



# Occupational Exposure to Ultraviolet Radiation: Current Knowledge & Future Challenges

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# Presentation Overview

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- What is UV Radiation
- Sources of UV Radiation
- Health Effects of UV Exposure
- Occupational Exposure to UV
- Control/Protection Measures
- Risk Management for UV Exposure
- Case study

# Why is Occupational UV Exposure a Concern?

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- “Ultraviolet radiation is one of the most significant physical risks in the working environment...14.5 million EU workers are exposed to solar radiation at least 75% of their working time, which translates to 7.4% of all employees in the EU... the risk seems to be increasing in the contemporary working and living environment...existing information is not sufficient to create a full picture of occupational exposure to UV...the implementation of legislative measures also seems to be insufficient”

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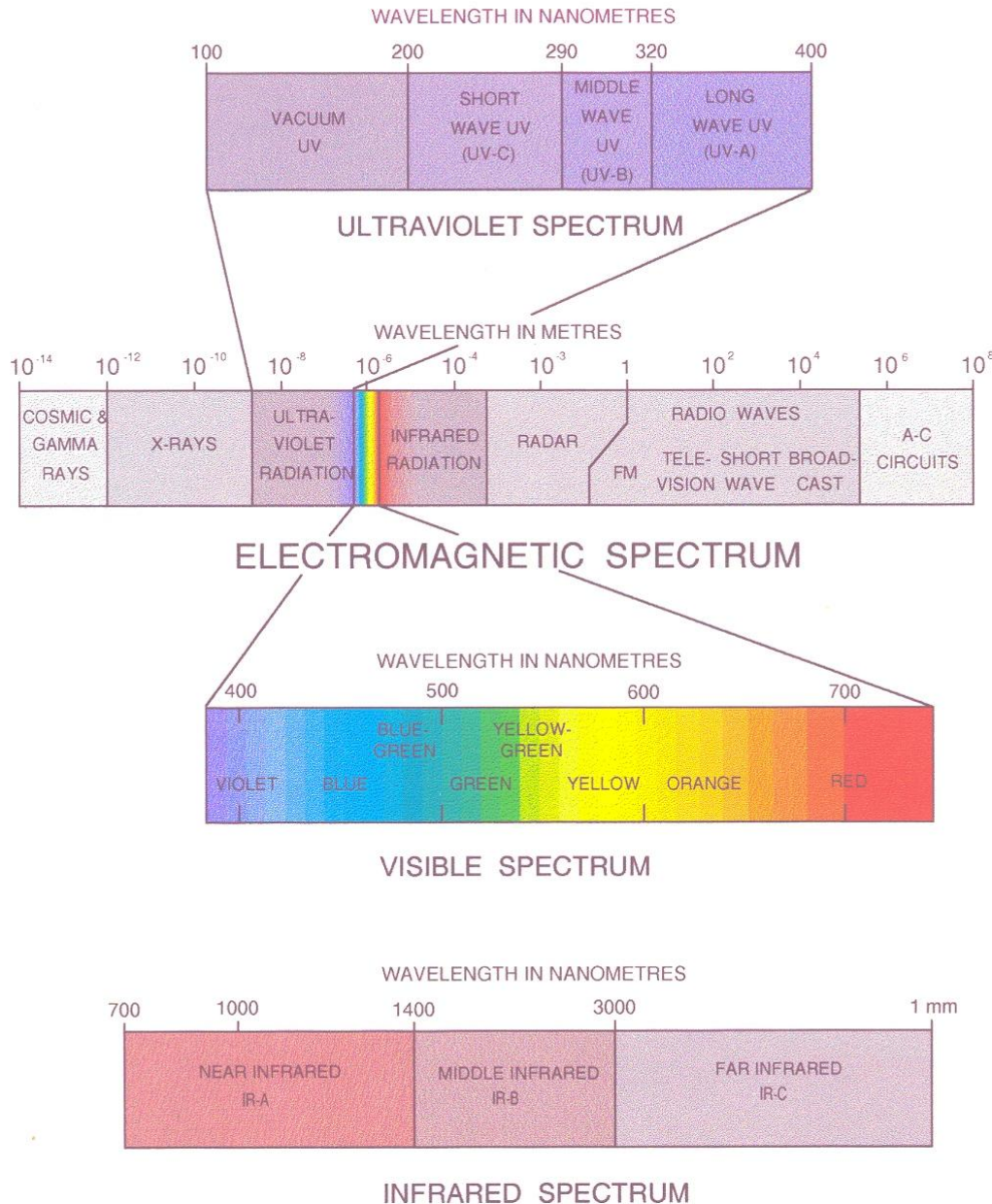
(European Agency for Safety and Health at Work: *Outlook 1 – New and Emerging Risks in Occupational Safety and Health*, 2009)

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# WHAT IS UV?

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- Radiation can be thought of as energy in transit – waves or particles
- Photon energy and wavelength inversely proportional.
- Photons with  $<12.4\text{eV}$  (100nm) don't have sufficient energy to ionize matter.

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# SOURCES OF UV

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# Occupational Sources of UV

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- Natural: the sun
- Electrical or gaseous discharge: incandescent lamps, fluorescent lamps, welding arcs.
- Lasers.
- Artificial sources:
  - Emit UV either deliberately (eg. for medical therapy) or as a by-product (eg. welding).
  - Most sources also emit other wavelengths of radiation (eg. infrared, visible).
  - Some sources also emit UV-C (for solar UV, this is absorbed by the ozone layer).

# High Intensity Sources of UV



Sun – Outdoor workers



Welding Arcs



# What Factors Influence Solar UV Levels at the Earth's Surface?

## MAJOR

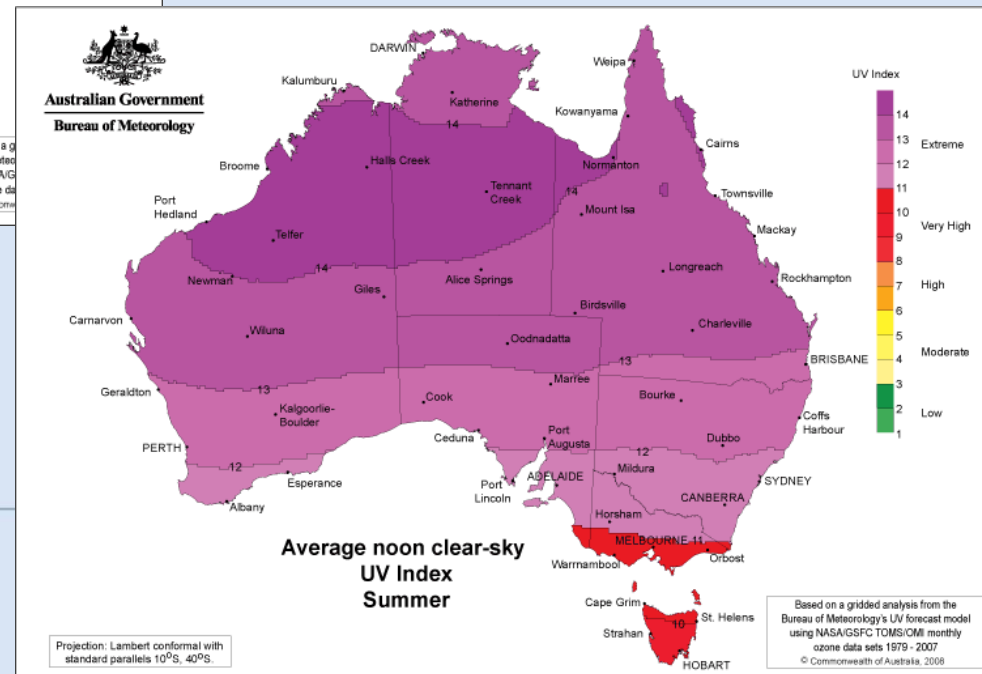
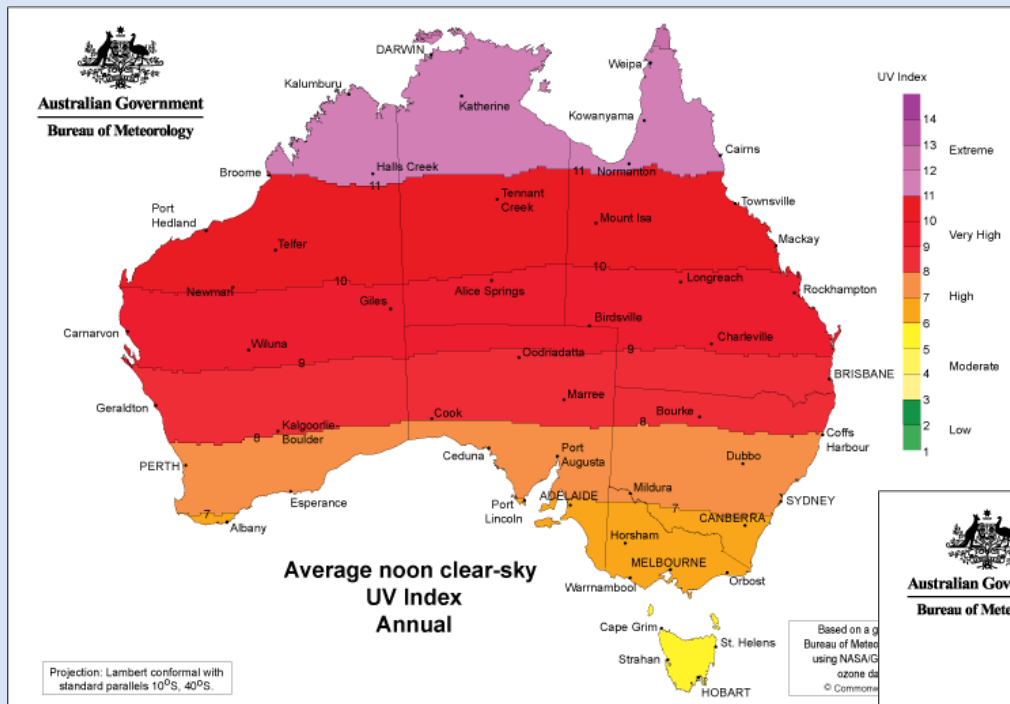
- Time of day
- Season
- Latitude
- Altitude
- Total column ozone
- Aerosols
- Cloud cover
- Tilt of earth's axis
- Earth-Sun Distance

## MINOR (Not well known)

- Short term  $\text{TCO}_3$  variations due to weather systems
- Quasi-Biennial Oscillation
- The El Niño-Southern Oscillation (ENSO)
- Sunspots (solar activity)
- Volcanic eruptions
- Unresolved long term trends

(Source: Dr Michael Kimlin)

# Queensland 'The Sunshine State'



# UV Index for Canada

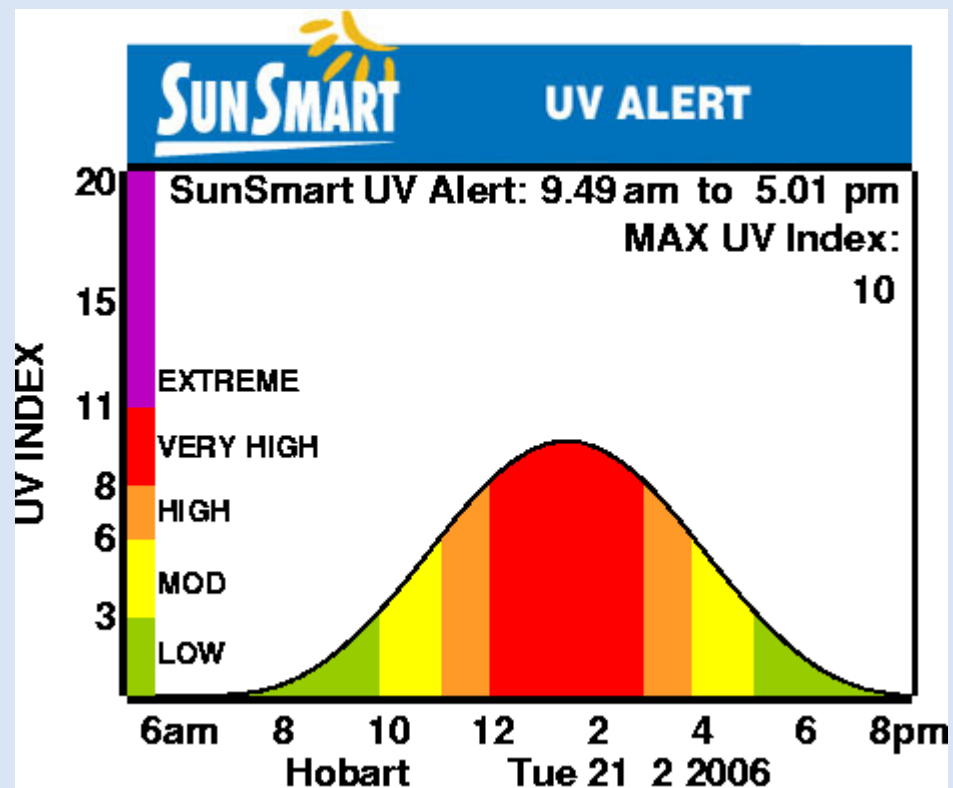
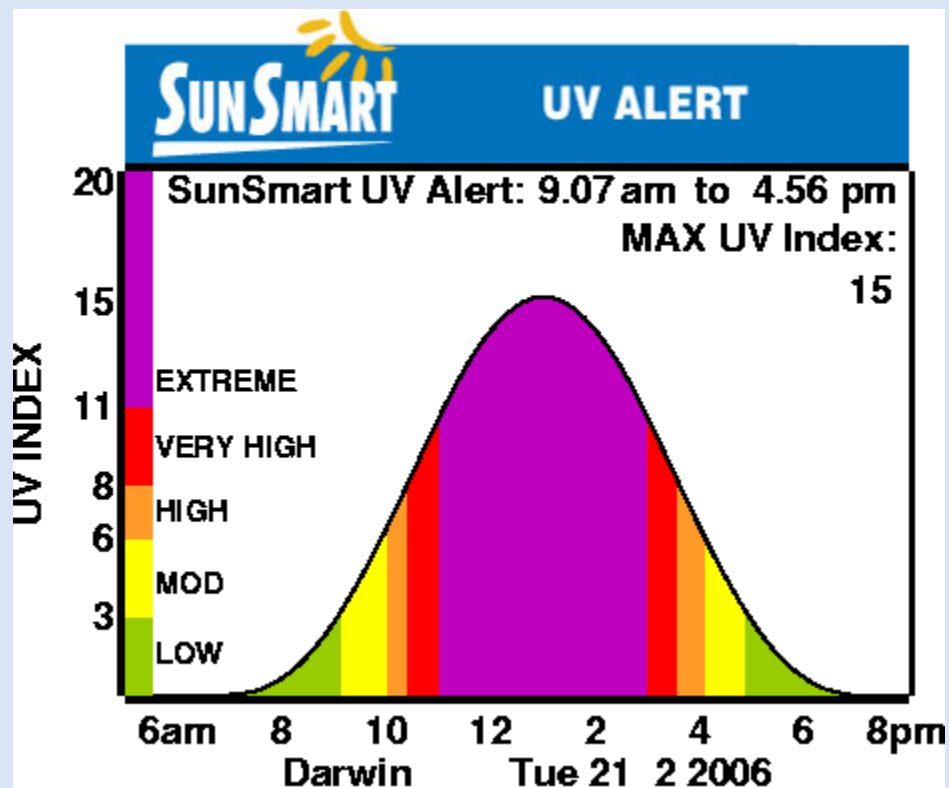
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- Typical early summer midday values:

Toronto, Ottawa, Montreal, Halifax, Calgary, Whistler, BC	8
St. Johns, Vancouver, Victoria, Edmonton, Winnipeg	7
Yellowknife, Iqaluit	5
North Pole	2

- Winter values (e.g. Thurs 9 Feb) – Toronto = 2

(Source: <http://www.ec.gc.ca/uv>)



(Source: Australian Bureau of Meteorology)



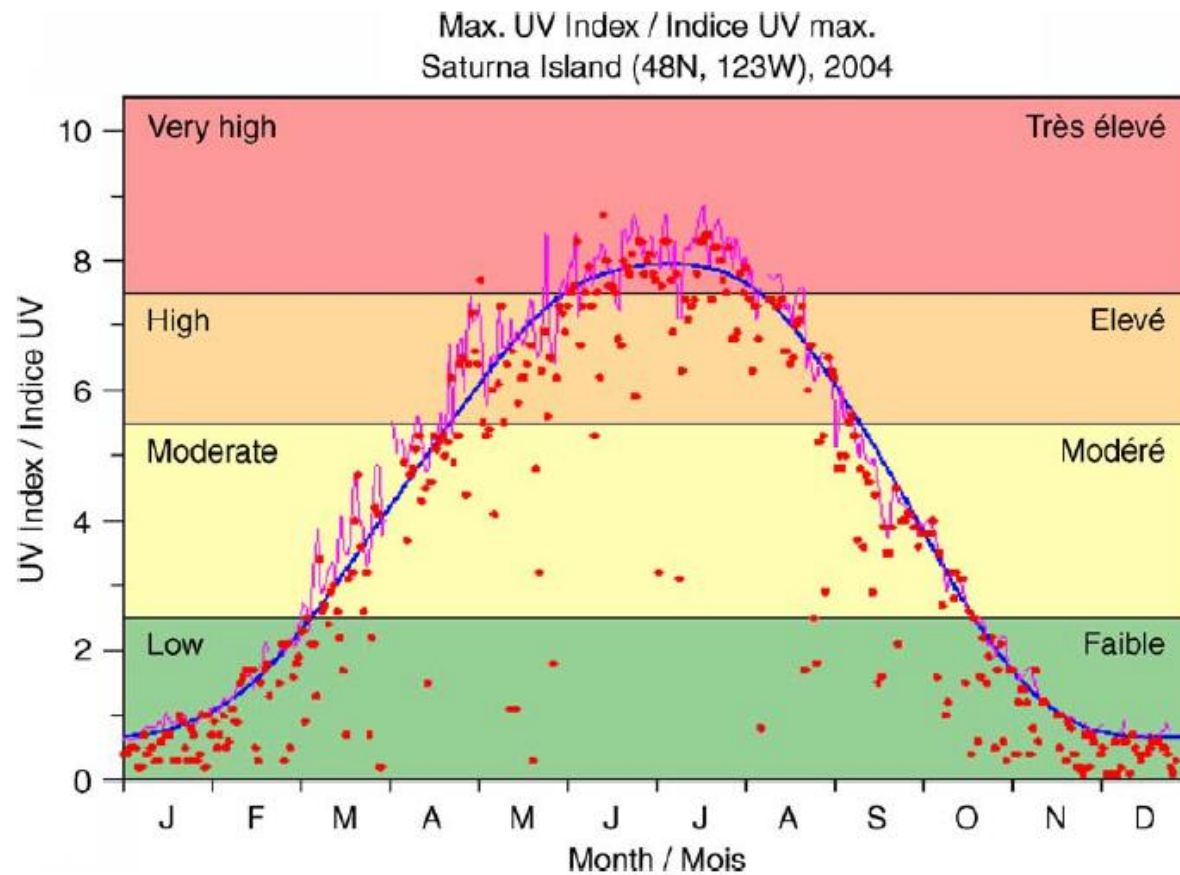


Fig. 1. Annual variation in measured daily erythemal exposure expressed as UV Index for Island, BC, Canada. This illustrates the great variation in UVI with season at 48°N (Source: Environment-Canada).

(Source: Sliney & Wengraitis, 2006)



# What is Welding?

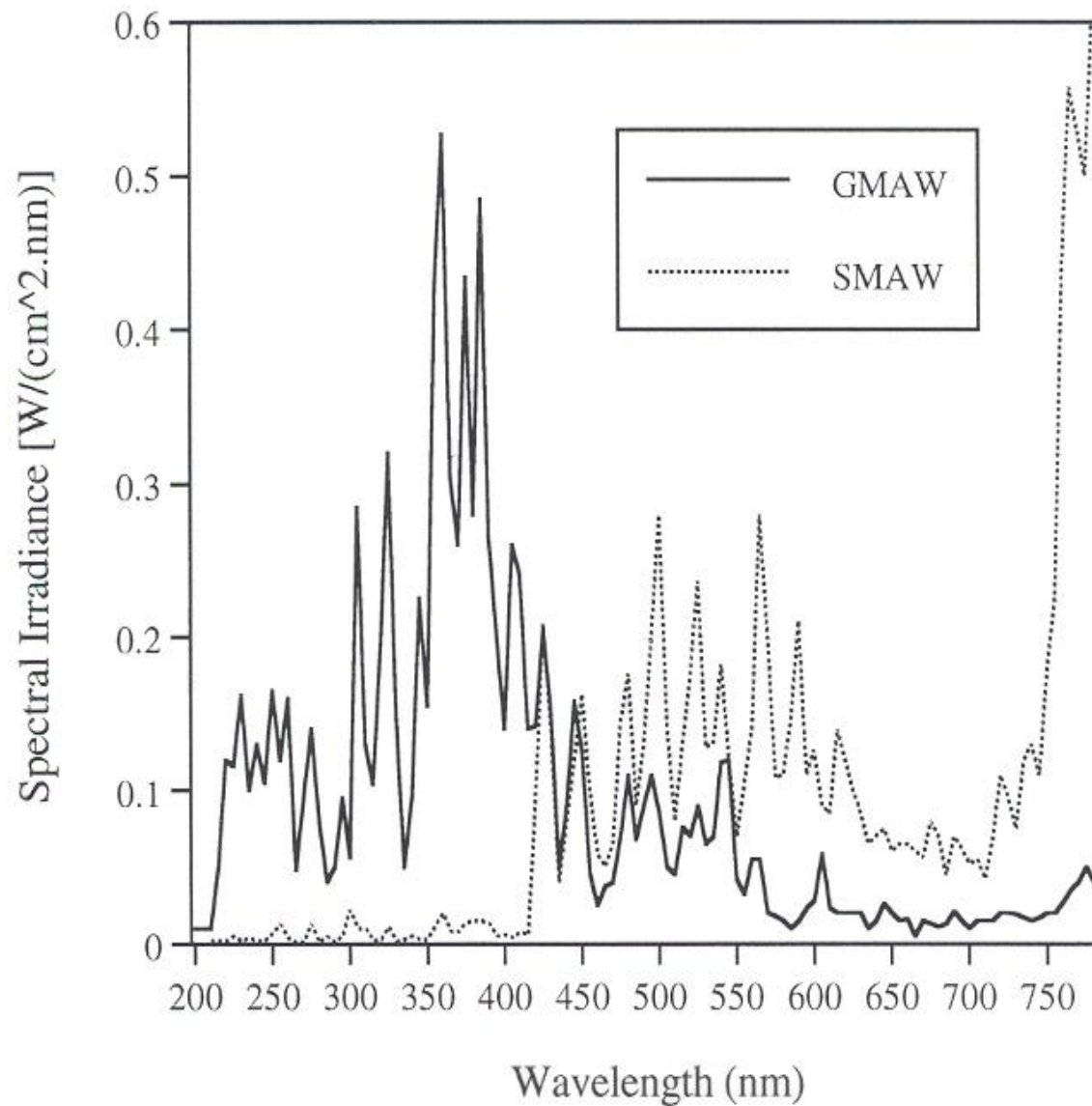


- Welding is a metal fabrication process in which metals are joined by the application of heat or pressure → melt metal → join when solidify.
- UV, visible and IR radiation are by-products of the welding process – emitted by the arc formed between the electrode and the base metal.
- Welding arc time is on average 20% of operational time, 180 ‘strikes’ per 8hr work day (Tenkate, 2008)

# Factors Influencing UV Emission from Welding

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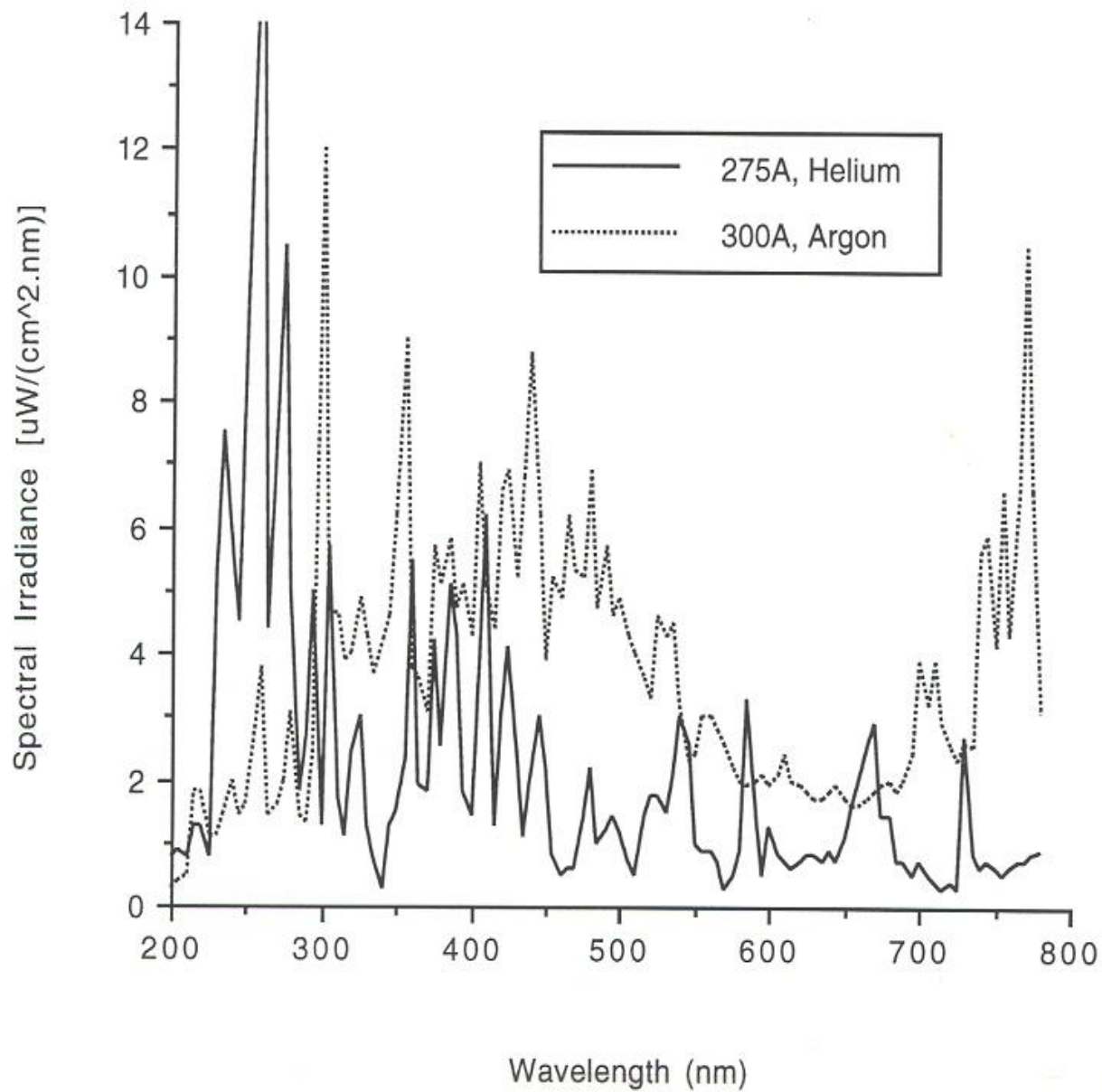
- Type of electrode
  - Stage of rod life
  - Fumes and smoke
  - Base metal\*
  - Tip size, flame type and filler metal composition.
  - Arc voltage, arc current\*, arc gap
  - Shielding flux or gas\*
  - Joint geometry
  - Practical difficulties (Tenkate, 1998)
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- GMAW ignition phase ~25ms – UV emission is 10x steady state arc (Eriksen, 1985)



GMAW of mild steel, current =90A; SMAW of mild steel, current =100A

(Data from Marshall et al, 1977)





GTAW of mild steel at 100cm from arc. (Data from Sliney and Wolbarsht, 1980)

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# HEALTH EFFECTS OF UV

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# Adverse Health Effects of Solar UV

## Skin:

- Erythema (S)
- Chronic sun damage (V)
- Photodermatoses (S)
- Squamous cell carcinoma (S)
- Basal cell carcinoma (S)
- Malignant melanoma (S)

(Based on: Armstrong, 1994; Armstrong & Krickler, 2001; Oliva & Taylor, 2005)

## Eyes:

- Climatic droplet keratopathy (L)
- Pinguecula (L)
- Pterygium (L)
- Photokeratitis (S)
- Cortical Cataract (S)
- Solar retinopathy (S)
- Uveal melanoma (S)
- AMD (I)

Weight of evidence: S = sufficient, L = limited (suggestive, not conclusive), I = inadequate, V = variable

# Recent Case Report:

Unilateral Dermatoheliosis in retired delivery truck driver  
(28 yrs) – ? Skin damage from UVA exposure through  
window glass



(Gordon & Brieva, 2012)



# UV and Skin Cancer

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- **12<sup>th</sup> Report on Carcinogens** (US Dept. Health and Human Services, 2011):
  - Solar radiation: known human carcinogen
  - Exposure to sunbeds and sunlamps – known
  - Broad-spectrum UV – known
  - UV-A: reasonably anticipated
  - UV-B: reasonably anticipated
  - UV-C: reasonably anticipated
- **IARC** (IARC, 2012: Monograph 100D):
  - Solar radiation: Group 1 – carcinogenic to humans
  - Use of UV-emitting tanning devices – Group 1
  - UV radiation (UV-A, UV-B, UV-C) – Group 1
  - Welding and ocular melanoma – sufficient

# Skin Cancer and Occupational UV Exposure

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- SCC: Meta-analysis of 16 studies found ↑ risk of SCC with occupational UV exposure, 2 studies no association → pooled OR (95% CI) = 1.77 (1.40-2.22) ( $p < 0.001$ ); ? underestimation of true association due to confounders, self-selection among outdoor workers, imprecise reference group, method for assessing UV exposure (direct vs job title) (Schmitt et al, 2011)
- BCC: Meta-analysis of 23 studies of outdoor work and BCC risk → pooled OR (95% CI) = 1.43 (1.23 – 1.66) ( $p = 0.0001$ ). Occupational UV: 11 studies sig. +ve assoc., 6 studies nonsig. ↑ risk; 2 studies no effect; 5 studies nonsig. ↓ risk (Bauer et al, 2011)

# Skin Cancer and Occupational UV Exposure

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- NMSC: 34,000 new cases in each in Australia from occupational exposure (Fritschi & Driscoll, 2006); occupational sun exposure is a significant risk factor (Green et al, 1988; Beral et al, 1981; Marks et al 1989).
  - MM:
    - chronic exposure weakly associated with increased risk, occupational exposure not associated (Gallagher & Lee, 2006)
    - ↑ risk for intermittent exposure; ↓ risk for heavy occupational exposure/outdoor workers or chronic exposure (Vagero et al, 1986; Elwood & Jopson, 1997; Gandini et al, 2005)
  - Variable results for skin cancer and outdoor work, possibly due to fair skinned people self-selecting for indoor work (Green et al, 1996).
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# Welding Eye Injuries

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- Reesal *etal*, 1989:
    - 21% of all eye claims made by welders.
  - Lombardi *etal*, 2005:
    - 5% of all claims = eye injury (25% = welders)
    - 63% of all claims are foreign body, 30% burns – welders higher proportion – 87% UV related.
    - Welders: 63% foreign body, 20% UV
    - Non-welders: 41% UV, 40% foreign body.
  - Imberger *etal*, 1998:
    - 12% of all cases from welding.
    - 54% flash burn, 32% foreign body.
    - Mistiming of arc strike, remove eye protection due to poor visibility.
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- 25% of welding related cases to non-welders.



# Health Effects from Welding UV

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- Acute effects related to Welding UV:
  - Surveys: visual discomfort symptoms, photokeratitis, erythema.
  - Case reports: photokeratitis, erythema
- Chronic effects related to Welding UV:
  - Surveys: pinguecula, pterygium, cortical cataracts.
  - Case reports: pterygium, spheroidal degeneration, NMSC.
  - C/C studies: pterygium, uveal melanoma.
- Chronic effects not related to Welding UV:
  - C/C studies: NMSC, MM, corneal endothelium damage.
- Limited # of c/c studies, small #'s subjects

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# OCCUPATIONAL UV EXPOSURE

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# Numbers of Workers Exposed to UV

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- Outdoor workers
  - Australia: 1.2M (CCA, 2007)
  - Canada:
    - 5,410,213 (26%) work outdoors in summertime; 75% male; higher proportion are aged 16-24yrs; % varies across country (NSS2 – Marrett et al, 2010)
    - 1.5M (8.8%) potentially exposed to solar UV; 82% male; largest industry groups = construction, farming, services to buildings & dwellings (CAREX, 2012)
  - Europe: approx 14.5M (EASHW, 2009)
  - Great Britain: 1.28M for 1990 (6.8%) (est. 10-30% of working population work outdoors) (Ruston et al 2007 for HSE)

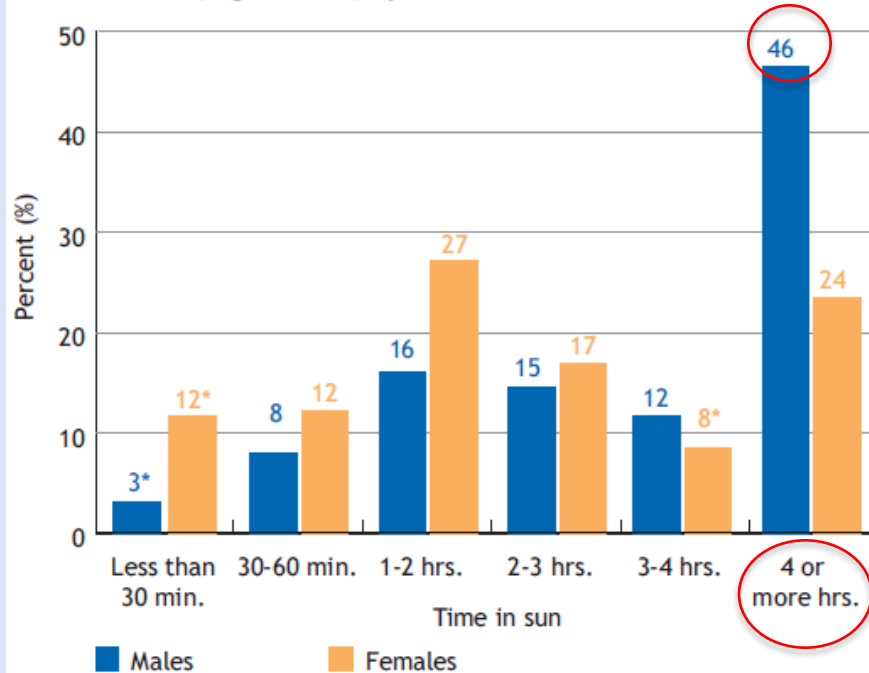
# Numbers of Workers Exposed to UV

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- Artificial sources
  - Canada: 141,000 potentially exposed to artificial UV at work; 78% male; 87,000 welders (96% male); 6,400 medical laboratory technologists & pathology assistants (CAREX, 2012)
  - US: welders in 2010: 337,300 (521,000 in 2000) (US Bureau of Labor Statistics, 2012)
  - Australia: >50,000 welders (ARPANSA,, 2006)

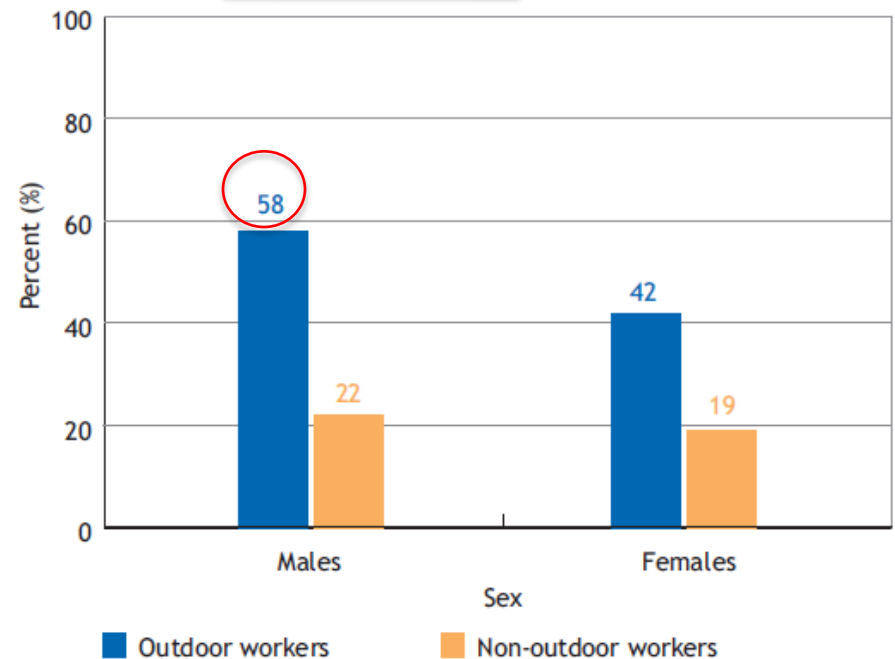
Two thirds of outdoor workers spend two or more hours per day of work time in the sun. Over half of outdoor workers spend at least two hours per day of leisure time in the sun.

Time spent in the sun during work time by Canadian outdoor workers, ages 16-64, by sex



\*Figures should be interpreted with caution: N≥10 but coefficient of variation 16.6%-33.3%.

Canadian outdoor and non-outdoor workers, ages 16-64, spending 2 or more leisure-time hours in the sun, by sex



Age-standardized to the 2001 Canadian population.

Outdoor workers: spend more time in sun during work and leisure than other adults; more likely to get burnt

(CPAC 2010 – 2006 2<sup>nd</sup> National Sun Survey)

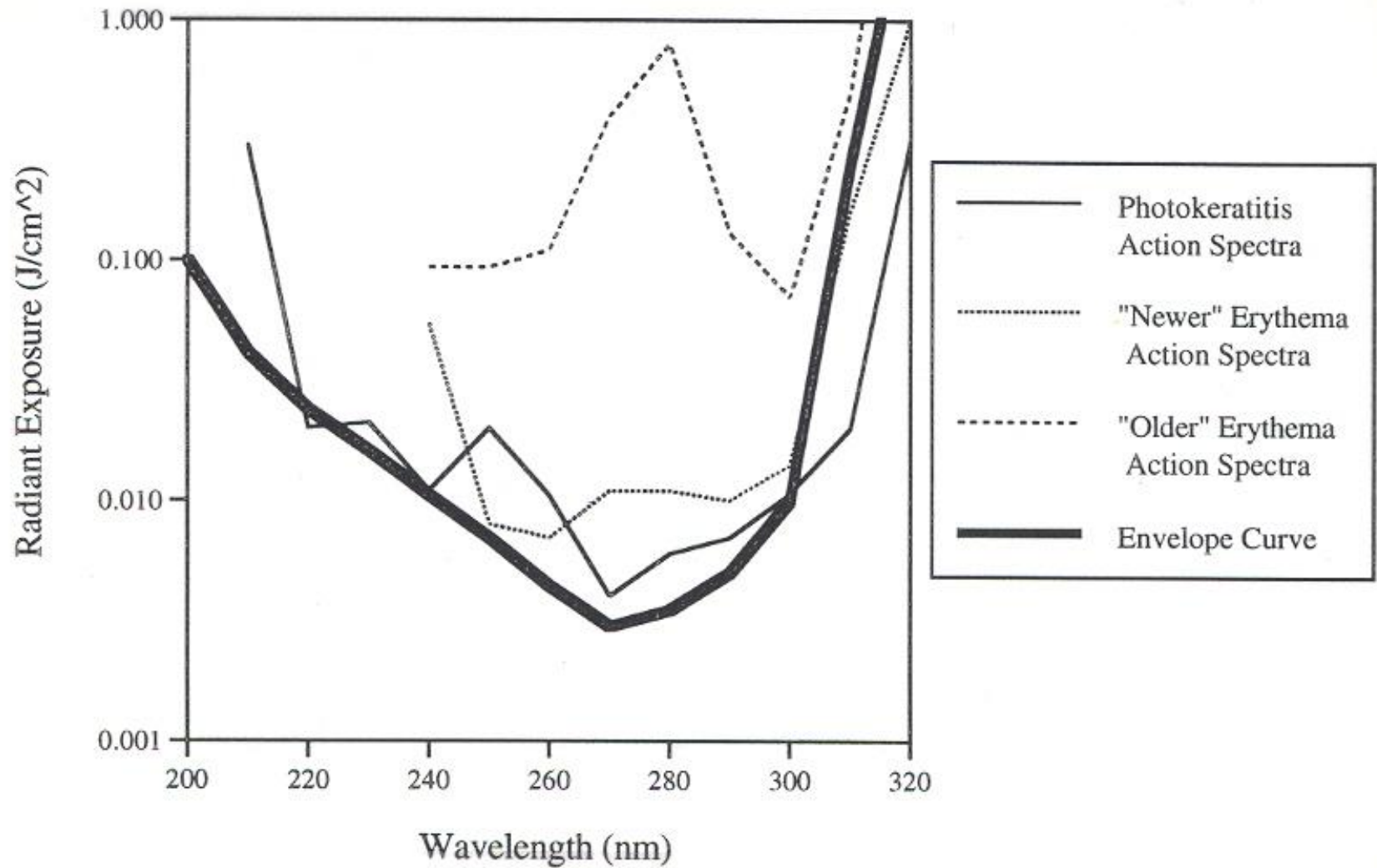
# Exposure Levels – Hours/Proportion of Day

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- **Australia** (NHEWS, 2010):
  - Survey of 4500 workers in all industries, Jan to July 2008.
  - 34% reported direct exposure to sunlight at work
  - Average daily exposure = 4.4 hrs, 12.2 hrs weekly
  - Highest exposure: Agriculture = 5.5hrs/day, 22hrs/wk; construction = 5.5hrs/day, 19hrs/wk
- **Canada (CAREX)** (Peters et al, 2012):
  - Low: almost never exposed – truck & delivery drivers,
  - Moderate: indoor/outdoor mix – crane operators, carpenters, maintenance labourers, couriers.
  - High: >75% outside – farmers, construction; 61% (897,000 workers)



# Occupational Exposure Standard



(Slincy, 1972)

# ICNIRP Guidelines / ACGIH TLV

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- ‘represents conditions under which it is expected that nearly all individuals may be repeatedly exposed without acute adverse effects and, based upon best available evidence, without noticeable risk of delayed effects’.
- Radiant exposure/dose of 30J/m<sup>2</sup> effective spectrally weighted irradiance (180 to 400nm), 8hr period.

$$E_{eff} = \sum E_{\lambda} \cdot S(\lambda) \cdot \Delta\lambda$$

- Permissible exposure time (sec) = 30J/m<sup>2</sup> ÷ E<sub>eff</sub>

# Interpretation of Exposure Standard

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- ACGIH:
  - Sources include welding arcs, lamps, solar radiation.
  - Probability of developing skin cancer depends on a variety of factors
- ICNIRP:
  - Considered to be absolute limits for direct exposure to the eye, and ‘advisory’ for skin exposures because of the wide range of susceptibility.
  - Excursions above the TLV for well-adapted skin have been considered by many not to pose a serious risk. Certainly, this higher skin exposure is routinely accepted in an outdoor work environment.

# Interpretation of Exposure Standard

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- ICNIRP cont:
  - Use of the guideline in an outdoor setting poses many problems of adequate dose assessment both for the eye and skin
- Australia:
  - Adopted the ICNIRP exposure standard but only for artificial sources – for outdoor workers *‘application of the exposure limits...is not practical and limiting UVR exposures to as low as possible is the most effective approach’* (ARPANSA, 2006)

“Almost all provinces and territories exclude solar radiation in occupational UVR exposure limits” (CAREX Canada, 2012)

# Adoption of Standard by Legislation

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- In Ontario, the “Ministry of Labour’s Radiation Protection Service applies the threshold limit values (TLVs) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) for occupational exposure to UV radiation. These limits are enforced in Ontario workplaces by the ministry under section 25(2)(h) of the Occupational Health and Safety Act”.
  - “Measurement of UV radiation, as well as the determinations of exposure levels, allowable exposure times and compliance with the guidelines, must be carried out by a qualified person with appropriate equipment”.
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# Assessment of Human UV Exposure

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- The measurement of UV exposure on humans is a very difficult task.
  - Exposures to humans vary according to:
    - Time spent outdoors
    - Time of day and year (ambient UV levels)
    - Activity undertaken
    - Body posture
    - Personal behavior
    - UV protective devices used
    - Sources of exposure and their emission spectra
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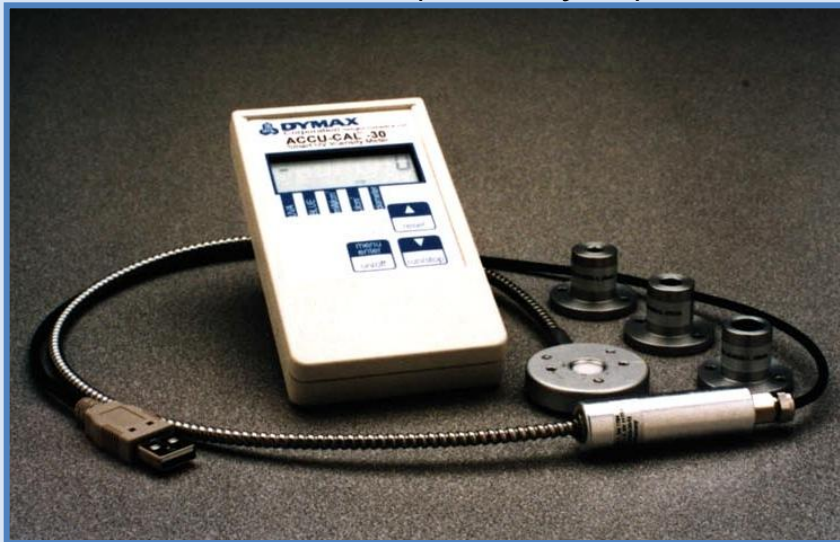




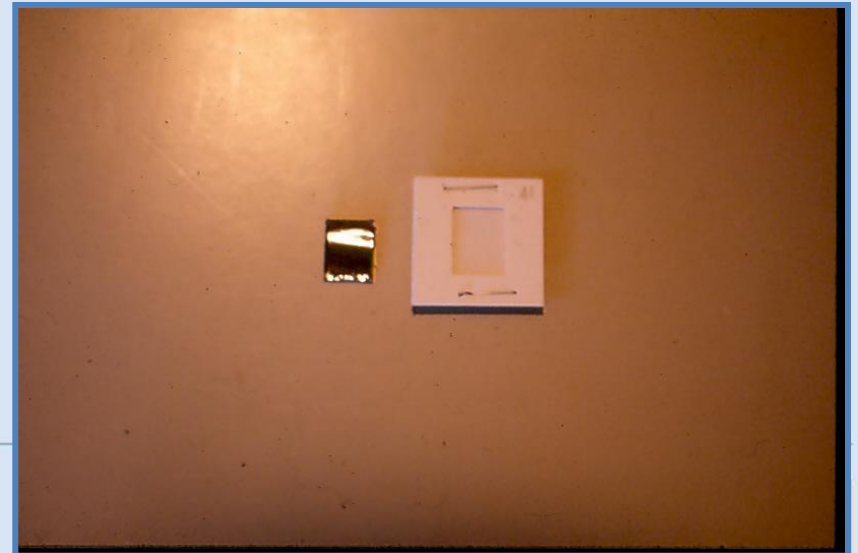
Broadband Solar UV  
Radiometer (NovaLynx)



Potable SpectroRadiometer  
(StellarNet)



UV Radiometer (ACCU-CAL)



Polysulphone film

# Uses of Polysulphone – UV Protection Offered by hats



(Photo: Dr Michael Kimlin)



Source	$E_{eff}$ (W/cm <sup>2</sup> )	Exposure time		
		TLV	Photokeratitis	Erythema
Welding, GMAW, Steel	$1.3 \times 10^{-3}$	2.3 sec	3.1 sec	4.6 sec
Welding, GMAW, Al	$1.25 \times 10^{-3}$	2.4 sec	3.2 sec	4.8 sec
Welding, GTAW, Steel	$7.09 \times 10^{-5}$	42.3 sec	56.3 sec	84.6 sec
Phototherapy lamp, type A, unenclosed	$2.5 \times 10^{-5}$	120 sec	160 sec	240 sec
UVR curing unit	$4.2 \times 10^{-7}$	120 min	160 min	240 min
Solar UVR:				
- Darwin, 12.4°, summer	$5.5 \times 10^{-6}$	9 min	12 min	18 min
winter	$2.6 \times 10^{-6}$	19 min	25 min	38 min
- Hobart 42.8°, summer	$3.6 \times 10^{-6}$	14 min	19 min	24 min
winter	$1.1 \times 10^{-7}$	450 min	600 min	900 min

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**Table 1.** The variation of time to exceed the ICNIRP<sup>5</sup> guidelines  $T_{\max}$ , time to achieve erythema  $T_{\text{erythema}}$  and the equivalent SED per hour for solar UVR of various UV Indices

UV index	$T_{\max}$ (min)	$T_{\text{erythema}}$ (min)	$\text{UVR}_{\text{eff}}$ (SED h <sup>-1</sup> )
2	39.5	66.6	1.8
4	19.8	33.3	3.6
6	13.2	22.2	5.4
8	9.9	16.7	7.2
10	7.9	13.3	9.0
12	6.6	11.1	10.8
14	5.7	9.5	12.6
16	4.5	8.4	14.4

(Gies & Wright, 2003)

# Occupational UV Exposure

Main factor is whether a person is an indoor or outdoor worker, however, occupational exposure levels vary dramatically:

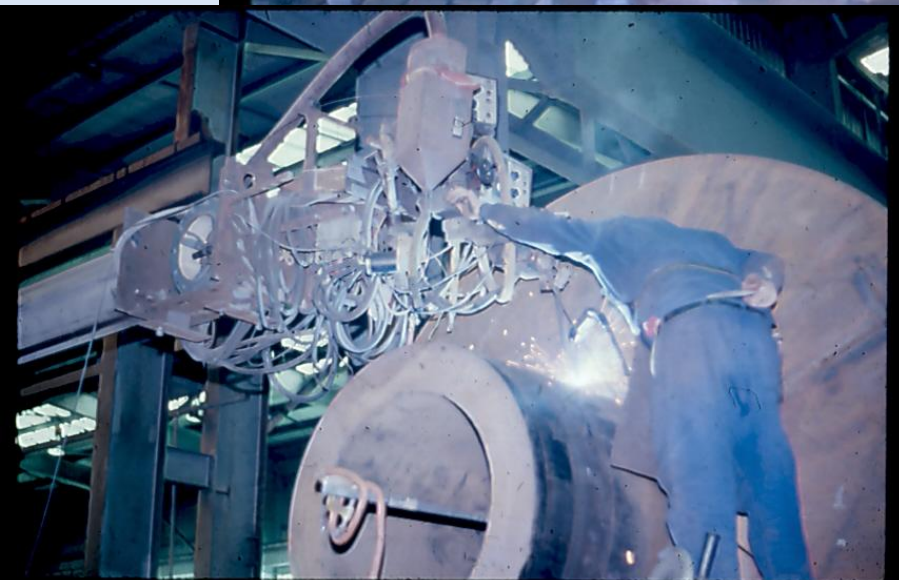
<i>Study</i>	<i>Category</i>	<i>% of Ambient</i>
Larko and Diffey (1983)	Outdoor workers	10 to 70%
Holman et al (1983)	Physical Education Teachers	30 to 50%
	Gardner, Carpenter, Bricklayer	44 to 85%
Gies and Wright (2003)	Construction workers (median, all)	26%
	Pavers-Tilers	114%
	Traffic controllers	69%
	Roofer	45%
Leach et al (1977)	Indoor workers	2 to 4%
Larko and Diffey (1983)	Indoor workers	6%
Holman et al (1983)	Classroom Teacher	7 to 11%

# Personal Occupational UV Exposure – Outdoor Workers

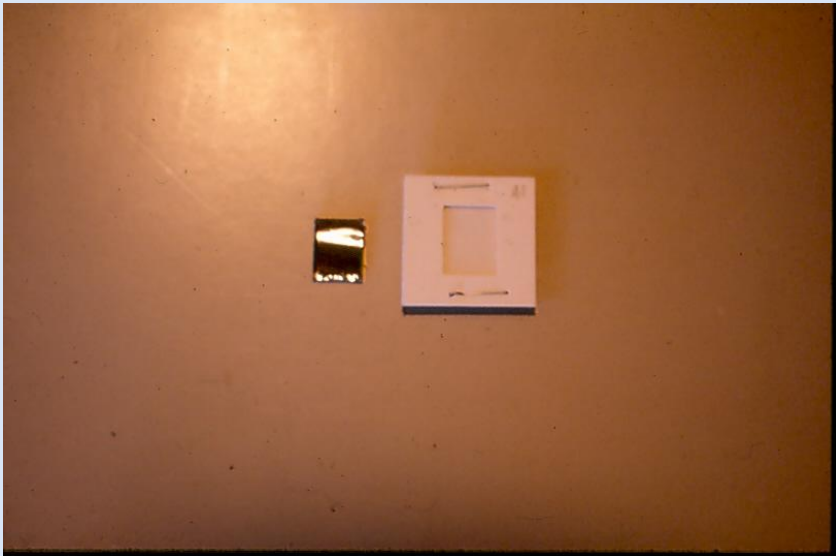
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- Exposures are often many times the OEL.
- Construction workers in Qld (Gies and Wright, 2003):
  - Below OEL: 10%; 1 to 2x OEL: 13%
  - 2 to 3x OEL: 16%; 3 to 4x OEL: 14%
  - >4x OEL: 47%; >10x OEL: 7.3%
- Lifeguards in 4 locations in USA (Gies et al, 2009):
  - 74% exceeded OEL; 39% > 4x OEL; 65% sufficient for sunburn
- Vineyard workers in Italy: all workers > OEL for all seasons; in spring all workers >10x OEL at back of neck (Siani et al, 2011)
- Building, horticulture, road workers in NZ: all workers > OEL; mean exposure was 5x OEL (Hammond et al, 2009)

“Evidence that solar UV exposure has ever been measured in Canada was not located” (CAREX Canada, 2011)











# Personal UV Exposures in a Welding Environment

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- Ocular (& face) exposures:
  - welders = 3 to 4.3x OEL
  - boilermakers 2.5 to 5x OEL
  - non-welders = 9 to 12x
- Body (chest) exposures:
  - welders = 3000x OEL
  - boilermakers = 60x OEL
  - non-welders = 13x OEL
- Ambient levels: 5.5x OEL

(Tenkate & Collins, 1997)



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# CONTROL / PROTECTION MEASURES

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# Limiting Excessive UV Exposure

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- Legislative obligations/duties (Part 3 of WHS Act-Qld; ; Ontario OHS Act, s 25(2)(h), s28(1)):
  - Employer: risk management; protecting employees from excessive exposure.
  - Employee: comply with instructions of employer, re: workplace health and safety, eg. wearing of PPE.
- Hierarchy of control measures:
  - Elimination
  - Substitution
  - Isolation (of the hazard from human exposure)
  - Engineering controls
  - Administrative controls
  - Use of PPE

# Controlling Solar UV

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- Measures: scheduling of work activities; shade provision; PPE; clothing; hats; sunglasses; sunscreen; worker training.
  - 50% of outdoor workers take adequate personal protection – face and lower arms the least protected sites, use of sunscreen and wide-brimmed hats is low  
(Borland et al, 1991; Girgis et al, 1994; Shoveller et al, 2000; Stepanski & Mayer, 1998; Salas et al, 2005; Pichon et al, 2005).
  - Reasons: forgetting to use PPE, feeling that sun protection is inconvenient, wanting to get a tan, unconcerned with sun exposure (Shoveller et al, 2000)



# Controlling Artificial UV

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- Administrative controls:
  - Identify hazards and correct operating procedures.
  - Restrictions on worker access.
  - ↑ distance & ↓ duration of exposure.
  - Warning signs and worker training.
- Engineering controls:
  - Isolating/enclosing high intensity sources
  - Non reflective paints/surfaces.
  - Interlock/alarms on access panels and enclosures

# Controlling Artificial UV

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- PPE:
  - Clothing; Eye and Face protection: *ANSI Z87.1 – Occupational and Educational Eye and Face Protection Devices*
- *ANSI Z49.1-2005 Safety in Welding, Cutting and Allied Processes:*
  - Personnel & general area: protective screens, reflective surfaces, welding booths, eye and face protection (ANSI Z87.1), protective clothing (gloves, aprons, leggings, capes and sleeves), noise, respiratory PPE, training.
  - Ventilation, fire prevention, confined spaces.

# Welding Helmets

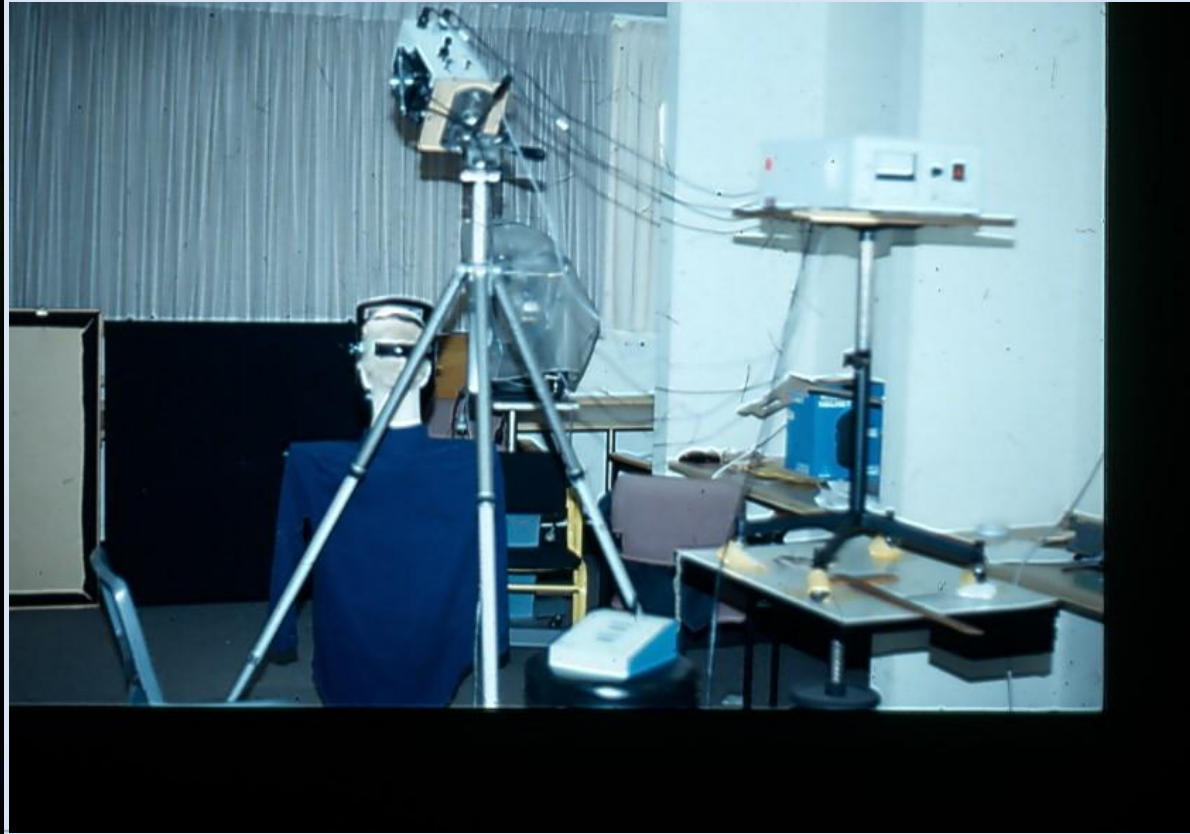
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- Design has been relatively unchanged for many years.
- Questions raised on possible infiltration of UV.
- Many workers make their own modifications to provide additional protection.



# Helmet Infiltration Study (Tenkate and Collins, 1997b)

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# RISK MANAGEMENT FOR OCCUPATIONAL UV

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# Risk Management for Occupational UV Exposures

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- Workplace policy on UV exposure
- Employee training & information
- Risk Management Framework
  - Identification of hazards: identification of sources.
  - Assessment of risk: estimate exposure levels, compare to OEL.
  - Choose appropriate control measures: control hierarchy = elimination, substitution, engineering controls, administrative controls, use of PPE.
  - Implement appropriate control measures.
  - Monitoring and review effectiveness of control measures.
- Post-incident exposure management

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(Source: ARPANSA, 2006)



# Case Study – Implementation of a sun safety policy by Dyno Nobel



# Conclusions & Future Challenges

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- Outdoor workers and workers exposed to certain artificial sources (e.g. welding arcs) are frequently exposed to UV levels well above the current OEL; this is a large proportion of the workforce
- These workers are at additional risk of developing NMSC, possibly MM, a range of acute and chronic skin and eye conditions; however, limited studies or variable results.
- Range of control/protection measures available, but some have variable effectiveness (e.g. welding helmets) and many workers (particularly outdoor) do not use some/many of the measures.
- Variability in interpretation of the exposure standard
- Limited enforcement of exposure standard
- Limited data on occupational UV exposures
- Variability in success of implementing sun protection policies
- Risk management approach is critical, however it can be difficult to undertake effective risk assessment