# Ultraviolet and Visible Light Exposure Among Indoor Agricultural Workers

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## 1. Introduction

### 1.1. History of Cannabis in the United States

Regulations on cannabis sale, possession, and use have varied throughout US history. Prior to 1906, cannabis pharmacies were able to sell cannabis products unrestricted. In 1906, the US Congress passed the Pure Food and Drug Act, which mandated labeling on cannabis and related products (Musto, 1999). This federal law was followed by a number of state-level regulations enacted between the 1910s and early 1920s limiting sale to pharmacies (Gieringer, 1999). The Marijuana Tax Act of 1937 federally outlawed personal cannabis possession or exchange and added an excise tax on all medical and industrial transactions. The act also required sales logs of all transactions involving any part of the cannabis plant (US Congress, 1937). The 1952 Boggs Act and the 1956 Narcotics Control Act brought heavier punitive measures and the addition of mandatory sentencing (PBS, 2014). In 1969, the Leary vs. United States supreme court decision declared the Marijuana Tax Act to be unconstitutional due to the violation of self-incrimination stated in the fifth amendment (US Supreme Court, 1969). In response, Congress quickly passed the Controlled Substances Act a year later (Davis, 2015). During the five years between 1973 and 1978 the trend in US cannabis regulation changed, with eleven states decriminalizing marijuana (Scott, 2010).

However, the decriminalization was short lived. The 1980s ushered in some of the most stringent cannabis restrictions in US history. The Comprehensive Crime Control Act of 1984 specified mandatory sentencing guidelines and the Anti-Drug Abuse Act of 1986 reinstated mandatory prison sentence. And, 24 states adopted three-strikes laws calling for high punitive measures following repeated convictions for cannabis manufacture, possession, use, or sale (PBS, 2014).

In 1996, the first decriminalization act that has endured to date, Proposition 215 was passed in the State of California, legalizing medical cannabis. Its passage marked the beginning of modern dualistic cannabis regulation: allowed at the state, but banned at the federal level (Califorinia Department of Public Health, 2011). The Supreme Court case Gonzales vs. Raich of 2005 led to a verdict which maintained the federal ban, re-

enforcing the duality (US Supreme Court, 2005). Since the 2005 verdict, the scale of this duality has grown. Currently, 17 states and the District of Columbia have decriminalized cannabis in some form with Washington and Colorado States legalizing recreational use of cannabis (McKenna, 2014).

### 1.2. Washington State Cannabis Legal History

In 1998, Washington State voters approved Initiative 692, the Medical Use of Marijuana Act, legalizing the use, possession, sale, and cultivation of cannabis. Specifically, the law allowed patients prescribed cannabis for medical purposes to buy and possess a prescribed amount on person provided the patients carry valid documentation. More recently, in 2012, Washington voters approved Initiative 502, legalizing recreational cannabis. The initiative legalized general public possession of marijuana, but restricted the legal on-person amount to 16 ounces and purchasers to 21 years of age or older (L&C, 2012).

### 1.3. Washington State Cannabis Industry

Prior to legalization, the Washington State marijuana industry was focused on circumventing laws. For example, the industry bred higher potency plants to maximize shipment space for distribution. Furthermore, some moved grow operations indoors to prevent detection and improve production efficiency (Becket 2008). These aspects of the industry continue to be used in the current legal framework because growing high potency strains is more efficient than previous less-potent strains. And, the practice of indoor growing also remains due to its ability to control the quality of production and protection against theft (Facility 1 Manager, 2015).

Despite the legalization of cannabis in the state, little to no historical statistical data are available for the industry, which is a direct result of the discord between state and federal laws. With no cannabis-specific North American Industry Classification System (NAICS) codes or specific federal regulations allowing production, work, or sale, all statistics are lumped into other non-specific industry classifications, such as

agriculture, medical, pharmaceutical, chemical laboratory, etc. This makes it difficult to account for the numbers of workers or the financial statistics for the cannabis industry.

Cultivation, extraction, and consumer products are identical to medical products, but regulation and taxation differs. Financial statistics for recreational cannabis are accessible because taxation mandates public financial recordkeeping (L&C, 2012). The tax system divides the industry into three units: producer, processor, and retail. Operating a business in any of the three sectors requires a license. The license identification number is tied to taxation, which is used to implement financial tracking. Based on these records, there are 704 producer/processor licenses in Washington State as of May 2016. In the first year of active taxation (2015) total revenues generated by the industry were roughly $257 million with about $67.5 million in tax revenue. Projections based on population and industry growth suggest continued growth in revenues, with an estimated $350 million in tax revenue by 2019 (Smith, 2015). The doubling of production in Washington State between June 2015 and January 2016 supports this projection. Detailed financial data that make up these totals are publically available at Washington State Liquor and Cannabis board website. Unfortunately, although financial data exist, data on worker counts or detailed work type classification do not exist.

### 1.4. Occupational Hazards Associated with Marijuana Use

The legalization of cannabis potentially presents new occupational health and safety concerns. Cannabis use results in impairments, including difficulty concentrating, impaired memory of recent events, dreamlike states, impaired motor coordination, impaired driving and other psychomotor skills, slowed reaction time, impaired goal-directed mental activity, and altered peripheral vision (Adams & Martin, 1996). Workplace use may lead to worker injury and death especially during operation or proximity to heavy equipment. Blood testing is the only accurate impairment test, with urine samples showing no correlation to impairment and breathalyzers unable to detect compounds related to cannabis consumption. With no non-invasive impairment testing methods, workplace testing is currently infeasible (Phillips et al., 2015).

### 1.5. Occupational Hazards for the Marijuana Growing Industry

This thesis is focused on the indoor growing facilities for cannabis (described in Methods). Only one study on occupational exposures in indoor marijuana grow operations has been conducted (Martyny, Serrano, Schaffer, & Van Dyke, 2013). In the study, 30 indoor marijuana grow operations were examined in order to determine potential exposures to first responders. Samples for airborne fungal spores, volatile organic compounds, carbon dioxide, carbon monoxide, and delta-9-tetrahydrocannabinol (THC) were obtained. The group detected pesticides, but none that were of high toxicity. Although combustion was used in $CO_2$ enrichment no elevated CO was detected. Surface sampling detected the presence of THC, but not at doses that are hazardous. However, high levels of airborne *Cladosporium* and *Penicillium* fungal spores were measured. Since the study was searching for acute hazards for first responders, ultraviolet radiation (UVR) was not investigated.

### 1.6. Grow Bulbs

The indoor growing practice for cannabis may involve traditional greenhouse, supplemental light greenhouse, and total artificial light room styles of growing (Marijuana Business Association, 2015). All styles control temperature and humidity of the grow room, with classification depending on source of light. In a traditional greenhouse, all light is provided by solar radiation. In a supplemental light greenhouse, light is provided by both solar and grow bulb sources. In a total artificial light room, grow bulbs are the source of all light. This thesis focuses on total artificial light rooms.

The bulbs used for indoor growing emit ultraviolet radiation (UVR), visible light, and infrared radiation designed to stimulate high plant growth response. The most common bulb types are metal-halide (MH), high pressure sodium (HPS), with the fluorescent and light emitting diode (LED) common but less popular. Generally, HPS and fluorescent bulbs are used for seedling growth, while MH and LED bulbs are used for vegetative growth (Yorio & Mackowiak, 1995). We observed reflective hoods installed around most grow bulbs to redirect light to a desired location. The hoods are

typically rectangular or circular in design and depend on the geometry of the bulb. Figure 1 shows a typical bulb hood setup.

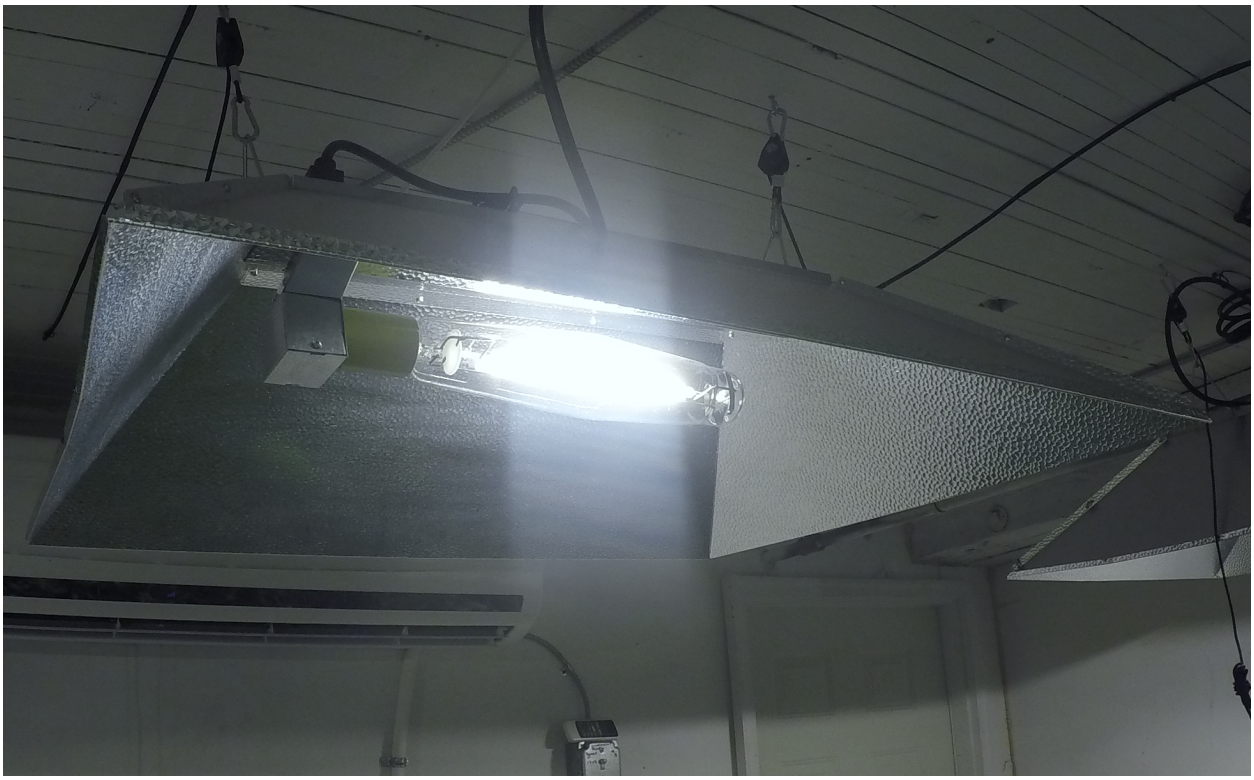


**Figure 1.** Metal halide bulb and a rectangular hood setup.

Some research has connected the use of high intensity bulbs to development of adverse health effects. One study showed damaged metal halide lamps can cause onset of photokeratitis and UV burns in children and adults with a median onset after 7 hours of exposure (Kirschke, Jones, Smith, & Schaffner, 2004). Other studies also link use of metal-halide lamps, particularly in gymnasiums, to photokeratitis onset (Betts, Smilkstein, Rumack, & Cwinn, 1986; Rose & Parker, 1979). Compact fluorescent lamps (CFL) pose little risk to individuals of normal sensitivity, but may be harmful to photosensitive patients (Moseley & Ferguson, 2011). Cells exposed to CFLs exhibited a decrease in the proliferation rate, a significant increase in the production of ROS, and a decrease in their ability to contract collagen (Mironava, Hadjiargyrou, Simon, & Rafailovich, 2012). Measurements of UV emissions found significant levels of UVC and UVA, which appeared to originate from cracks in the bulb phosphor coatings. Another study found exposure to a spectrum with intense UVC and some UVB emitted by a

germicidal lamp created an overexposure condition over 100 times higher than the International Commission for Non-Ionizing Radiation Protection (ICNIRP) exposure limit. A few hours after the exposure, the two subjects reported acute UV injury symptoms and continued reporting clinical signs for over 2 years (Zaffina et al., 2012).

### 1.7. Common UV exposure in occupational settings

Ultraviolet radiation (UVR) is electromagnetic radiation with wavelengths between 100 to 400 nm. The spectrum is classified into UVA, UVB, and UVC bands according to wavelength. Wavelength boundaries of UVA, UVB, and UVC vary, but this thesis will use the International Agency for Research on Cancer (IARC) bands: UVA [315 - 400 nm], UVB [280 - 315 nm], and UVC [100 - 280 nm].

Exposure to different UV wavelengths may differ between indoor and outdoor occupations. Solar radiation is filtered by the upper levels of the atmosphere with most UVC and 90% of UVB absorbed. UVA passes through the atmosphere with little change (Roy, Gies, Lugg, Toomey, & Tomlinson, 1998). Indoor lighting is artificial, and not filtered though the entire thickness of the atmosphere, and thus may contain higher UVB and UVC emissions. Most studies of indoor UV use a UVR – a summation of UVA, UVB, and UVC, which is difficult to separate into the three sub-categories without full spectrum data (Tenkate, 2012).

The agriculture and construction industries employ a large number of workers, large portions of which are expected to work outside. Each industry employs totals of 1.1 and 4.8 million workers respectively (US Census Bureau, 2015). Other major occupations such as sailors, pilots, and lifeguards also traditionally work outdoors, but employment statistics indicate they are dwarfed by the agriculture and construction industries with counts of 12,900, 66,900 (US Census Bureau, 2015), and 5,000 (USLA, 2015) respectively.

Indoor occupations that have UV exposure include welders, lab technicians, and agricultural workers. There are 38,800 welders in the United States (US Census

Bureau, 2015). Some lab technician tasks may also involve UV exposure. Some indoor agriculture may also involve UV exposure, but worker counts are unavailable since the closest NAICS codes is a combination of industries “Greenhouse, nursery, and floriculture production”.

Few studies quantify indoor UV exposure, and fewer still focus on indoor UV occupational exposures. The most characterized indoor UV exposures are tanning beds, but these studies have little relevance to occupational exposure. The tanning bed studies suggest, however that artificially created solar emulating light is associated with negative health outcomes (WHO 2009).

### 1.8. Health effects associated with UVR exposure

The health effects associated with UV exposure depend on the spectral profile of the radiation. Severity varies with duration and intensity of exposure, inducing both acute and chronic health outcomes. The primary target organs are the skin and eyes, which are reviewed below.

Erythema is the most common result of skin overexposure to UVR (Hausser, 1928). Its severity is influenced by exposure time and spectral profile (Coblentz, Stair, & Hogue, 1931). Tanned skin is noted as having resistance to erythemic incidence, with up to one magnitude greater UV exposure needed to induce erythemic response (McKinlay & Diffey, 1987). Chronic exposure to sunlight accelerates skin aging and increases risk of skin cancer, with UV wavelength profile causing variations of health impact (Cunningham-Dunlop, 1977). Many studies revealed association between UV exposure and multiple types of DNA damage including protein-DNA crosslinks, single strand breaks, and thymine glycol formation (Ichihashi et al., 2003). Furthermore, UV exposure is associated with apoptosis of keratinocytes and production of tumor necrosis agents (Aragane et al., 1998; Rehemtulla, Hamilton, Chinnaiyan, & Dixit, 1997; Schwarz et al., 1995). UVR induces superoxide radical (+$O_2$-), hydrogen peroxide ($H_2O_2$) and hydroxy radical (+OH). These reactive oxygen species (ROS) are associated with cutaneous aging including tumor development and inflammation (Cerutti, 1985).

In contrast to UVR exposure, exposure to UVA requires comparatively higher intensity and longer duration exposure to induce erythema (McKinlay & Diffey, 1987). UVA is associated with DNA damage through oxidative stress and targets DNA base guanine, producing reactive oxygen species that activate transcription factors such as Ap-1 and NFκB. Ap-1 and NFκB can cause apoptotic cell death (Cadet, Douki, Pouget, & Ravanat, 2000). UVA plus UVB intensifies erythemic response (Willis, Kligman, & Epstein, 1972). Exposure may produce $^1O_2$ possibly through chromophores, such as porphyrin in skin (Ichihashi et al., 2003).

Erythema caused by UVB is more severe than erythema caused by other UV wavelengths due to ability for UVB radiation to penetrate further into the epidermis. Peak erythema sensitivity occurs at 295 nm (Hausser, 1928). UVB exposure decreases intercellular lipid cohesion, which results in lower delamination energies. The suspected mechanism is structural change to SC lipids and keratin (Biniek, Levi, & Dauskardt, 2012). Some animal studies indicate that UVB is the most likely of the UV classifications to cause skin cancer (Gange & Rosen, 1986). UVB radiation causes formation of dimeric photoproducts between adjacent pyrimidine bases on the same strand in DNA, resulting in cis-syn cyclobutane pyrimidine dimers (CPD) lesions at the C to T and CC to TT transitions (Miller, 1985; Ziegler et al., 1993 ). The CC to TT tandem mutation is an absolutely specific marker of UV-induced gene alteration (Brash et al., 1991). The second most common adducts formed by UVB are pyrimidine-pyrimidone photoproducts (6-4). The mechanisms are suspected to cause many negative health effects associated with UVB exposure such as cancer incidence and rapid cell apoptosis (Clingen et al., 1995; Mitchell, 1988). UVB produced CPDs and (6-4) are repaired effectively, but even so, incorrect repair rarely induces oncogene mutation. However, the mutations induce cell transformation, leading to malignant tumor cells (Campbell, Quinn, Ro, Angus, & Ress, 1993; Levitt & Hickson, 2002; Rees, 1994). UVB may produce ROS such as $+O_2$- and $H_2O_2$. The latter is associated with phosphorylation of EGFR, suggesting $H_2O_2$ has a role in cellular signaling (Owen et al., 2000). UVB can reduce skin cancer immune surveillance in rodents. The suspect mechanism is modulation of expression of co-stimulatory function of epidermal Langerhans cells (LCs)

and lymphocytes. In addition, mice chronically exposed to UVB radiation display systemic defects in recognizing antigens (Ichihashi et al., 2003).

UVC causes the fastest, not necessarily most severe, incidence of erythema. Monowavelength UVC tests indicated that as wavelength increases, longer exposure duration is required for incidence of erythema. Tested wavelengths were 254, 280, 297, 303, and 313 nm (Berger, Urbach, & Davies, 1968). DNA exposure to UVC results in oxidation of guanine, however, resulting health effects are unclear (Ichihashi et al., 2003).

The eye has several UVR filtering layers between the cornea and retina to prevent retinal photodamage. The cornea absorbs all UVC and roughly 90% of UVB. The lens and vitreous humor absorb all UVA and further attenuate UVB (Young, 1984). Induced severity of photochemical and thermal injury is influenced by the angle of light entering the eye, natural eye motion, and spectral profile of radiation (Surdu et al., 2013). Ocular Squamous cell carcinoma is correlated with latitude, and the mechanism is suspected to be exposure to UV radiation (Newton, Ferlay, Reeves, Beral, & Parkin, 1996). A small case-control study identified an association (95% OR: 2.49 - 671) between ocular conjunctival intraepithelial neoplasia and solar elastosis (Tulvatana et al., 2003). A case-control of 60 Ugandan patients with a clinical diagnosis of conjunctival squamous cell carcinoma and 1,214 controls diagnosed with other cancers not known to be associated with solar UV exposure showed the risk for conjunctival squamous cell carcinoma increased with higher exposure durations. The reference exposure was 0 - 9 hours a week with odds ratios of 1.9 and 2.4 for exposure durations of 10 - 19 and ≥20 hours, respectively ($P = 0.05$). (Newton et al., 2002). Many studies report associations between solar exposure and ocular melanoma (Hakansson, Floderus, Gustavsson, Feychting, & Hallin, 2001; Seddon et al., 1990; Tucker et al., 1985; Vajdic et al., 2001). Seven studies examining welding UVR exposure reported odds ratios for ocular melanoma above unity (Guenel et al., 2001; Holly, Aston, Ahn, & Smith, 1996; Lutz et al., 2005; Seddon et al., 1990; Siemiatycki, 1991; Tucker et al., 1985).

Higher intensities of UVA radiation are required to induce photokeratitis in animals with wavelengths above 295 nm being almost entirely absorbed by the lens and vitreous humor of the eye (Pitts, Cullen, & Hacker, 1977). UVB exposure durations between 1.5 to 24 hours are associated with development of photokeratitis (Pitts & Tredici, 1971). UVB exposure in rabbits results in cataracts (Pitts et al., 1977). Threshold data for photokeratitis incidence exists for specific wavelengths between 220 to 310 nm with maximum eye sensitivity occurring at 270 nm and thresholds ranging from 4 to 14 $mJ/cm^2$ (Pitts & Tredici, 1971). Overexposure to UVB and UVC is causally linked to keratoconjunctivitis incidence (Pitts et al., 1977). Isolated UVC eye response studies have not been performed.

### 1.9. Health Effects Associated with Visible Light Exposure

Although the main focus of this thesis is indoor agriculture exposure to UVR, visible light exposure (380 - 700 nm) is also a health concern. Visible light exposure causes thermal and photochemical injury at the retina and choroid of the eye and thermal injury on the skin. Eyes have particularly high sensitivity to blue light wavelengths (400 - 480 nm) with peak sensitivity at 440 nm (ICNIRP, 2004). Studies have found that exposure to blue light may stimulate brain activity (Alkozei et al., 2016), and may disrupt melatonin production, which is associated with circadian patterns and sleep (Brainard et al., 2001). The eye is a target organ because it focuses radiation to a single retinal point, thus even short exposures to intense visible light can cause injury (Sliney & Wolbarsht, 1980). Both thermal and photochemical eye injuries result in irreversible vision damage (Young, 1984). Skin is of less concern as a target organ because high radiant exposure stimulates a natural pain-aversion reflex, reducing exposure (IARC, 2012).

### 1.10. Relevant Standards

Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs) do not exist for non-ionizing UVR, however, the American Conference of Governmental Industrial Hygienists (ACGIH) has published applicable threshold limit values (TLVs), which serve as best-practices guidelines. The ACGIH TLVs represent conditions under which it is believed that nearly all healthy workers may be repeatedly

exposed without acute adverse health effects. They do not apply for unstudied conditions including interactions with genetics, geographic latitude, prescription drugs, plant chemicals, cosmetics, and oils (ACGIH, 2015).

The UV TLV refers to ultraviolet incoherent radiation with wavelengths between 180 to 400 nm, with subgroups of UV broadband (180 to 400 nm) and UVA (315-400 nm). The broadband TLV is in the units of effective irradiance (eff. $W/cm^2$), an energy density measure of UV radiation weighted by human response to specific wavelengths. UV broadband and UVR are interchangeable terms referring to the total UV band. The UVA TLV is in units of irradiance ($W/cm^2$), an energy density without health weighting. The Light and Near Infrared Radiation TLV specific to blue light (305 to 700 nm) is based on the unit of radiance ($W/[cm^2*sr]$), which is a directional unit of energy density that only includes light approaching orthogonal to the sensor. The 'sr' in the radiance unit stands for steradian. Steradian is defined as the solid angle which, having its vertex at the center of the sphere, cuts off a spherical surface area equal to the square of the radius of the sphere.

The ACGIH TLVs work by setting a limit on the amount of accumulated light energy a worker can receive in a 24-hour cycle. Accumulation of light energy is governed by exposure duration and intensity. Table 1 details the TLV equations and conditions of use.

**Table 1.** The ACGIH TLV equations and conditions that govern selection.

| Exposure Type | Application | TLV | Equation Number |
|---|---|---|---|
| UVR | | $E_{eff}\left(\frac{W}{cm^2}\right) * t_{exp}(s) \leq 0.003\left(\frac{J}{cm^2}\right)$ | 1 |
| UVA | Duration <1000 s | $E_{UVA}\left(\frac{mW}{cm^2}\right) * t_{exp}(s) <= 1000\left(\frac{mJ}{cm^2}\right)$ | 2 |
| UVA | Duration >1000 s | $E_{UVA} <= 1\left(\frac{mW}{cm^2}\right)$ | 3 |
| Blue Light | Duration ≤10,000 s | $L\left(\frac{W}{cm^2 * sr}\right) * t(s) <= 100\left(\frac{J}{cm^2 * sr}\right)$ | 4 |
| Blue Light | Duration >10,000 s | $L\left(\frac{W}{cm^2 * sr}\right) <= 0.01\left(\frac{W}{cm^2 * sr}\right)$ | 5 |
| Blue Light | Radiance >0.01 W/(cm$^2$*sr) | $t_{exp}(s) <= \frac{100\left(\frac{s}{\frac{W}{cm^2 * sr}}\right)}{L_B\left(\frac{W}{cm^2 * sr}\right)}$ | 6 |

Equations 3 and 6 indicate that the TLVs for UVA and blue light have thresholds of 1.0 (mW/cm$^2$) and 0.01 (W/[cm$^2$* sr]), respectively. Spectral intensities under these thresholds represent conditions that pose no health risk regardless of exposure duration. Details of the parameters for these equations (e.g., $L$, $t_{exp}$) are described in the ACGIH guideline documentation (ACGIH, 2015).

Alternative measures of UV exposure include the standard erythemal dose (SED), a measure erythemally weighted with the same health response function the ACGIH incorporated, set to 1 SED = 100 eff. J/m$^2$, and the minimum erythemal dose (MED), the UVR required to produce a minimal erythemal response in a particular skin. Canada, the European Union, and other countries not including the United States enforce the International Electrotechnical Commission (IEC) labeling standard IEC

62471-1 (SVL, 2016). Bulbs must be tested in accordance with IEC methods, the results of which classify the bulb in 1 of 4 risk levels. It is important to note that this standard only applies to labeling and does not place restrictions on worker exposure in any way.

### 1.11. UVR Exposure Controls

Controls of occupational UVR exposure include administrative control (e.g., scheduling), engineering control (e.g., barriers), and personal protection equipment (PPE). Although UVR exposure response is well studied, a literature review for efficacy of control methods yielded few results, with some methods such as sunglasses well investigated and regulated, but others like schedule control and barriers hardly researched.

OSHA websites recommend personal protection such as clothing, hats, sunglasses, sunscreen, and avoiding the outdoors between 10am to 4pm (OSHA, 2003). OSHA does not explicitly classify UVR as a “recognizable hazard that can or is likely to cause death or serious harm to employees”, which would automatically mandate UVR exposure protection through the OSHA “General Duty Clause”. However, heat-stress is explicitly classified in this manner, and UVR protection emerges as by-product. OSHA letters of interpretation encourage mandatory breaks and shelter from sunlight. These letter statements have been enforced in court cases (OSHA, 2016).

A literature review did not uncover research directly investigating the relationship between schedule control and exposure reduction effectiveness. However, the scheduling of exposure durations may be implemented based the expected reduction on total accumulated spectral energy in $J/cm^2$, a measure many studies use as the exposure metric (Boniol, Autier, Boyle, & Gandini, 2012; IARC, 2012), and described in more detail in this thesis research.

The most studied and regulated UVR personal protection equipment are eyewear protection. In the United States “non-prescription and fashion eyewear” sunglasses are regulated by the Food and Drug administration, and production must conform to the American National Standard Institute Z80.3 standard (FDA, 2015). For occupational

applications, sunglasses must conform to the Z87.1 standard. The standards are legally linked to sunglasses products by intended function. Both standards govern transmittance, durability, reflectiveness, eye coverage area, and color modifying limits (ANSI Z80.3, 2015; ANSI Z87.1, 2010). An important difference in the context of indoor growing is that the occupational standards include UVC while the Z80.3 standards do not. The implication of this difference is explored in this thesis.

### 1.12. Aims of the Research

The primary purpose of this thesis is to characterize unprotected worker exposure to UVR and resulting risk of eye and skin damage. The secondary purpose is to describe risk of eye and skin damage while incorporating personal protection equipment (PPE) use and time-activity behavior patterns.

The primary hypothesis is that 8-hour UVR exposures in the facilities will cause eye and skin damage in unprotected workers based on health interpretation of the ACGIH TLVs. A secondary hypothesis is that proper PPE and exposure duration planning can reduce risk to levels below ACGIH health impact thresholds.

There are three Specific Aims of the research:

Aim 1: Conduct area measurements and personal exposure sampling of UVR levels in cannabis growing facilities.

Area samples of UVR levels will be systematically collected at varying distances from bulbs in two cannabis nurseries and two cannabis grow rooms. Additionally, a limited number of UVR personal exposure measurements will be collected from two workers in the grow rooms.

Aim 2: Interpret exposure measures through the ACGIH TLVs.

Based on the UVR intensity measurements collected from Aim 1, allowable exposure durations will be determined based on the ACGIH TLVs.

Aim 3: Explore potential UVR exposure controls.

Two control methods will be investigated: schedule control and use of PPE. A framework for schedule control will be presented using hypothetical time-activity in conjunction with the allowable exposure durations from Aim 2. PPE control for eye protection will be explored by comparing data obtained from an occupational eyewear manufacturer and previously published literature on non-prescription fashion sunglasses, to determine potential efficacy against UVR exposure in the cannabis industry.

The findings from this research may provide new information on occupational UVR exposures for a relatively new and understudied industry. Findings may also have broader relevance to other industries that utilize grow bulbs for agricultural production. Other large industries also grow crops indoors. The 'local food' movement led to development of an indoor agriculture industry valued at approximately one billion dollars as of 2005 (Newbean, 2015). The pharmaceutical industry also uses indoor grow practices to make vaccine ingredients that require precise conditions not achievable outdoors (Illumitex, 2013). Furthermore, the research may lead to useful methods that may help future research that better characterizes exposures in these industries, and evaluates the effectiveness of different exposure controls.

## 2. Methods

Working as part of a team of researchers for Labor and Industries Safety and Health Assessment and Research for Prevention Program (LNI SHARP), we performed a UVR (180 to 400 nm), UVA (315 to 400nm), and blue light (305 to 700 nm) exposure survey at two indoor cannabis production facilities in Washington State. Sample spectral profiles were selected in accordance with the ACGIH TLVs to estimate health risks from exposure. We developed and implemented separate area and personal sampling methods using observations on regular worker location, orientation, and room layout made during previous walkthroughs of the facilities. The sampled facilities, measurement methods, and data analytical methods are described below.

### 2.1. Production facilities

The indoor growing methods for occupational and recreational cannabis are identical. The process begins in a nursery. Seeds are placed into individual small pots, which are placed on tables or shelves with grow lights located directly above the seedlings. Water and fertilizer are applied by hand to the plants. After the seedlings germinate, enter vegetative growth, and reach a certain size (varies by facility), the plants are moved into a grow room, and replanted in roughly 10 gallon pots that are organized into rows with grow lights located about 30 cm above the plants running in a parallel along the row. A water and fertilizer distribution system is installed. As the plants grow, workers prune, set grow netting, apply pesticides, and perform daily inspections of plant progress. When the plants reach a predetermined final size, the conditions in the grow room are changed in a trade secret manner to induce flowering. At peak flowering, the entire room is harvested, the plants dried, and the buds hand removed from the plant. The buds are then collected and shipped to a processing facility. There are variations of growing marijuana including greenhouse use, full outdoor growing, and a combination nursery with outdoor vegetative growing. In Washington State, these variations may be less common than the process first described, and occupational hazards resulting from them are not considered in this thesis (Marijuana Business Association, 2015).

The research was conducted at two sites, which follow the aforementioned process of nursery-to-grow room production. Facility 1 housed a nursery and two grow rooms. The sampled grow room had dimensions of 14.9 by 11.6 m with seven plant rows running parallel to the short wall. Facility 2 housed one nursery and four grow rooms. The sampled grow room had dimensions of 9.8 by 6.1 m with moveable rows fixed parallel to the short wall. Grow room layouts of the two facilities were similar. Observed characteristics of the grow rooms include bulbs hanging at variable heights aligned with crops, reflectors surrounding bulbs, and both the crops and bulbs organized in parallel rows. All of the lights in Facility 2 were fixed at a height of 190 cm from the floor. Figure 2 shows both grow rooms where surveys were performed.

**Figure 2:** The grow rooms tested in Facility 1 (left) and 2 (Right)

Nursery layouts in both facilities were unique and did not resemble grow rooms. Nursery room sizes were not measured, but were smaller than grow rooms. In Facility 1's nursery, grow lights were mounted from the ceiling in the middle of the rectangular room, with an adjustable cord that allows the lights to be raised as the plants (which encircle the room) grow taller, allowing for optimal distance between the light (and its heat) and the top of the plant to be maintained. In the Facility 2 nursery, plants lined walls with different-model adjustable-height lights hanging above.

Various grow bulb models were seen in the facilities. In an attempt to acquire the spectral profile emitted from the bulbs, we contacted each manufacturer. None of the manufacturers provided the requested profiles. Despite the setback, basic specifications

for each observed bulb were available online, and are listed in Table 2. Labels on some bulbs were worn or absent and are marked ‘unknown’ in the table.

**Table 2:** Specifications by bulb type and manufacturer.

| Location | **Manufacturer**, Model Number | Wattage | Initial Lumens | Color Temp |
|---|---|---|---|---|
| Facility 1 Nursery | **Philips**, F54T5/841 HO EA<br>**Philips**, F32T8/TL841 ALTO<br>**Unknown**, High Pressure Sodium | 49W<br>100W<br>Unknown | 5000<br>9400<br>Unknown | 4100K<br>4100K<br>Unknown |
| Facility 1 Grow Room | **Atlas Lighting**, MH1000/U | 1000W | 110000 | 4200K |
| Facility 2 Nursery | **Sun Blaze**, 960320<br>**Ultra Sun**, MS1000/7500K<br>**Unknown**, Light emitting diode<br>**USHIO**, AMH-400/Opti-Blue 5001674 | 54W<br>1000W<br>Unknown<br>400W | 5000<br>100,000<br>Unknown<br>39000 | 6500K<br>7500K<br>Unknown<br>7000K |
| Facility 2 Grow Room | **Unknown**, Metal Halide | Unknown | Unknown | Unknown |

### 2.2. Radiometer

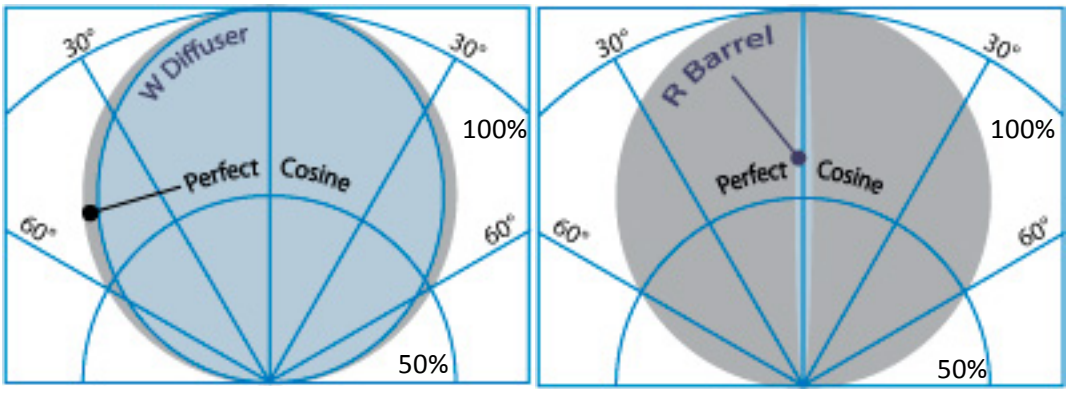
Measurements were conducted using a radiometer, the International Light Technology 5000 sampling hub (ILT 5000, Peabody, MA) with interchangeable wavelength sensors that express the spectral emissions in units that are directly comparable to the ACGIH TLVs. Sampling was performed using the UVR effective irradiance sensor (model SED240/ACT5/W), a UVA irradiance sensor (model SED033/UVA/W), and blue light sensor (model SED033/TBLU/SCS395/R). The sensors’ units of measure were effective irradiance (eff. $W/cm^2$), irradiance ($W/cm^2$), and radiance ($W/[cm^2*sr]$). Instrument limits of detection as reported by the manufacturer were $5 \times 10^{-9}$ (eff. $W/cm^2$), $2.67 \times 10^{-10}$ ($W/cm^2$), and $5.56 \times 10^{-9}$ ($W/[cm^2*sr]$), respectively (ILT, 2016).

According to the manufacturer's website, the effective irradiance for the UVR sensor is weighted according to the 2005 German Deutsches Institut für Normung (DIN) standard 14255-1. The German and ACGIH standards are not identical. However, the

weighting functions within both are identical because both organizations incorporated the 1989 (reaffirmed in 2004) International Commission on Non-ionizing Radiation Protection (ICNIRP) spectral weighting function (DIN, 2005). Thus, spectrally weighted measurements taken with this sensor are applicable to ACGIH TLVs.

The radiometer supported only one sensor at a time, so all area and personal sampling were repeated at least once per sensor. The sensors were factory calibrated prior to use. Data were downloaded from the radiometer to a computer using the Datalight II Datalog software and exported to Microsoft Excel. Any readings below the limit of detection were treated as having a value of LOD / √2, under the assumption that the data were log-normally distributed.

International Light Technologies provides sensor sensitivity to angle of incoming light. The specifications are reproduced in Figure 3, and illustrate that the angle of response for the blue light sensor is considerably narrower than the UVR and UVA sensors.




UVR and UVA Sensors | Blue light sensor

**Figure 3:** Sensor sensitivity to angle of incoming light. For UVR and UVA (left), the blue circle represents sensor response at various angles. For blue light (right), the blue line in the middle of the graph is the response.

### 2.3. Area Measurements

Sample location and orientation considered worker behavior, worker location, and room layout. Because nursery layouts varied and had an irregular layout, we selected sampling locations based on the expected location and orientation of a worker's head.

#### 2.3.1. Grow Room Area Sampling

During a walkthrough performed prior to UV sampling, we observed workers completing majority of plant related tasks, such as watering or pruning, within roughly 75 cm of a bulb, and oriented such that their body was faced directly towards the row of plants. To emulate the location, orientation, and account for row layout we set the sensors on a tripod at a height of 1.6 m (the height of an average American male's eyes) (Beardmore, 2013), and oriented the sensor perpendicular to both the floor and the row. We noted spacing between bulbs was consistent within, but not between grow rooms and chose to sample at locations aligned with the center of the bulb, the edge of the hood, and between the grow bulbs. Sampling aligned with the center of the bulb, and with the radiometer perpendicular to the floor represents a "worst case" rather than a representative scenario for exposure. Selection of sample locations in reference to a bulb allows the investigation of spectral intensity drop off as the measurement point is moved away from the selected bulb.

Because the instrument hub could only support one sensor at a time, sensors were interchanged to collect samples for different wavelengths at each position. To account for potential variation, we collected five measurements at each sampling location, allowing the sensor reach a stable reading after roughly five seconds. Readings from the sensors were manually recorded. For each sample, the straight-line distance from the sensor to the center of the bulb and the height of the bulb from the floor was recorded. Sampling was conducted at varying heights from the floor to assess variations in UV levels in this dimension.

Sampling was conducted both at middle- and end-of-row locations. In the selected rooms of facilities 1 and 2, four and three middle-row lights and three and three

end-row lights, were selected from a total of 49 and 24 bulbs, respectively. All middle-row lights were associated with five total sampling locations, while all end-row lights were associated with four locations at Facility 1 and seven locations at Facility 2 (Figure 4). In this manner, we sampled a total of 32 locations from seven lights in Facility 1, and 36 locations from six lights in Facility 2.

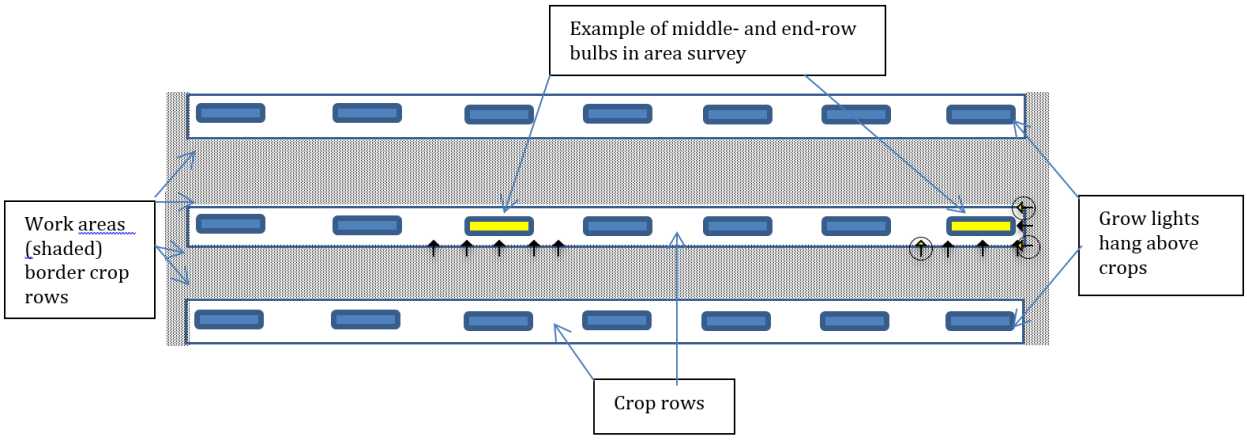



**Figure 4**: Overhead view of plant rows and lights in a grow room. The surveyed bulbs are marked in yellow with sample locations and orientations shown using black arrows. The circled arrows indicate additional sample locations taken at Facility 2 that were not used in Facility 1.

### 2.3.2. Nursery Area Sampling

While all grow room layouts observed were similar, nursery layouts had greater variability both within and between the facilities. We selected sample locations by estimating the location and orientation of a typical worker, and sampling the closest bulb. For Facility 1, sensor height remained at 1.6 m, oriented perpendicular to the floor, but Facility 2's plant shelves layout made this method unrepresentative of actual worker exposures. Instead, we chose to keep the distance between the sensor and bulb constant at 41 cm, roughly the observed distance that a worker would keep his head while handling the plants. For both facilities, we recorded the stable spectral emission and distance from the sensor to the center of the bulb.

In facilities 1 and 2, we selected two and four lights out of a total of 10 and 18

lights, respectively.  In Facility 1, three locations at varying distance to the bulb were sampled for each light. In Facility 2, one location was sampled for each light. In this manner, we sampled a total of six locations from two lights in Facility 1, and four locations from four lights in Facility 2.

### 2.4. Personal Exposure Sampling

Personal exposures were sampled for two workers, one per facility, working in a single grow room at each facility (the same grow room as where area sampling was conducted). The workers wore the radiometer hub on their belt, with the sensor mounted on their hardhat.  The sensor was mounted parallel about 15 cm above their eyes (Figure 5). Each worker wore the radiometer for three 20-minute intervals (one interval per sensor) with the radiometer logging at 1 sample per second. During each interval we made time logged observations of the worker's task, behavior, location, and productivity.

**Figure 5:** Sensor location on helmet.

### 2.5. Analysis of Measurements in the context of the ACGIH TLV

Descriptive statistics were computed for spectral intensities for different wavelengths and facilities were computed for both area and personal exposure samples. To link exposure data to exposure limits, the measurements were used as input for the appropriate ACGIH TLV equation. The output of the TLV equation was allowable duration, in seconds, which an unprotected worker may be exposed at the specified spectral intensity. The allowable durations computed from the TLV equations were

interpreted in relationship to standard 8-hour workday.

### 2.6. Analysis of Factors Associated with Exposure

After checking for independence of observations, homoscedasticity, and multicollinearity data from grow room area measurements were analyzed using multivariate linear regression to investigate the association between spectral intensity to measurement distance, bulb height, and facility for each sensor. Model fit was evaluated using the $R^2$ coefficient, and coefficients for variables were considered statistical significance if $P \leq 0.05$. The first model considered was:

Spectral Intensity = $B_0 + B_1 * X_{Distance}(cm) + B_2 X_{Height}$ (cm) + $B_3 X_{Facility}$ ('0' for facility 1 or '1' for facility 2

Then, we transformed the measurement distance into 1/distance$^2$ to investigate whether an inverse square model also fits the data.

Spectral Intensity = $B_0 + B_1 * 1/X^2_{Distance}$ (cm) + $B_2 X_{Height}$ (cm) + $B_3 X_{Facility}$ ('0' for facility 1 or '1' for facility 2)

### 2.7. Exposure Prediction Model

A framework for modeling a worker's exposure given specified working conditions was explored. This "exposure prediction model" is based on linking time-activity scenarios to the ACGIH TLVs. Since the ACGIH TLV equations are based on exposure duration and spectral intensity, they must be provided for the time-activity scenarios. The purpose of the model is to inform administrative controls (i.e., scheduling), such that potential worker time-activity in different nursery/grow room environments will not exceed the TLVs.

The model functions by estimating a proposed schedule's total UVR exposure energy (eff. J/cm$^2$) and dividing it by total task time (must be under 24 hours) to get the average exposure (eff. W/cm$^2$) for a single worker. The UVR TLV equation is then used

to convert the expected average exposure to allowable exposure duration. If the allowable duration is below the total task time, the proposed schedule may be safely implemented. The equations below implement the model.

$$\frac{Total\ Estimated\ UVR\ Energy\left(eff.\frac{J}{cm^2}\right)}{Total\ Expected\ Time\ Working\ (s)} = Average\ Exposure\ \left(eff.\frac{W}{cm^2}\right) \quad (1)$$

For a proposed schedule to not exceed the TLV, the following condition must be satisfied:

$$\frac{Average\ Exposure}{0.003} \geq Total\ Time \quad (2)$$

To calculate total estimated UVR energy we first must calculate the sum of the individual task energy contributions. Estimated UVR energy for single tasks will be calculated by multiplying an average exposure constant assigned to the task with the work duration scheduled. In this implementation of the model, the exposure constants will be set to the average exposure our worker experienced while performing a specific task. Work duration may be estimated based on the number of plants that need to undergo the task, and time it takes to perform the task on each plant. Data for both the exposure constant and per plant task duration were obtained from the personal monitoring log of facility 2. Incorporating this into Equation 1 results in Equation 3:

$$\left(\frac{\sum_0^n I_t * D_t * P_t}{T} = Average\ Exposure\right) \quad (3)$$

Where:

$I_t$ = Exposure constant of a specific task in [eff. W/cm$^2$]
$D_t$ = Per plant task duration in seconds [s]
$P_t$ = Number of plants that need to undergo the task
$n$ = Number of tasks
$T$ = Total expected time [s]

*Average exposure* = average spectral intensity (eff. W/cm$^2$) over the course of the proposed schedule.

Taking the *Average Exposure* and the expected time *T* from above, and inputting them into the ACGIH TLV equation for UVR (Equation 1) results in the following:

$$\frac{Average\ Exposure\left(eff\,\frac{W}{cm^2}\right)}{0.003\left(\frac{J}{cm^2}\right)} \geq \ T(s)$$

If the condition above is satisfied, the proposed schedule will likely not exceed the TLV.

### 2.8. Personal Protection Equipment

It was not possible to isolate UVB and UVC total by subtracting the UVR measurements from total UVA measurements since the units of UVR are weighted by biological effect. Without an unweighted emissions profile, it was not possible to evaluate sunglass effectiveness from the data directly. However, UV transmittance performance data on all occupational sunglasses produced by the manufacturer, UVEX, was obtained. These data were compared to similar data for non-prescription fashion sunglasses from a published study (Gursoy, Basmak, Esen, & Esen, 2015).

## 3. Results

### 3.1. Sampling Results

All three sensors recorded accurate zero and calibration light values before and after each sampling session. Spectral intensities above the limit of detection were recorded in every sampling session.

#### 3.1.1. Area Sampling Results

Summary statistics for the UVR, UVA, and blue light area measurements, grouped by grow room/nursery and facility are presented in Table 3. All UVA and blue light readings never exceeded the TLV thresholds (based on TLV equations 3 and 6). However, the TLV for UVR has the potential to be exceeded within an 8-hour (i.e., 480 min) work shift based on the mean and median UVR levels found in the sampled nurseries of both facilities.

Table 4 provides summary statistics for the UV and blue light measurements collected in just the grow rooms, grouped by sampling position. We added the end edge and end between positions to the sampling method for facility 2. Although there are differences in potential exposure by position of the sampling relative to the bulb center, again, we do not find that any of the TLVs based on mean UVR at each sampling position are likely to be exceeded within an 8-hour period. Within facility 1, the Center position tended to correspond to the highest UV and blue light levels, while there was relatively little difference by position measured in facility 2.

Table 5 illustrates the variations in UV and blue light grouped by distance between sensor and the bulb. The nursery from facility 2 was excluded from this stratification because sampling distance was constant at 41 cm, a result of unusual room layout. The nursery from facility 1 only had 6 samples, none of which fell into the 55-63 and 73-84 cm bins. Measurements collected from nursery 1, suggest that TLV for UVR might be exceeded within 8 hours at all of the sampled distances. While there tended to be some variations in median UVR levels by sampling distance for the grow

rooms in both facilities, even the shortest sampling distances did not result in potential exceedances of the UVR TLV within 8 hours.

Table 6 shows the recorded height of the bulbs in the grow rooms. Only bulbs in grow room Facility 1 had variable heights.

**Table 3:** Summary of area sampling in grow rooms and nurseries, with time to exceed TLV based on the corresponding min, max, median, mean UVR

| | UVR (eff. $mW/cm^2$) | Corresponding time to exceed TLV (min) | Blue Light[1] Radiance ($mW/cm^2*sr$) | UVA[1] Irradiance ($mW/cm^2$) |
|---|---|---|---|---|
| **Grow room, Facility 1:** n=32 (7 bulbs) | | | | |
| Min | $< 5e^{-6}$ | > 10000 | $9.60*10^{-4}$ | $9.47*10^{-4}$ |
| Max | $2.00*10^{-4}$ | 250 | $6.00*10^{-2}$ | $5.86*10^{-2}$ |
| Median | $3.50*10^{-5}$ | 1377 | $5.90*10^{-3}$ | $3.16*10^{-3}$ |
| Mean | $5.05*10^{-5}$ | 939 | $1.77*10^{-2}$ | $9.31*10^{-3}$ |
| SD | $5.57*10^{-5}$ | - | $2.14*10^{-2}$ | $1.36*10^{-2}$ |
| **Grow room, Facility 2:** n=36 (6 bulbs) | | | | |
| Min | $< 5e^{-6}$ | > 10000 | $1.10*10^{-2}$ | $1.40*10^{-2}$ |
| Max | $1.30*10^{-4}$ | 385 | $8.80*10^{-2}$ | $6.30*10^{-2}$ |
| Median | $6.40*10^{-5}$ | 794 | $4.10*10^{-2}$ | $3.50*10^{-2}$ |
| Mean | $6.86*10^{-5}$ | 749 | $4.50*10^{-2}$ | $3.73*10^{-2}$ |
| SD | $2.16*10^{-5}$ | - | $2.01*10^{-2}$ | $1.21*10^{-2}$ |
| **Nursery, Facility 1:** n=6 (2 bulbs) | | | | |
| Min | $9.00*10^{-4}$ | 56 | $4.70*10^{-2}$ | $1.10*10^{-1}$ |
| Max | $1.10*10^{-3}$ | 45 | $2.40*10^{-1}$ | $3.10*10^{-1}$ |
| Median | $1.05*10^{-3}$ | 48 | $5.90*10^{-2}$ | $1.60*10^{-1}$ |
| Mean | $1.03*10^{-3}$ | 49 | $1.12*10^{-1}$ | $1.77*10^{-1}$ |
| SD | $8.50*10^{-5}$ | - | $8.86*10^{-2}$ | $6.86*10^{-2}$ |
| **Nursery, Facility 2**: n=4 (4 bulbs) | | | | |
| Min | $3.80*10^{-4}$ | 131 | $5.20*10^{-4}$ | $2.80*10^{-3}$ |
| Max | $6.60*10^{-4}$ | 76 | $2.70*10^{-1}$ | $5.10*10^{-1}$ |
| Median | $4.60*10^{-4}$ | 109 | $8.65*10^{-2}$ | $4.14*10^{-2}$ |
| Mean | $4.90*10^{-4}$ | 102 | $1.11*10^{-1}$ | $1.49*10^{-1}$ |
| SD | $1.21*10^{-4}$ | - | $1.25*10^{-1}$ | $2.43*10^{-1}$ |

[1]All data for blue light and UVA spectrums were below the TLV.

**Table 4:** Measurements grouped by position relative to the selected bulb.

| Facility 1 Grow Room | | n | UVR (eff. mW/cm$^2$*10$^5$) | | | | UVA[1] (mW/cm$^2$*10$^3$) | | | Blue[1] (mW/cm$^2$*sr*10$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean Dist. (cm) | Mean | TLV (min) | SD | Mean Dist. (cm) | Mean | SD | Mean Dist. (cm) | Mean | SD |
| End Bulb | Center | 3 | 50 | 8.67 | 504 | 9.91 | 48 | 27.3 | 27.1 | 49 | 57.0 | 3.61 |
| | Edge | 6 | 54 | 5.04 | 975 | 5.12 | 56 | 12.3 | 13.2 | 53 | 16.2 | 19.5 |
| | End | 3 | 95 | 2.57 | 1470 | 3.40 | 92 | 1.91 | 1.21 | 92 | 17.3 | 17.1 |
| Aisle | Center | 4 | 54 | 7.13 | 603 | 8.29 | 54 | 16.8 | 20.1 | 53 | 28.6 | 27.5 |
| | Edge | 8 | 59 | 4.71 | 936 | 5.34 | 62 | 6.53 | 5.69 | 59 | 14.5 | 18.2 |
| | Between | 8 | 93 | 3.48 | 1362 | 3.67 | 92 | 2.24 | 1.27 | 92 | 2.08 | 1.08 |

| Facility 2 Grow Room | | n | UVR (eff. mW/cm$^2$*10$^5$) | | | | UVA[1] (mW/cm$^2$*10$^3$) | | | Blue[1] (mW/cm$^2$*sr*10$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean Dist. (cm) | Mean | TLV (min) | SD | Mean Dist. (cm) | Mean | SD | Mean Dist. (cm) | Mean | SD |
| End Bulb | Center | 3 | 61 | 6.60 | 757 | 2.54 | 60 | 41.3 | 17.6 | 54 | 32.7 | 19.1 |
| | Edge | 6 | 70 | 5.46 | 914 | 3.46 | 69 | 40.0 | 11.3 | 66 | 46.5 | 26.6 |
| | End | 3 | 70 | 6.95 | 719 | 6.28 | 65 | 45.7 | 27.5 | 62 | 33.0 | 11.4 |
| | End edge | 6 | 76 | 6.63 | 753 | 2.59 | 74 | 34.0 | 8.7 | 68 | 34.2 | 9.40 |
| | Between | 3 | 86 | 6.03 | 829 | 0.74 | 86 | 29.5 | 7.3 | 83 | 50.3 | 25.3 |
| Aisle | Center | 3 | 57 | 7.67 | 652 | 3.88 | 58 | 38.0 | 17.0 | 58 | 64.3 | 17.6 |
| | Edge | 6 | 66 | 7.88 | 634 | 0.88 | 67 | 41.7 | 9.07 | 67 | 53.2 | 15.5 |
| | Between | 6 | 81 | 6.58 | 759 | 0.60 | 79 | 32.2 | 3.54 | 79 | 45.2 | 23.2 |

[1]All data for blue light and UVA spectrums were below the TLV

**Table 5**: Spectral intensities stratified by measurement distance. The spectral intensity values presented are medians of samples within a distance category.

| **Grow room, Facility 1 (n=32 / 7 bulbs)** | | | | |
|---|---|---|---|---|
| **Distance Categories** | **UVR (eff. mW/cm$^2$)** | **Corresponding time to exceed TLV (min)** | **Blue Light[1] (mW/cm$^2$*sr)** | **UVA[1] (mW/cm$^2$)** |
| 40 - 55cm (n=11) | $6.00*10^{-5}$ | 833 | $4.30*10^{-2}$ | $1.20*10^{-2}$ |
| 55 – 63cm (n=10) | $2.55*10^{-5}$ | 1960 | $2.50*10^{-3}$ | $4.80*10^{-3}$ |
| 63 – 73cm (n=1) | $6.00*10^{-6}$ | 8333 | $1.12*10^{-2}$ | $2.70*10^{-3}$ |
| 73 – 84cm (n=2) | $3.10*10^{-6}$ | 16130 | $1.90*10^{-3}$ | $2.10*10^{-3}$ |
| 84 – 136cm (n=8) | $4.00*10^{-5}$ | 1250 | $2.30*10^{-3}$ | $1.30*10^{-3}$ |
| **Grow room, Facility 2 (n=36 / 6 bulbs)** | | | | |
| **Distance Categories** | **UVR (eff. mW/cm$^2$)** | **Corresponding time to exceed TLV (min)** | **Blue Light[1] (mW/cm$^2$*sr)** | **UVA[1] (mW/cm$^2$)** |
| 40 - 55cm (n=3) | $7.80*10^{-5}$ | 641 | $2.80*10^{-2}$ | $5.75*10^{-2}$ |
| 55 – 63cm (n=5) | $8.70*10^{-5}$ | 574 | $4.70*10^{-2}$ | $5.00*10^{-2}$ |
| 63 – 73cm (n=13) | $8.00*10^{-5}$ | 625 | $4.90*10^{-2}$ | $3.90*10^{-2}$ |
| 73 – 84cm (n=12) | $6.10*10^{-5}$ | 819 | $3.60*10^{-2}$ | $3.10*10^{-2}$ |
| 84 – 136cm (n=4) | $6.00*10^{-5}$ | 833 | $3.60*10^{-2}$ | $2.70*10^{-2}$ |
| **Nursery, Facility 1 (n=6 / 6 bulbs)** | | | | |
| **Distance Categories** | **UVR (eff. mW/cm$^2$)** | **Corresponding time to exceed TLV (min)** | **Blue Light[1] (mW/cm$^2$*sr)** | **UVA[1] (mW/cm$^2$)** |
| 40 - 55cm (n=1) | $1.10*10^{-3}$ | 45 | $2.40*10^{-1}$ | $3.10*10^{-1}$ |
| 55 – 63cm (n=0) | No Data | - | No Data | No Data |
| 63 – 73cm (n=2) | $9.70*10^{-4}$ | 52 | $4.70*10^{-2}$ | $1.70*10^{-1}$ |
| 73 – 84cm (n=0) | No Data | - | No Data | No Data |
| 84 – 136cm (n=3) | $1.10*10^{-4}$ | 45 | $5.90*10^{-2}$ | $1.55*10^{-1}$ |

**Table 6.** Summary of grow room bulb height from floor.

| | Bulb count | Min (cm) | Max (cm) | Median (cm) | Standard Deviation (cm) |
|---|---|---|---|---|---|
| Grow Room 1 | 7 | 160 | 185 | 173 | 9 |
| Grow Room 2 | 6 | 188 | 188 | 188 | 0 |

### 3.1.2. Personal Sampling Results

Table 7 shows summary statistics for the personal sampling. Each interval represents the measurements collected during a single 20-minute interval when the worker was working the grow room. No personal samples were collected in nurseries. Data from the Facility 1 UVR and blue light intervals were corrupted during transfer from the radiometer to a computer, and thus resulted in no usable data. Measured UVA and blue light spectral intensities never exceeded the TLV thresholds. UVR data from the single facility 2 worker suggests that there may be concern that the TLV would be exceeded within an 8-hour shift.

Observation notes collected during UV and blue light measurements are shown in Panel 1. Combining the observational notes and the personal monitoring logs provided insights into behavioral influences on sensor readings, which will be explored in Discussion.

**Table 7**. Summary of personal sampling.

| **Facility 1 Worker**<br>Task: Pruning | **UVR Interval**<br>n = 1200<br>eff. $mW/cm^2$ | <br><br>TLV time (min) | **Blue Interval**<br>n = 1200<br>$mW/(cm^2*sr)$ | **UVA Interval**[1]<br>n = 1200<br>$mW/cm^2 * 10^3$ |
|---|---|---|---|---|
| Mean | No Data[2] | -- | No Data[2] | 3.4 |
| SD | No Data[2] | -- | No Data[2] | 11 |
| Min - Max | No Data[2] | -- | No Data[2] | < .000267– 29.9 |
| | | | | |
| **Facility 2 Worker**<br>Tasks: Pruning, Net Setting | **UVR Interval**<br>**n = 1200**<br>eff. $mW/cm^2*10^5$ | <br><br>TLV time (min) | **Blue Interval**[1]<br>n = 1200<br>$mW/cm^2*sr*10^2$ | **UVA Interval**[1]<br>n = 1200<br>$mW/cm^2*10^3$ |
| Mean | 11.2 | 446 | 1.22 | 12.7 |
| SD | 3.81 | N/A | 2.28 | 9.71 |
| Min - Max | < .5 – 23.1 | > 10000 - 216 | < .000556 – 14.9 | < .000267–6.39 |

[1]All data for blue light and UVA spectrums were below the TLV
[2]Data corrupted when downloaded from radiometer
[3]Personal samples were only conducted in grow rooms, not nurseries.

*Facility 1 UV Broadband Personal Sampling Interval:*
The worker pruned crops in the middle of the grow room while switching between a sitting and crouching position. His head was oriented downwards towards the crops at almost all times. All work during the interval occurred in a small location near the center of the room with a roughly 1-meter change between start and finish location. He completed pruning of 4 plants.

*Facility 1 Blue-Light Sampling Interval:*
The worker pruned crops in the middle of the grow room while switching between a sitting and crouching position. His head was oriented downwards towards the crops at almost all times. All work during the interval occurred in a small location near the center of the room with a roughly 2-meter change between start and finish location. He completed pruning of 4 plants.

*Facility 1 UVA Personal Sampling Interval:*
The worker pruned crops in the middle of the grow room while switching between a sitting and crouching position. His head was oriented downwards towards the crops at almost all times. All work during the interval occurred in a small location near the center of the room with a roughly one meter change between start and finish location. He completed pruning of 4 plants.

*Facility 2 UV Broadband Personal Sampling Interval:*
The worker started by pruning but was approached by a fellow worker at roughly 9 minutes into the interval to help set webs. Posture during pruning was sitting with his head oriented downwards. During net setting he stood with his head oriented straight to coordinate setting nets with the other worker.

*Facility 2 UVA Personal Sampling Interval:*
The worker continued setting webs, but now they worked in the corner of the room. During this interval he faced the other worker. Head orientation remained upright during this interval.

*Facility 2 Blue Light Personal Sampling Interval:*
The worker continued setting webs, but moved to the corner of the room. During this interval he primarily faced the wall. Behavior, location, and task in the interval was almost identical to UVA.

**Panel 1:** Summary of personal sampling interval notes

### 3.2. Multivariable Regression Analysis Results

Results of the multivariable regression for the linear distance model are shown in Table 8. After adjusting for the influence of bulb height and facility on UVR measurements, an increase in bulb-to-sensor distance of 1 cm was found to be associated with a change of UVR spectral intensity of $-6.99*10^{-10}$ eff. W/cm$^2$ (P = 0.014). In the same model, an increase in bulb-to-floor height of 1 cm was found to be associated with a change of UVR spectral intensity of $2.85*10^{-9}$ eff. W/cm$^2$ (P =0.001). While these factors were found to be statistically significant, overall, the model performed somewhat poorly with an $R^2$ of only 0.29.

Similar regression models for UVA and blue light measurements revealed similar directionality of associations between spectral intensity and measurement distance and bulb height as those found for UVR. However, the coefficient for measurement distance was considerably larger for UVR than the same coefficient in the UVA and blue light models.

The multivariable regression models based on a 1/distance$^2$ variable did not perform appreciably better than the linear distance model ($R^2$ of 0.33, 0.82, and 0.42 for UVR, UVA, and blue light, respectively), and thus the results are not presented.

**Table 9:** Coefficients for multivariate regression of intensity to measurement distance, bulb height, and facility

| (n=68) for each spectral band | Measurement Distance | Bulb Height | Facility | Constant |
|---|---|---|---|---|
| UVR (eff. $mW/cm^2 * 10^5$) $R^2 = 0.2949$ | -0.00699 (CI: -0.125, -0.0146) | 0.285 (CI: 0.128, 0.443) | -1.84 (CI: -4.95, 1.28) | -39.7 (CI: -66.9, -12.5) |
| UVA ($mW/cm^2 * 10^3$) $R^2 = 0.7975$ | -0.348 (CI: -0.480, -0.216) | 0.548 (CI: 0.182, 0.914) | 22.3 (CI: 14.8, 29.7) | -26.3 (CI: -161.1, 10.85) |
| Blue ($mW/sr*cm^2 * 10^3$) $R^2 = 0.4445$ | -0.352 (CI: -0.636, -0.0681) | 0.383 (CI: -0.393, 1.16) | 23.9 (CI: 8.06, 39.6) | -26.3 (CI: -161, 108.5) |

### 3.3. Exposure Prediction Model Results

The model is task driven. Over the course of crop production, numerous tasks are performed. Those performed under grow lights include: (1) watering seedlings, (2) fertilizing seedlings, (3) possibly applying pesticides to seedlings, (4) setting growth support nets, (5) possibly applying pesticide to vegetative state plants, and (6) pruning. Of the above tasks, one through three occur in the nursery, while four through six occur in the grow room. During our visits, we observed watering and fertilizing of seedlings and performed personal sampling during pruning and support net setup. We did not observe pesticide application in either setting.

#### 3.3.1 Task Intensity Constant

Observations may inform the relevant tasks for which spectral intensity data are needed for modeling. In particular, the expected spectral intensity during a task – the variable *I* (in eff. W/cm$^2$) can be calculated for each task by combining UV sampling data with time stamped observational notes of behavior. Figure 6 shows a time series of the UVR personal sampling interval for the one worker we have data for, and the specific times when the worker was performing the two tasks.

Observation notes detail that between minutes 3 – 9 the worker sat while pruning plants, and then during minute 9 stood to help another worker set support netting in the minute 10 - 17 interval. A two sample T-test comparing the pruning (n=360) and net setting (n=420) work returned a significant difference in mean UVR exposure between the two intervals ($P < 0.001$). However, it is also important to observe from the time-series that there is considerable within-task variation in UVR measurements. There also exists a general upward trend in the time-series that warrants further investigation.

Nevertheless, the mean exposure between 180 to 540 seconds for Pruning was $7.24 \times 10^{-8}$ eff. W/cm$^2$ and between 600 to 1020 seconds for Net Setting was $1.44 \times 10^{-7}$ eff. W/cm$^2$ (Table 10). We will assign these values to the variable *I*.

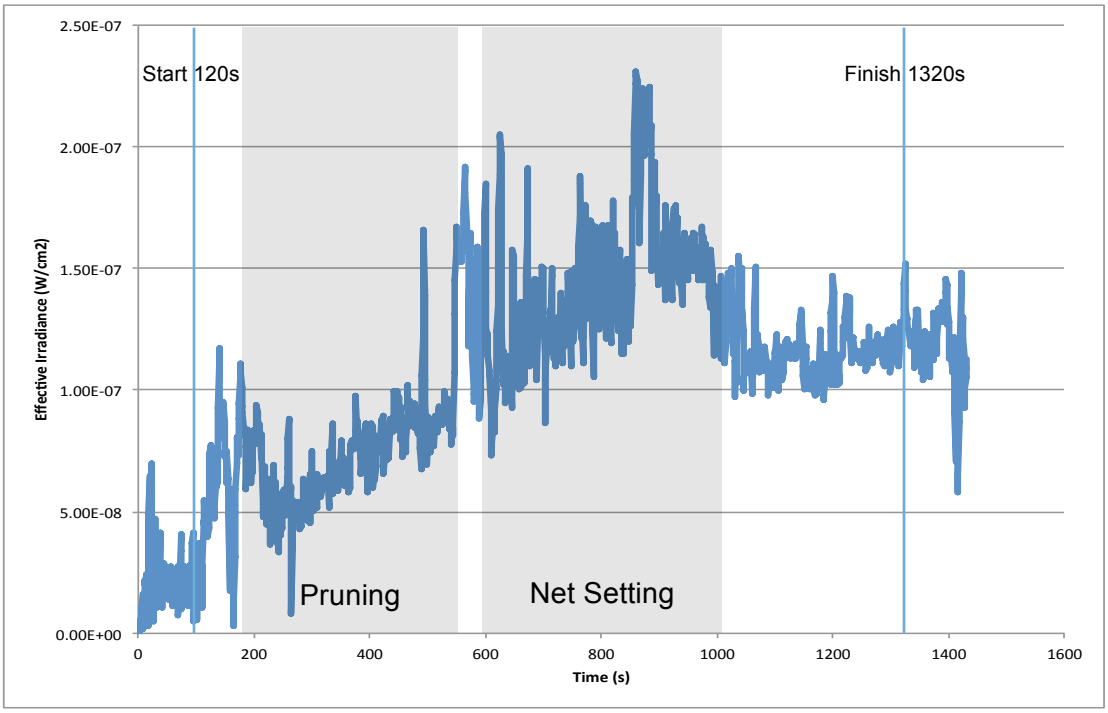



**Figure 6:** The personal sampling log of UVR taken from Facility 2. The log indicates the test subject was sitting while pruning between three minutes and nine minutes then transitioned to net setting between ten minutes and seventeen minutes.

**Table 10**: Summary Statistics for UVR for Worker in Facility 2 by Task

| | Mean (eff. W/cm$^2$) | Median (eff. W/cm$^2$) | SD (eff. W/cm$^2$) |
|---|---|---|---|
| Pruning (180 - 540s) | $7.24*10^{-8}$ | $7.49*10^{-8}$ | $1.76*10^{-8}$ |
| Net Setting (600 - 1020s) | $1.44*10^{-7}$ | $1.43*10^{-7}$ | $2.95*10^{-8}$ |

### 3.3.2. Task Duration Constant

Similarly, observational notes were used to estimate the “per plant” duration of each task. Over the course of the six 20-minute sampling intervals workers had a median of 4 pruned plants and 10 net set plants. Thus, the per plant durations for pruning and net setting were 5 minutes and 2 minutes, respectively. These values were assigned to the model variable *D*.

### 3.3.3. Example Model Calculation

Using the parameter values estimated above it was possible to show a hypothetical example application of the scheduling model, in which a worker is required to set support netting for 50 plants and prune 50 plants.

Step 1: Establish model variables of tasks.

1. Set up netting for 50 plants
    a. I = $1.44*10^{-7}$ (eff. W/$cm^2$)
    b. C = 50 (plants)
    c. D = 2 (min/plant)
2. Prune 50 plants
    a. I = $7.24*10^{-8}$ (eff. W/$cm^2$)
    b. C = 50 (plants)
    c. D = 5 (min/plant)
3. Calculate total time
    a. T = 50 (plants) * 2 (min/plant) + 50 (plants) * 5 (min/plant) = 350 minutes

Step 2: Input the variables and calculate average exposure across all tasks.

$$\frac{\left\{1.44 * 10^{-7}\ \left(\frac{W}{cm^2}\right) * 2\ \left(\frac{min}{plant}\right) * 50\ (plants)\right\} + \left\{7.24 * 10^{-8}\left(\frac{W}{cm^2}\right) * 5\left(\frac{min}{plant}\right) * 50(plants)\right\}}{350}$$

$$= 9.29 * 10^{-8}\ (eff\frac{W}{cm^2})$$

Step 3: Use the UVR TLV to calculate allowable time under the calculated exposure.

$$\frac{\left(\frac{0.003}{9.29 * 10^{-8}}\ (s)\right)}{60\ \left(\frac{s}{min}\right)} = 538\ (\text{min})$$

Since 350 < 538 minutes, this hypothetical schedule would be acceptable.

### 3.4. Personal Protection Equipment Results

The sunglass manufacturer UVEX provided UV transmittance performance data on all occupational sunglasses. In every spec sheet, transmittance between 200 to 400 nm was less than 0.01%. Figure 7 is an example of the UVEX provided data, the UVEX Amber sunglasses model (UVEX, 2015).

Based on the data provided by UVEX, applying a 99.9% reduction factor to our highest UVR measure 1.10 x $10^{-3}$ eff. mW/$cm^2$ results in 1.10 x $10^{-6}$ eff. mW/$cm^2$, a value under the ACGIH TLV. However, this assumes that light does not leak around the lens.

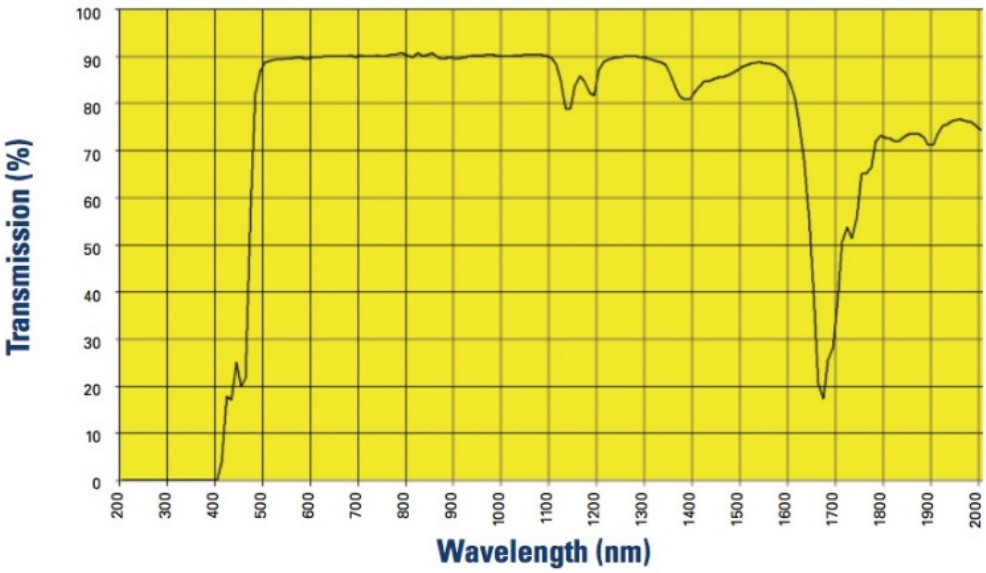



**Figure 7**: Transmittance of the UVEX “Amber” model. Notice the steep reduction in transmittance below 400 nm. Every occupational lens that UVEX manufactures has the same or similar reduction.

In contrast to the findings based on UVEX occupational eyewear, Gursoy et al., analyzed the performance of a random sample of 38 unbranded consumer sunglasses (Gursoy et al., 2015). All sunglasses allowed less than 5% UVC and UVB transmittance. However, 11 out of the 38 sunglasses failed to meet the European standard (100% UVR absorbance) for sunglass lens performance primarily due to high UVA transmittance. Peak UVA transmittance was 35% at 380 nm.

The worst performing Z80.3 sunglasses investigated in the Gursoy paper had greater transmittance than all other samples (n=38) at every UVR wavelength tested. This pair had a transmittance of under 5% for wavelengths under 350 nm. Between 350 to 400 nm this same pair has a transmittance between 5 to 35%, with the 35% peak at 380 nm. Because transmittance is not uniform at all wavelengths, we cannot say exactly how much reduction in exposure the pair would offer against UVR. However, because no UVA samples exceeded the TLV threshold, low UVB and UVC transmittance indicates the worst performing sunglasses would offer adequate protection.

Figure 8 shows examples of both the non-prescription and occupational sunglasses. One of the biggest differences between the non-prescription fashion eyewear and the occupational standard are in coverage. The occupational standard mandates full lateral coverage implemented by a fixed or detachable shield with no openings larger in diameter than 1.5 mm. Coverage must be lateral from the vertical plane of the lenses and tangential to a point not less than 10 mm posterior to the corneal plane and not less than 10 mm in height above/below the horizontal plane. Coverage area must be at minimum 40 mm in width by 33 mm in height in an elliptical shape centered over each eye and centered on the geometrical center of the lens.


**Figure 8:** Different coverage requirements between ANSI Z87.1 (occupational - left) and Z80.3 (non-prescription and fashion eyewear - right) are visible in sunglass design. (Left image from uvex.com; right image from Oakley.com)

## 4. Discussion

### 4.1 Comparison to ACGIH TLVs

This study's major finding is that some area and personal UVR samples at both indoor growing facilities are sufficiently high that if individuals work in these environments for more than 8 hours, the ACGIH TLVs have the potential to be exceeded. Exceeding the TLVs indicates conditions exist in work zones where unprotected workers may be at risk of retinal burns, erythema, premature skin aging, and cancer. Our results indicate UVR is the exposure of concern since the highest blue light reading (0.00027 W/[$cm^2$*sr]) is 37 times less than the TLV (0.01 W/[$cm^2$*sr]) threshold and the highest UVA reading (0.51 mW/$cm^2$) is roughly half the TLV (1.0 mW/$cm^2$). Because the UVR TLV was exceeded while the UVA TLV was not, bulb emissions likely contained UVB and/or UVC wavelengths. It is premature to rule out UVA and blue light as risk factors because of small sample size and un-validated methods.

From our area samples, the highest UVR measurements were collected in nurseries, with eff. irradiance intensities exceeding the TLV in as few as 131 minutes. At both facilities, grow room UV eff. irradiance maximums were lower than nursery minimums, with the highest grow room sample exceeding the TLV in 235 minutes. But, we did not collect data to determine whether workers would typically exceed these exposure durations.

From our personal sampling, the mean and median of the exposure from the Facility 2 UVR interval coincided with times to exceed TLV of 457 and 446 minutes respectively. Although these times are under an 8-hour timeframe, suggesting that TLVs may be exceeded, we did not collect data on whether a worker will remain in the grow room for more than these durations under typical work conditions.

### 4.2 Exposure Modifying Variables

During all Facility 1 sampling intervals, the worker pruned plants near the center of the room. The worker's lower position and downward head orientation may have lowered the measurement values. Since all Facility 1 intervals occurred near the center of the grow room, it is unclear how the central location would affect spectral intensity readings.

The Facility 2 UVR interval started with the worker pruning, and 9 minutes into personal sampling another worker enlisted the subject to work on net setting. There is a clear increase in sensor readings between the two tasks, attributed to sensor proximity to bulbs and upright posture. After the UVR interval, the workers moved to the edge of the room. Because the sensor readings are not directly comparable to one another, we cannot compare exposure between centrally and edge located work. From Figure 6, there seems to be an upward trend in UVR exposure throughout the sampling period. More research is required to investigate why this occurred.

During Facility 2 UVA and blue light measurement intervals, the worker net set with upright posture at the edge of the grow room. The upright posture is expected to increase readings while it is unclear how the edge of the room affects exposure.

From the untransformed multivariable linear regression, the distance coefficient showed a statistically significant negative relationship in all sensor type data. The transformed UVR and UVA models had similar, but slightly higher $R^2$ coefficients than their untransformed counterparts. Generally, neither model performed particularly well for UVR ($R^2$ of 0.29 and 0.33 for the linear distance and inverse distance squared models, respectively).

For both the untransformed and transformed distance models, a bulb height change of 1 cm was associated with a positive statistically significant change in spectral intensity except for blue light. The positive correlation may be due to the hood reflectivity or capturing of more light from neighboring bulbs. Light from higher bulbs is

reflected off the angled hood, and the sensor picks up light emitted from both the front and rear of the target bulb. It is expected that at even higher height settings the relationship sign might switch to negative. The blue light sensor is very sensitive to measurement direction, and reflected light coming at an angle to the sensor would not contribute to the reading. Some bulb hoods were below the sensor height of 165 cm. The hoods created a barrier between the selected bulb and the sensor and probably lowered measurements. Running the model with low height measurements removed did not change the positive statistically significant relationship of UVR or UVA or change the coefficient values by more than 42%.

The intensity difference in area samples between nurseries and grow rooms may be attributed to use of different bulbs. In the cannabis facilities we sampled, grow rooms used metal halogen bulbs, while nurseries used high-pressure sodium (HPS) bulbs (Hortilux, 2015). The sampling method used in the nursery, orienting the sensor towards the nearest bulb, also contributed to the intensity of the measurements. However, the nursery method is similar to testing the middle location of a selected grow room bulb, and the lowest nursery intensity exceeded the highest grow room sample.

We expected that bulb location at the edge or the center of the row would affect measurement intensity. There seemed to be a clear difference in intensity by position in facility 1, with higher intensity at the center position. However, no clear trend was observed from measurements in facility 2.

### 4.3 Exposure Variability and Uncertainty

Table 11 presents total grow room data for both types of sampling and the percent difference between the values. Values from UVR and UVA area and personal sampling shared similar peak readings in the rooms where both types of sampling were conducted. Facility 2 UVR peak readings were $1.30 \times 10^{-7}$ and $2.31 \times 10^{-7}$ eff. W/cm$^2$ while UVA peak readings were $6.30 \times 10^{-5}$ and $6.39 \times 10^{-5}$ W/cm$^2$ with the area values listed first. Facility 1 UVA peak readings were $5.86 \times 10^{-5}$ and $2.99 \times 10^{-5}$ W/cm$^2$ for area and personal sampling, respectively. Thus, neither method drastically overestimated

exposure relative to the other. Conversely, measurements for blue light were not similar, possibly because the blue light sensor is more sensitive to directional influences.

Given large data variability (percent differences of roughly 600,000% between the minimum and maximum readings), and different sampling methods, we observed percent differences between personal and area sampling within a one order of magnitude, which suggests that the findings are robust between two very different methods. Furthermore, coherence in the maximum values indicates that neither method produced large outliers relative to the other.

**Table 11:** Personal and area samples presented together with percent difference.

| Grow Room 1 | UVR | | | UVA | | | Blue Light | | |
|---|---|---|---|---|---|---|---|---|---|
| | Personal eff $W/cm^2$ | Area eff. $W/cm^2$ | Percent Difference | Personal $W/cm^2$ | Area $W/cm^2$ | Percent Difference | Personal $W/cm^2*sr$ | Area $W/cm^2*sr$ | Percent Difference |
| **Max** | NA | $2.0e^{-4}$ | NA | $2.99e^{-2}$ | $5.86e^{-2}$ | -95.98 | NA | $6.00e^{-2}$ | NA |
| **Mean** | NA | $3.5e^{-5}$ | NA | $3.40e^{-3}$ | $3.16e^{-3}$ | 7.05 | NA | $5.90e^{-3}$ | NA |

| Grow Room 2 | UVR | | | UVA | | | Blue Light | | |
|---|---|---|---|---|---|---|---|---|---|
| | Personal eff.$W/cm^2$ | Area eff. $W/cm^2$ | Percent Difference | Personal $W/cm^2$ | Area $W/cm^2$ | Percent Difference | Personal $W/cm^2*sr$ | Area $W/cm^2*sr$ | Percent Difference |
| **Max** | $2.31e^{-4}$ | $1.30e^{-4}$ | 43.72 | $6.39e^{-2}$ | $6.30e^{-2}$ | 1.41 | $1.49e^{-1}$ | $8.80e^{-2}$ | 40.94 |
| **Mean** | $1.09e^{-4}$ | $6.50e^{-5}$ | 40.36 | $1.54e^{-2}$ | $3.50e^{-2}$ | -127.27 | $2.22e^{-2}$ | $4.10e^{-2}$ | -84.68 |

### 4.3.1 Area Sampling Variability and Uncertainty

Area sampling variability may be attributable to differences in the immediate surroundings of the sensor. In both grow rooms and nurseries, tall plants, support frames, walls, other bulbs, and thick support netting can block the bulb light. More objects or large plants might reduce light exposure. It should be noted that these surrounding factors were unchanged during the entire sample run for each room. However, hood shape and size varied between, but not within grow rooms. The effect of hood variation on our measurements is unclear.

A potential source of uncertainty is from the sensors themselves. Studies have shown that sensors calibrated to different sources of light may record incorrect spectral intensities with errors of up to 7% (Huang, Dai, Yu, Wu, & Ouyang, 2011). Sensitivity to angle was considered in planning for the study, and is not expected to bias results. All

measurements with the sensors were kept orthogonal to the direction of the row, as opposed to directly facing selected bulbs, so that surrounding bulb contribution would not be underrepresented. The purpose of the ‘between’ position was to minimize contribution of the selected bulb while maximizing surrounding bulb intensity contribution.

The UVR standard deviation in Facility 1’s grow room was roughly double that of facility 2’s (Table 3). This could be related to the observed Facility 1 intensity drop apparent when samples are grouped by measurement position (Table 4). A potential cause is a difference in bulb spacing. We did not take measurements of the spacing between grow bulbs, but it is visually apparent that the spacing is larger in facility 1 (Figure 2).

When grouping by measurement (Table 3), we observe that the standard deviations are quite large relative to the mean spectral intensity. This is most likely attributable to the difference in heights between bulbs but also probably partly due to small sample size per grouping.

#### 4.3.2. Personal Sampling Variability and Uncertainty

High variability in measurements was expected due to sensor sensitivity to orientation and position. Changes in worker posture, position, behavior, movement, and task may have increased variability in the measured spectral intensities. However, since unprotected eye exposure is also very sensitive to light orientation, the data variability may be more, rather than less, representative of actual unprotected eye exposure.

A large uncertainty is how placement of the sensor affects exposure data. Reflection off the helmet lip probably did not influence the sensor because the ILT sensor is only sensitive to incoming light at a minimum of 60 degrees to sensor’s forward orientation. Reflected light at the extreme lip of the helmet would have an angle of incident of well over 90 degrees. Figure 9 provides an illustration of the helmet lip concern.

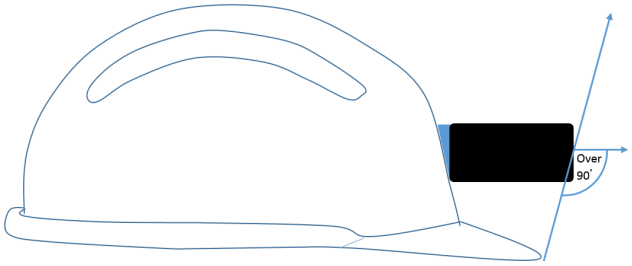



**Figure 9.** An illustration of the vector light would have to travel to reflect off a hard hat lip.

Positioning the sensor roughly 15 cm above the eyes may have positively biased personal sampling data. Alternatives proposed included fixing the sensor to safety glass frames or fixing it onto an ear, but we feared the lopsided weight and possible visibility limitation would impact behavior far more than a helmet. Small distance changes in area sampling influenced readings, and it is expected that a 15 cm height difference between eye and sensor position would overestimate exposures. In any case, we did not perform detailed evaluation of the effect of sensor position and angle on the measurements, and this examination is probably warranted in future studies.

### 4.5. Comparison of Findings to Other Studies of UV Exposure

Most existing UV exposure research uses the standard erythemal dose (SED). Because both the SED and the ACGIH TLVs use the same Mckinley et al. 1987 skin response weighting function, we can directly compare our readings to results from other studies after adjustment. We convert our data from eff. $W/cm^2$ into eff. $J/m^2$ by continuing to assume an exposure of 8 hours (28,800 seconds) and converting $cm^2$ to $m^2$. The resulting SEDs are shown in Table 12. Table 13 lists summary statistics from other studies.

**Table 12**. Samples converted to SED assuming constant exposure over an 8-hour day.

| **Grow Room 1** | eff. mW/cm$^2$ | SED (100 eff. J/m$^2$) | **Grow Room 2** | eff. mW/cm$^2$ | SED (100 eff. J/m$^2$) |
|---|---|---|---|---|---|
| Min | < 5e$^{-6}$ | 0.010 | Min | < 5e$^{-6}$ | 0.010 |
| Mean | 5.05*10$^{-5}$ | 0.145 | Mean | 6.86*10$^{-5}$ | 0.198 |
| Max | 2.00*10$^{-4}$ | 0.576 | Max | 1.30*10$^{-4}$ | 0.374 |
| **Nursery 1** | eff. mW/cm$^2$ | SED (100 eff. J/m$^2$) | **Nursery 2** | eff. mW/cm$^2$ | SED (100 eff. J/m$^2$) |
| Min | 9.00*10$^{-4}$ | 2.59 | Min | 3.80*10$^{-4}$ | 1.09 |
| Mean | 1.03*10$^{-3}$ | 2.96 | Mean | 4.90*10$^{-4}$ | 1.41 |
| Max | 1.10*10$^{-3}$ | 3.17 | Max | 6.60*10$^{-4}$ | 1.90 |

**Table 13.** Summary of other SED studies investigating occupational UV exposure.

| **Publication** | **Study Population** | **Target Organ** | **Measure Label** | **SED (Daily)** |
|---|---|---|---|---|
| (Vernez et al., 2015) | French outdoor ag workers | Whole Body | Median | 0.95 |
| | French outdoor ag workers | Whole Body | Max | 1.81 |
| (Chorley, Higlett, Baczynska, Hunter, & Khazova, 2014) | Pilot during 2hr flight | Eye | Total | 1.4 |
| (Milon, Bulliard, Vuilleumier, Danuser, & Vernez, 2014) | Nonspecific outdoor workers | Face | Median | 0.85 |
| | Nonspecific outdoor workers | Face | Max | 4.39 |
| (Schmalwieser et al., 2010) | Austrian farmers | Whole Body | Mean | 2.99 |
| | Austrian farmers | Whole Body | Max | 14.20 |
| (Serrano, Cañada, & Moreno, 2009) | Gardeners | Shoulder | Mean | 4.125 |
| | Lifeguards | Shoulder | Mean | 11.43 |
| (Zhu et al., 2015) | Total daily UVR in region | Geographic | min | 17.29 |
| | Total daily UVR in region | Geographic | max | 48.67 |

The SED doses found in our study ranged from 0.01 to 3.17 SED with significant mean intensity difference between individual rooms ranging from 0.1 to 3.02 SED. Previous studies' SED values vary greatly, making it difficult to compare or generalize. Yet, similar SED results can be found from Boniol et al. (2015) and Milon et al. (2013) with mean SED values of 0.95 and 0.85, respectively. Within agriculture populations, Boniol et al. (2015) again reported comparable mean SED, while Schmalwieser et al. (2010) and Serrano et al. (2009) reported mean exposures higher at 2.99 and 4.125, respectively. Other studies found even higher occupational exposures. Chorley et al. (2014) measured pilot exposure to UV and found that after a 2-hr flight the total SED dose was 1.4. Finally, Zhu et al. (2015) measured potential total solar contribution over various geographic regions in China, finding total exposure potentials of at minimum 17.29 over the course of a whole day. Thus, most studies show mean SED exposures higher than those we have found in the sampled cannabis grow facilities. This is encouraging because it indicates facility conditions may be safer than their outdoor counterparts.

### 4.6. Exposure Prediction Model

The underlying assumption of the exposure prediction model is that tasks have unchanging average exposures if the worker and room are fixed. Our estimates for pruning and net setting exposure intensity were meant simply as a demonstration of how the model could be implemented. Average exposure intensity values for a task should be derived from a time frame representative of the changing conditions and behavior of the room and worker.

The reason for the conceptualization of this prediction model is to circumvent the lack of scheduling information. Workflow in a grow room is planned around deadlines for task completion rather than hourly by task length. While task length is not tracked, inventory is. The potential advantage to the model is it can be incorporated into existing inventory systems once average exposures for certain tasks are assessed.

### 4.7. Personal Protection Equipment

Data on the transmission of UV light through occupational eyewear, provided by the manufacturer, UVEX, suggests that use of occupational glasses will reduce UV exposure to the eye to levels far under the TLV allowable levels. The key to achieving reduced exposures in real-world settings is development of a safety culture that encourages proper sunglass usage. Employers are already mandated to enforce safety glass use for impact injury. However, UV emissions do not fall under impact injury and at least anecdotally, from the few workers involved in this study, the hazards of UV exposure may be underappreciated. The culture, a natural product of lack of UV regulation and a dearth of media devoted to bulb emission hazard awareness may collectively contribute to the observed lack of use of safety glasses.

Based on the results of the Gursoy paper, Z80.3 sunglasses may offer adequate protection for UVR. Less than 5% of UVB and UVC passes through the worst of the 38 sunglasses sampled. Performance of the worst performing model began to allow UVA transmittance at 350 nm. Since no UVA TLVs were exceeded during sampling, and the worst sunglasses block the majority of UVB and UVC, use of the worst pair of sunglasses may block enough emission to prevent exceeding the TLVs in under 8 hours for even the highest measured values. However, there still remains the issue of inadequate eye coverage with non-occupational eyewear, such that real-world performance may not as effective in reducing UVR exposure.

ANSI sunglass standards for non-prescription and fashion eyewear (Z80.3) and occupational (Z87.1) sunglasses were written for different environments. The Z80.3 standards, written for outdoor use, may not be applicable to occupational environments. Two potential issues with the Z80.3 standards are lens leakage and wavelength specific transmittance. Z80.3 standards coverage requirements were designed accounting for a single overhead solar source. Coverage requirements do not account for multiple sources surrounding the wearer. Occupational Z87.1 glasses have much broader coverage requirements motivated perhaps less by radiation, and perhaps more by impact hazard. A second difference in the standards is handling of UVC. Solar radiation

has almost no UVC component after passing through the atmosphere, and thus the spectrum grouping is not covered in the Z80.3 standard. The occupational standard requires occupational sunglasses to block a majority of UVC transmittance. We do not know bulb spectral profile from the facilities, but Z80.3 sunglasses may be inadequate if UVC is a significant portion of emission.

### 4.8. Limitations

#### 4.8.1. Time

We only had one day at each facility. This coupled with sampling time greatly limited the number of samples it was possible to collect. Each single sample took roughly one minute: 15 seconds to setup position, 15 for the reading to stabilize, and 30 to collect the sensor distance and bulb height. We only had one sampling hub for three sensors, so each position had to be repeated 3 times with a different sensor. Changing sensors and calibration took roughly 15 minutes. The three personal sampling runs at each location took a total of roughly one and a half hours. These time requirements prevented development of a more ideal characterization that would involve sampling every bulb in a single grow room, and also measurement of a single lit bulb. This would provide us with more samples to better establish a relationship between bulb height and distance. In addition, the single bulb measurement would allow us to determine surrounding bulb contribution by subtracting single bulb measurements from area sampling. Finally, the original method called for double the number of spectral intensity samples at each sampling location. We also wanted to angle the sensor downwards to face the plants, but did not have time to do so.

#### 4.8.2. Methods development

Since we had no previous studies as a guide, method design choices were best attempts at collecting representative samples. Our decisions were based on only a few observational walkthroughs prior to the sampling visits.

We located area sampling positions in the grow room rows because we observed all tasks performed from the rows. Grow room layout and bulb type were homogenous,

so we chose to characterize the area around individual bulbs. We knew hood geometry and bulb type were not homogenous between facilities, so we selected the center, edge, and between sample positions rather than set distance. We oriented the sensor perpendicular to the direction of the row, facing the plants, because we observed workers facing plants at all times. We did not orient the sensor directly toward the target bulb we suspected that this orientation would not account for surrounding bulb contribution or emulate worker. We chose the height of the sensor to be representative of the average male's eye location, but future work might focus on average female height.

Our primary objective for personal sampling was to minimize worker behavior modification. We explored different sensor locations and subjectively decided the most comfortable position was on the front of a helmet. Other locations were considered, but none were as comfortable as the helmet location. The helmet location flaw is the 15 cm higher sensor position relative to the eyes and its effects are discussed in the exposure modifying variables section. We believe we were successful at reducing impact on behavior, as the workers had no problem performing work in any position, including at times crouching and crawling.

#### 4.8.3. Scope

We only surveyed two of the 704 cannabis growing facilities in Washington State. The limited scope prevents generalization of results to all facilities.

### 4.9 Future Research

Area sampling with a spectrometer is needed to isolate the problem spectra. Collecting more data across a variety of workers and conditions, and longer shift personal sampling is an ideal sampling strategy because it most accurately reflects average worker exposure and exposure variability. Further research is needed to validate the personal sampling methods devised here and to examine the effectiveness of personal protective equipment when handling multiple light sources. Furthermore, the health outcomes of long-term exposure to indoor UV light are not well studied.

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