ABSTRACT

Objective: To investigate if the levels of optical radiation hazards in glassblowing are well classified according to the hazard types defined in the Canadian Standards Association (CSA) standard for industrial eye protectors.

Methods: We carried out radiometric measurements, and questionnaire survey in 4 university glassblowing laboratories, and 3 private studios.

Results: There is exposure to low levels of UV and IR radiation in all glassblowing operations. A supra-threshold IR radiation level exists in the craft glassblowing. The use of eye protectors is based on past experience regardless of the level of ocular exposure.

Conclusions: Optical radiation hazards exist in both craft and scientific glassblowing. There seems to be an inadequate understanding about radiation types encountered by glassblowers.

ABRÉGÉ

Objectif: Étudier si les niveaux des radiations électromagnétiques dangereux dans l'industrie de soufflage de verre sont bien documentés et conformes aux normes actuelles de la CSA (Canadian Standards Association), afin de déterminer si les souffleurs de verres utilisent adéquatement des protecteurs oculaires.

Méthodes : Des mesures radiométriques ont été prises dans quatre laboratoires universitaires de soufflage de verre et trois studios professionnels privés.

Résultats : Il y a un niveau relativement bas de radiation ultraviolet (UV) et infrarouge (IR) dans toutes les étapes de soufflage de verre, cependant il existe un niveau d'exposition plus élevé d'infrarouge dans le soufflage de verre au milieu professionnel. L'utilisation des protecteurs oculaires est basée sur l'historique et non sur le taux d'exposition oculaire.

Conclusions : Les dangers reliés aux radiations électromagnétiques existent aux deux niveaux de l'industrie de soufflage de verre, notamment scientifique et professionnel. Les souffleurs ont une compréhension insuffisante envers l'utilisation des lunettes protectrices et les différents types de radiation.

Eye Exposure to Optical Radiation in the Glassblowing Industry: An Investigation in Southern Ontario

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Glassblowing is a well-established industry which involves the shaping of a mass of glass into any form after the glass material has been heated to a viscous state. A wide variety of glass materials such as silica, soda-lime, potash, boron, quartz, and cobalt are handled in glassblowing. Eye care practitioners and industrial hygienists need to be able to advise on occupational eye safety and protection, based on an adequate knowledge of the noxious agents in the work environment. Glassblowing consists mainly of craft and scientific types, which use furnace and lathe heating systems, respectively. Optical radiation is encountered in glassblowing.

Optical radiation refers to that portion of the electromagnetic spectrum (EMS) ranging in wavelengths from 100 to 10×10^6 nm.¹ The different subdivisions of the optical radiation spectrum are shown in Table I. For convenience, wavelengths from 315 to 400 nm, and 700 to 1100 nm are designated as near-UV and near-IR radiation, respectively. Considerable hazardous levels of optical radiation are encountered in glassblowing operations daily.²⁻⁹ The harmful effects of the long-term ocular exposure to cumulative levels of radiation in glassblowing have been recognized since the late 19th century.² These effects include cataracts, pterygia, keratitis and chronic dry eye problems. The total optical radiation received by glassblowers

working near melting furnaces for approximately 8 hours daily was reported to be within the range of 2000 to 3000 J/cm². Approximately 10% of the total was in the near infrared (IR-A) waveband below 1400nm.¹⁰ Matelsky (1968)¹¹ reported that after daily exposure to IR irradiance at 0.08 to 0.4 W/cm² for 10 to 15 years, some glass and steel workers developed cataracts.

Apart from corneal and lenticular damage due to near-UV and near-IR, radiation-induced retinopathy also could occur from exposure to near-UV, and short wavelength visible radiation without a significant increase in the local temperature of the irradiated tissue.¹² For both short- and long-term safety, maintaining effective safety guidelines is critical in any workplace. As industrial processes change with technological advancement, the associated workplace hazards and protective measures need to be reassessed regularly. The literature provides few assessments of optical radiation hazards and ocular protection in glassblowing operations. The available census figures indicate that there are over 1,250 glassblowers (male 1,070; female 180) in Ontario.¹³ The number of glassblowers in southern Ontario could not be obtained in the government occupational category publication since most glassblowing installations employ fewer than 5 staff. Judging by the widely used end-products including decorative glass wares, light bulbs such as lead Osram-sylvania SG10, SG12, and Phillip lead glass replacement (barium-strontium) lamps, glassblowing is an integral occupational and public health aspect of society.

In the present study, we used the American Conference of Governmental Industrial Hygienists (ACGIH) recom-

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mended threshold limits¹⁴ for daily UV and IR radiation exposure to compare our on-site radiation measurements. Industrial hazards are classified in the CSA Z94.3-99 standard as following: group A (flying objects), B (flying particles, dust and wind), C (heat, glare, sparks, and splash from molten metal), D (acid splash and chemical burns), E (abrasive blasting materials), F (glare, stray light requiring slight reduction of optical radiation), G (injurious optical radiation requiring moderate reduction), and H (injurious optical radiation requiring large reduction).¹ The CSA standard (CSA-Z94.3-99)¹ is similar to the American National Standards Institute (ANSI) Z87.1 standard for occupational eye protection. The ANSI Z87.1 standard¹⁵ lacks specific information on glassblowing. The CAN/CSA-Z94.3-99¹ addresses performance requirements for industrial eye and face protectors mainly in craft (artistic) glassblowing operations, without consideration for scientific glassblowing. The present study conducted on-site radiation measurements, and assessed whether glassblowing activities are adequately classified under CSA hazard type definitions. The CSA hazards classification is used as the basis for selecting industrial eye and face protection against optical radiation (e.g., Appendix A of CSA-Z94.3-99).

MATERIALS AND METHODS

Participating glassblowing installations were recruited through advertisements in local newspapers, the internet, and telephone solicitations. Study questionnaires and informed consents were mailed or delivered by hand to all the respondents, with a 70% response rate (out of 10 glassblowing sites visited, only 7 agreed to participate). This study followed the Helsinki declaration and was approved by the University of Waterloo Office of Research. Scheduled visits were arranged with the participating sites, the purpose of which was to assess: 1) the nature of the glassblowing task, 2) visual demand and proximity of workers' eyes to radiation sources, 3) types of glass materials handled, and 4) the emission spectra of radiation encountered in the different glassblowing

operations. Radiation measurements were carried out in 4 university and 3 private glassblowing installations using a spectroradiometer (LI-COR Inc., Lincoln, NE, USA). The operating waveband of our spectroradiometer ranged from 300 to 1100 nm, which is sufficient for assessing ocular exposure to optical radiation since the cornea is opaque to wavelengths below 295 nm and above 1350 nm.^{16,17} Also, an aversion mechanism which will normally result from any slight corneal discomfort and reflex tearing would reduce the effect of near-IR radiation longer than ~1100 nm. It has been shown that all available glassblowers' eye protectors absorb or cut off wavelengths below 315 nm.⁹ During radiation measurements, an aluminum-coated heat reflector was used at all furnace installations to protect the radiometer from thermal damage. The radiometer was positioned 50 cm from the molten glass material, i.e., approximately the same position as the workers' eyes. The normal glassblowing operation was performed for each radiometric scan. Scans were made across the waveband 300 to 1100 nm at 5 nm intervals. Three measurements were taken for each of the glass materials in their molten state at all the participating installations. To determine the levels of workplace ocular hazard due to optical radiation sources, the ACGIH guidelines¹⁴ were followed. Results from our representative radiation measurements were used to determine the CSA hazard classification for glassblowing, considered in relation to ACGIH¹⁴ recommended exposure limits.

RESULTS

The irradiation values (in W/cm²/nm) obtained from the different glassblowing operations are shown in Table II. The results were analyzed using analysis of variance (ANOVA) and Student-Newman-Keul tests. For the statistical analysis to be valid, it was assumed the radiometric data were independent and random. The radiant emission spectra of the different glass materials are reported elsewhere.⁹ The scientific glassblower uses lathe and tabletop heating systems, while the craft glassblower uses furnace system to melt or reheat the glass materials. Our survey revealed that

TABLE I
Illustrating the Divisions of the
Optical Portion of Electromagnetic
Spectrum

Wavelength (nm)	Divisions
Below 100	X and γ rays
100 - 200	Vacuum UV
200 - 280	UV-C
280 - 315	UV-B
315 - 400	UV-A
400 - 700	Visible
700 - 1400	IR-A
1400 - 3000	IR-B
3000 - 10x10 ⁶	IR-C

Note: For the purpose of clarity in this communication, wavelengths within UV-A and IR-A divisions will be referred to as near-UV and near-IR, respectively.

only 66% of the glassblowers used eye protection 100% of the time. Eye protector usage among glassblowers is based on past experience regardless of the level of radiant emission from a particular molten glass material.⁹

Furnace works are classified under hazard groups F and G in the Canadian Standard (CSA-Z94.3-99)¹ for industrial eye and face protection, but neither craft nor scientific glassblowing is specifically listed. Table II shows the comparisons between the calculated glassblowing irradiation levels and the ACGIH recommended threshold limit values (TLVs).¹⁴ In the near-UV wavelengths (315-400 nm), all glass materials emitted UV irradiation at levels one tenth the TLVs. In the visible wavelengths (400-700 nm), all glass materials produced irradiance levels significantly higher than the TLVs (Table II). In the near infrared, only soda-lime glass has irradiance levels about 4 times higher than the TLVs.

DISCUSSION

The statistical analyses indicated that the four glass materials observed in this study (i.e., soda-lime, borosilicate, quartz and cobalt) produced irradiance levels which are significantly different ($p = 0.0001$) from each other. This would indicate that ocular exposure is different across the glass materials, which might invariably imply that different types of eye protector would be required for different glass materials. Craft glassblowing operations are classified under hazard

TABLE II
The Spectral Irradiance Values (Within the Near-UV, Visible and Near-IR Wavebands) of the Molten Glass Materials Compared to the American Conference of Governmental Industrial Hygienists Recommended Threshold Limit Values (TLV)

Waveband (nm)	TLV (W/cm ²)	Glass Material/Irradiance (W/cm ²)			
		Borosilicate	Cobalt	Quartz	Soda-lime
315-400 (near-UV)	1.00 X 10 ⁻³	0.10 X 10 ⁻³	0.11 X 10 ⁻³	0.14 X 10 ⁻³	0.154 X 10 ⁻³
400-700 (light)	1.00 X 10 ⁻⁶	5.40 X 10 ⁻⁶	1.32 X 10 ⁻⁶	11.40 X 10 ⁻⁶	3.80 X 10 ⁻⁶
700-1100 (near-IR)	10.00 X 10 ⁻³	0.60 X 10 ⁻³	0.13 X 10 ⁻³	1.80 X 10 ⁻³	38.50 X 10 ⁻³

Adapted from Oriowo, Chou and Cullen, 1997⁹

TABLE III
Suggested Recommended Protective Eye Wear for Glassblowing Operations

Glassblowing Type	Glass Material	Recommended Eye Protection	
		Low/Medium Heating	High Heating
Craft	Soda-lime	Filterweld (≥2.5)*	Filter weld (≥2.5)*, or Calobar lenses
Scientific	Borosilicate	Didymium lenses	Didymium with transparent UV & IR cut-off filters
Scientific	Quartz	Filterweld (≥2.5)*, Calobar, copper-plated face shield	Same as under medium heating
Scientific	Cobalt	Didymium lenses	Didymium with UV & IR filters

Note: A type of effective IR and UV radiation filter is polycarbonate which is vacuum deposited with a copper metallic coating, and overlaid with quartz for durability. This provides 100% protection against UV radiation down to 280 nm and 96% protection against IR radiation up to 5000 nm. To control for any intense visible radiation, the polycarbonate lens may be dyed any colour.¹⁹

* Protective lenses with shade number equal or greater than 2.5 is advised.

groups F & G in the CSA-Z94.3-99 standards.¹ Hazard groups C and H are other classifications in the CSA standard that can apply to glassblowing. In our survey we found that soda-lime glass is the main material handled by craft glassblowers, while scientific glassblowers handled quartz, borosilicate and cobalt materials. Review of the literature reveals that no previous attention has been specifically given to scientific glassblowing in the optical radiation hazard classification. Our results show that the irradiance levels from the near UV (315 to 400 nm) wavelengths for the glass materials (Table II) are below the threshold limits (TLVs) recommended by ACGIH.¹⁴ However, in the visible spectrum (~400 to 700 nm), all the molten glass materials produced high intensity visible light greater than the TLVs. This high intensity visible light may be sufficient to cause chronic retinal damage in an unprotected eye. In the near-IR waveband (~700 to 1100 nm), irradiance levels from the heating furnaces

were higher than the near-IR TLVs. The quartz glass material, which demonstrated a continuum of spectral emission across the wavelength region, produced the highest irradiance levels of the glass materials used in scientific glassblowing. Of all materials used in both craft and scientific glassblowing, soda-lime produced the highest near-UV, visible and near-IR radiation. Previous investigations have confirmed that UV and IR irradiation could cause photokeratitis, cataract, and chronic retinal injury.^{12,16-18} Thus retinal damage due to chronic exposure from high intensity visible light, such as is often encountered in glassblowing, can occur. Molten soda-lime material produces suprathreshold IR, and a low level of near-UV radiation, which also could cause chronic corneal, lenticular and retinal damage in an inadequately protected eye.

Our findings show that exposure to optical radiation differs in the scientific and craft glassblowing operations and that optical radiation hazards exist in both types

of glassblowing. The data showing substantially low levels of near-UV, high intensity visible, and high near-IR radiation, suggest that scientific glassblowing should be classified under CSA hazard groups C, F and G, and craft glassblowing under groups C, G and H. Hazard groups C and F include heat and hot dipping, however, it should be noted that glare and stray light present potential hazards in scientific glassblowing operations as well. In the visible and near-IR regions of the optical spectrum, all the glass materials used in this study produce irradiance levels higher than the ACGIH TLVs. For instance, the molten soda-lime, a glass material commonly used in furnace operation, produces emissions with resultant irradiation more than 4 times higher than the TLVs both in the visible and the near-IR wavebands. Near-UV penetrates the cornea and is almost totally absorbed by the lens. Photokeratitis may result within several hours after exposure to the low near-UV irradiation from quartz, borosilicate and soda-lime materials.

Cataracts, which develop slowly in the lens, would require high UV and IR irradiance levels, usually from repetitive exposure. It can be argued that the near-IR irradiation from molten soda-lime glass material may cause cataract if the eye is unprotected. Thus, effective ocular protection against long-term radiation exposure in the glassblowing industry is necessary. In an earlier publication, we found that there is confusion among glassblowers over what type of eye protector to use when working with certain glass material.⁹ We reported that 80% of glassblowers use didymium lenses for working with all types of glass materials, and 20% use welders lenses, polycarbonate and cobalt lenses interchangeably with didymium lenses. Didymium lenses effectively eliminate the yellow sodium glare from molten borosilicate and other glass materials to enhance visibility. However, it provides no protective absorption of near-IR irradiation encountered in furnace glassblowing operations. A didymium spectacle with a filterweld™ clip-on would be protective. A summary of suggested eye protection for glassblowing operations is presented in Table III.

SUMMARY

The results of our investigation demonstrate differences between craft and scientific glassblowing operations. For the different glass materials, variation exists in the levels of ocular exposure to optical radiation in glassblowing ($p = 0.0001$). There is uncertainty among glassblowers about what type of eye protector is effective. Thus, worker's training about ocular protection is suggested. The CSA selection guideline should be revised to include both craft and scientific glassblowing specifically.

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