/day		≤100	
Threshold Limit Value - Ultra-Violet Radiation			
general calculation			3000/(seconds)
1 second exposure per day			3,000
1 minute exposure per day			50
10 minute exposure per day			5
30 minute exposure per day			1.7

Notes:

• is $\mu W/cm^2$ is microwatts per square centimetre, a unit of measurement of power delivered to an area of planar surface. microWatt is one millionth of a Watt. For point sources and small detector diameter, and distances as measured here, the unit of measurement provides accuracy within acceptable error [10].

• TLV is Threshold Limit Value. TLVs are published by the TLV Committee of the American Conference of Governmental Industrial Hygienists as guidelines for worker exposure .

The results indicate that welding and cutting produce different types and levels of emissions. Flame cutting using an oxyactylene torch, despite the intense emission in the visible region of the electromagnetic spectrum, is not a source of blue-light or UV radiation. Similarly, plasma arc cutting produces only low levels of emission.

In the case of blue-light emissions, the maximum permissible instrument reading is (10,000/seconds), where seconds refers to the exposure time in seconds. (This applies to times less than 10,000 seconds.) Conversely, for an instrument reading of 1000 $\mu W/cm^2$, the corresponding maximum permissible exposure time would be 10,000/1000 = 10 seconds. For an instrument reading of 100 $\mu W/cm^2$, the corresponding permissible exposure time would be 100 seconds.

The readings obtained in Table I suggest that exceedence of the Threshold Limit Value could occur where exposure duration is long, as in the case of operation of the plasma cutting machine, or where the exposure level is high. The latter is especially the case during MIG welding involving the robotic welding machines and manual production welding on long seams.

UV emissions predominated over blue-light emissions during MIG welding. In the case of plasma-arc cutting and TIG welding, blue-light emissions predominated over UV emissions. Argon or helium/argon shielded MIG welding is by far the most energetic emitter of both UV and blue-light radiation.

In the case of ultra-violet radiation, the maximum permissible instrument reading is (3000/seconds). Conversely, for an instrument reading of 1000 $\mu W/cm^2$, the corresponding maximum permissible exposure time during the workday of 8 hours would be 3000/1000 = 3 seconds. For an instrument reading of 100 $\mu W/cm^2$, the corresponding permissible exposure time would be 30 seconds.

Exposures during MIG welding easily could exceed the TLV.for UV exposure of the eyes and skin in the situations described here. Exceedence is also possible during TIG welding but much less so for plasma arc cutting.

The challenge in assessing exposure from discrete readings, as reported here, is to estimate the duration of exposure to the arc during the workday. Exposure varies according to the type of work. Fitting and tacking (small welds used to immobilize pieces) involve many exposures of short duration. In addition, these activities occur in proximity to production welding. Production welding involves manual welding (an extended version of tacking) and operation of automated welding units. Automated welding units can operate for periods easily extending to 15 minutes on long seams on large sheets of metal.

Due to its discrete nature (much like a single frame in a movie of thousands of frames), the data obtained in this study are not directly applicable for estimating the daily exposure of individuals. However, as indicated in articles in the technical literature, there is considerable evidence to indicate that individuals who work in close proximity to welding arcs, and in particular argon or helium/argon shielded metal inert gas welding, will be overexposed to UV and blue-hazard visible radiation. This technical information reinforces worker experience about bleaching of coveralls and radiation burns on unprotected skin. The best way to ensure that overexposure does not happen is through the use of personal protective equipment and enclosures.

Barriers traditionally have formed the basis of protection against optical radiation. Protection provided by a barrier depends on the relationship between the spectrum of the radiation source, absorption characteristics of the barrier and the spectral response of the eye and skin. The latter forms the basis for assessing exposure of unprotected eyes and skin contained in the TLV.

Sunscreens and sunblocks are cosmetic products that are applied on the skin [11]. These are blends of complex organic compounds that have the ability to absorb ultra-violet energy. These compounds re-emit this energy either as visible light or as heat. These substances are not without controversy, as some have been identified as potential carcinogens. As well, the consequences of long-term occupational, rather than casual recreational use of these products is unknown.

These products are tested on human volunteers. The test utilizes a lamp that produces a known intensity, rather than the sun. The test determines the length of time needed to produce reddening (erythema) of protected versus unprotected skin. The Sun Protection Factor is the ratio of the times needed to produce redness. To illustrate, an SPF of 15 means that protected exposure can occur for 15 times as long as the unprotected exposure before producing the same effect. This assumes that the lamp delivers energy at a constant rate and that the amount of energy needed to produce redness is the same in both cases.

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The approximate percent of UV energy blocked by a product having a given SPF is 100 % - (1/SPF). An SPF of 15 blocks about 93 % of the UV energy. An SPF of 30 blocks about 97 % of the UV energy. An SPF of 45 blocks 98 % of the UV energy. This calculation would suggest that increasing the SPF beyond 15 produces diminishing returns. While an SPF of 45 offers an improvement of only 1 % in protection against reddening, it offers considerably more protection against UVA than does an SPF of 30.

The spectrum of energies produced by welding arcs could differ from that produced by the lamp used in testing. This could produce differences in the level of protection offered by a product rated for protection against the sun.

The effectiveness of these products depends on the sensitivity of the underlying skin and the thickness of the application.

Fabrics and other impenetrable materials used in welding shields and helmets, coveralls, bibs, balaclavas and gloves have formed the basis for shielding the skin against welding emissions. There is little in the industrial hygiene literature regarding performance of these and other materials in the welding environment. Most of the information was developed through experience.

A recent study has indicated that typical summer-weight fabrics do not prevent the occurrence of skin tumors in mice. Similarly, a fabric that is effective against the sun does not provide guaranteed protection against other sources, such as the welding arc [12].

The Protection Factor (PF) is a rating of the effectiveness of a fabric in blocking ultra-violet. PF is the ratio of the effective dose without the barrier to the effective dose with the barrier. The Protection Factor is similar in concept to the SPF mentioned above. The PF uses filtered energy to mimic the response of the skin to the ultra-violet. The SPF relies on the actual response of the skin. The PF offered by a fabric is affected by bleaching and washing, erosion, creasing and development of leakage paths, such as holes and tears.

The ratio concept works the same as with sunblocks, as mentioned above. That is, an increase in the PF from 50 to 100 increases absorption from 98 to 99 %. PFs of fabrics tested for use in the sun range from 5 to 1000. Most lie in the range from 20 to 40.

Sliney and co-workers reported in an older study on the transmission of UV through fabrics used in work clothing [13]. The fabrics tested included leather, cotton, denim, Nomex, and other materials

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used in work clothing in industrial environments. The ratio of transmitted energy to incident energy was less than 0.0001 (0.01 %) for most fabrics. This was considered adequate for protection. (This study did not utilize the weighted measuring scale mentioned above.) The ratio of transmitted energy to incident energy in two lightweight fabrics (FR-8 Breeze and Nomex Green and Yellow) approached 0.01 (1 %). These and other fabrics that permit light transmission were deemed inappropriate for use in the welding environment.

The basis of eye and face protection for welders has been shaped structures that fit over the face and attach to the hardhat or are complete helmet-based units. Tenkate and Collins reported on average daily exposure of welders and bystanders who were using eye and face protection [14], [15]. While these studies were conducted in a steel fabrication shop, the nature of work performed by welders and others was similar to that performed in the facility described in this study. These authors found that the estimated daily eye exposure inside welding helmets at spectacles of welders and boilermakers exceeded the MPE (Maximum Permissible Exposure) by a factor of 4 to 5. Estimated exposures at spectacles of nonwelders were about 9 times the MPE. (The term, MPE, as used by these authors, has the same meaning as TLV.) These results strongly suggest that welders who do not wear eye protection under the welding shield and unprotected bystanders would receive exposures to the eye in the range of those mentioned here. These findings indicate that UV radiation enters the facial zone behind the welding shield, most likely by reflection off interior surfaces.

Tenkate and Collins also determined average daily exposures at the surfaces of clothing [14]. These ranged to 3,000 times the MPE for welders and 13 times the MPE for nonwelders. The former values were consistent with the estimates of Sliney et al. [13] mentioned in the previous section . As mentioned by Sliney et al., most fabrics used in work clothing provide protection at these levels and higher.

Despite the high levels of exposure, Tenkate and Collins [14] noted that none of the workers complained about or showed obvious signs or symptoms of acute exposure to UV radiation. These authors attributed this to the safety factors incorporated into the MPE (TLV). They estimate that the TLV for photokeratitis (welder's flash) has a safety factor of 5 and that for erythema (reddening of the skin) has a factor of 10. These factors ensure protection for all but the most sensitive of individuals. This discussion, of course, excludes consideration about chronic effects, mentioned previously.

Work performed by Eriksen on time profiles of spectra from welding arcs indicated that the newly struck arc emits considerably greater energy than that produced after several seconds [16]. Eriksen expressed concern about tack welders who close their eyes or move their heads to one side during short welds, instead of lowering their visors.

IV. CONCLUSIONS AND RECOMMENDATIONS

This study examined exposures at positions occupied by fitters, tackers, and production welders during arc welding and cutting on aluminum. Results strongly suggest the potential for overexposure of the eyes and skin to UV and blue-light visible radiation. The nature of the activity under which overexposure can occur, as described in the Introduction strongly argue for action to design protection against exposure to optical radiation from the arc into actions required to perform the work.

This concern is especially the case for operation of automated welding equipment. The need to be able to monitor the progress of the weld through viewing the unshielded arc and manipulation of controls to maintain operating parameters confounds the ability to protect these workers who are close in proximity to the source of the emission against overexposure..

All Personnel: All personnel in the area where this work is occurring should wear safety glasses containing sideshields at all times. Safety glasses containing nontinted lenses offer protection against most of the UV emissions. Individually fitted frames (as in prescription glasses) should be utilized.

Production Welders: Production welders must ensure that all areas of the skin and face are protected against exposure to the arc at all times, at minimum through wearing of fabrics having high resistance to penetration by UV and blue light. This must include the hands. This applies especially to operators of the automated welding machines. Operators of automated welding equipment should wear welding helmets and position the inner visor over the face at all times during operation of this equipment.

Tackers and Fitters: Tackers and fitters need equal levels of protection when the arc is struck. Skin protection (clothing, balaclavas/bib and gloves) in fitters is essential. The simplest means to ensure skin and eye protection of fitters is to require the wearing of a welding shield during the welding process.

These recommendations are consistent with and provide a basis for current recommended practises [17].

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