UV-C Exposure and Health Effects in Surgical Suite Personnel

David Sylvain, MS, CIH
Loren Tapp, MD, MS

Health Hazard Evaluation Report
HETA 2007-0257-3082
Brigham and Women's Hospital
Boston, Massachusetts
May 2009

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
NIOSH *National Institute for Occupational Safety and Health*

The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

Contents

Report

Appendix A

Acknowledgments

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
BWH	Brigham and Women's Hospital
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
HHE	Health hazard evaluation
IARC	International Agency for Research on Cancer
J/cm^2	Joules per square centimeter
MNA	Massachusetts Nurses Association
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
nm	Nanometer
NTP	National Toxicology Program
OEL	Occupational exposure limit
OR	Operating room
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PPE	Personal protective equipment
REL	Recommended exposure limit
STEL	Short-term exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
UV	Ultraviolet
UV-A	Ultraviolet radiation, long wavelength
UV-B	Ultraviolet radiation, medium wavelength
UV-C	Ultraviolet radiation, short wavelength
UVR	Ultraviolet radiation
UVGI	Ultraviolet germicidal irradiation
WEEL	Workplace environmental exposure limit
$\mu W/cm^2$	Microwatts per square centimeter

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a management request for a health hazard evaluation at Brigham and Women's Hospital (BWH) in Boston, Massachusetts. The request was submitted due to surgical staff's concerns about skin and eye symptoms. These symptoms were thought to be caused by ultraviolet wavelength C (UV-C) radiation produced by ultraviolet (UV) lamps mounted on the ceilings of orthopedic operating rooms (ORs). Site visits were made in October and December 2007.

What NIOSH Did

- We met with management, union representatives, and employees.
- We toured the orthopedic ORs and observed surgical staff at work.
- We used personal dosimeters to measure UV-C exposure to surgical staff during procedures.
- We looked at how well personal protective equipment (PPE) protected employees from UV-C radiation.
- We spoke with employees confidentially about possible work-related skin and eye symptoms.
- We looked at employee medical records.
- We looked at the ultraviolet germicidal irradiation (UVGI) policies for BWH.

What NIOSH Found

- UV-C exposure was 6 to 28 times greater than the NIOSH recommended exposure limit (REL) when dosimeters were placed outside hospital-approved PPE.
- UV-C exposure was well below the NIOSH REL when dosimeters were placed beneath hospital-approved PPE.
- Some surgical masks and one reinforced gown did not reduce UV-C to less than 0.2 microwatts per square centimeter ($\mu W/cm^2$) during spot measurements in an OR.
- Hospital-approved headwear and combinations of PPE (e.g., togas, layered gowns, scrubs, and jackets) reduced UV-C transmission to less than 0.2 $\mu W/cm^2$.
- Of 14 orthopedic OR nurses and technicians, five reported having symptoms possibly related to UVGI exposure while employed at BWH. Three employees had eye changes, one had skin changes, and one had eye and skin changes.
- Most OR staff said they lacked training in UV-C hazards.
- Some OR staff found PPE uncomfortable and cumbersome.
- For various reasons, most OR staff did not wear sunscreen at work as required by hospital PPE protocols.
- Skin and eye screening records did not report changes that were thought to be caused by UV-C exposure. However, three employees were diagnosed with melanoma, three with basal

cell carcinoma, and five with actinic keratoses out of 22 skin screenings since 2003.

- Since our site visits, BWH has stopped using UVGI in the ORs.

What BWH Managers Can Do

- Remove UV lamp fixtures in ORs. This will prevent UV-C exposure during surgeries.
- Continue annual skin screenings for employees previously exposed to UV-C.

What BWH Employees Can Do

- Notify BWH's Occupational Health Services of skin lesions that appear on UV-exposed skin.
- Have any skin lesions evaluated by a physician.

Summary

Some orthopedic OR nurses and technicians have reported skin and/or eye symptoms believed to be due to OR UV-C exposure. Employee medical records found six skin cancers on skin screening examinations since 2003. Our investigation found that orthopedic OR staff exposures to UV-C beneath two layers of PPE were well below the NIOSH REL. Since the last NIOSH site visit in December 2007, BWH moved the orthopedic OR suite into an area equipped with laminar airflow and discontinued the use of UVGI for intraoperative infection control.

On May 18, 2007, NIOSH received an HHE request from the Director of Environmental Affairs at Brigham and Women's Hospital in Boston, Massachusetts. The request indicated that some orthopedic surgical staff were concerned about unspecified skin and eye symptoms that they attributed to germicidal UV-C radiation produced by ceiling-mounted UV lamps in orthopedic operating rooms.

On October 1–3, 2007, we met with employee, union, and management representatives, toured the orthopedic operating suites, measured OR staff UV-C exposure with personal dosimeters during a surgical procedure, measured UV-C exposure beneath PPE items, and reviewed hospital UVGI policies. We also conducted confidential employee interviews and reviewed medical records of BWH orthopedic OR staff. On December 10, 2007, personal dosimetry was conducted during orthopedic procedures in three ORs.

Orthopedic OR staff UV-C exposures, measured at shoulder height beneath a scrub shirt and warm-up jacket or surgical gown (i.e., two layers of PPE), were well below the NIOSH REL during 94- to 195-minute periods when UVGI was in use. Dosimeters placed outside PPE at shoulder height recorded UV-C doses that were 6 to 28 times greater than the REL. PPE assessment for UV-C attenuation identified surgical masks and a reinforced gown that did not reduce irradiance below 0.2 $\mu W/cm^2$. Other hospital-approved headwear and combinations of protective garments such as scrubs and warm-up jackets evaluated during this HHE attenuated irradiance to below 0.2 $\mu W/cm^2$.

Five of 14 orthopedic OR nurses and surgical technicians interviewed reported possible UVGI-related symptoms; three had eye irritation, one had actinic keratoses (a precursor to skin cancer), and one had both eye irritation and actinic keratoses. Most OR staff reported lack of training in UV-C hazards and did not wear sunscreen at work for a variety of reasons, while some found PPE cumbersome and uncomfortable.

None of the eye and skin screening examinations done by the hospital since 2003 documented changes that were attributed to UV-C exposure. However, of the 28 OR nurses and surgical technicians who participated in the examination, 3 were diagnosed with melanoma, 3 with basal cell carcinoma, and 5 with actinic keratoses.

Although medical screening exams of OR employees exposed to UV-C lamps did not document skin (redness) or eye (photokeratitis) changes directly related to UV-C exposure, employee reports of skin redness and eye discomfort after UV-C exposure may indicate that overexposures have occurred. The skin cancers and actinic keratoses found on employee skin exams are known to be caused by UV exposure from the sun. There is not enough information in the scientific literature to know if UV-C exposure causes cancer in humans, although evidence for cancer in animals exists. However, UV-C radiation has been classified as reasonably anticipated to be a human carcinogen by the NTP.

Infection control considerations aside, substitution of other infection control technologies such as laminar airflow is the preferred way to eliminate the UV hazard in ORs. In addition to eliminating the source of the hazard, substitution also eliminates the need for UV-C hazard awareness training, PPE training, ongoing supervision of PPE use, inspection and evaluation of PPE, and medical surveillance. Since the last NIOSH site visit in December 2007, BWH has discontinued the use of UVGI for intraoperative infection control.

Keywords: NAICS 62211 (General Medical and Surgical Hospitals), ultraviolet radiation, UV-C, UVGI, nonionizing radiation, skin cancer, photokeratitis, keratoconjunctivitis, infection control.

On May 18, 2007, NIOSH received an HHE request from the Director of Environmental Affairs at Brigham and Women's Hospital in Boston, Massachusetts. The request indicated that some orthopedic surgical staff were concerned about unspecified skin and eye symptoms that they attributed to germicidal UV-C radiation produced by ceiling-mounted UVGI lamps in orthopedic operating rooms.

The use of UVGI in orthopedic ORs was an ongoing concern for several years prior to this HHE request and was investigated by OSHA on January 19, 2007. The OSHA inspection was conducted in response to a formal complaint submitted by the MNA. The complaint was initiated after discovering that the UVGI lamp controls in one of the ORs had been tampered with and set at an inappropriately high setting. Following the inspection, OSHA sent a letter to management that included written recommendations to provide annual UV-C and PPE training and medical screening for all affected employees, and to ensure that all affected employees used required PPE. Following the inspection, OSHA encouraged BWH to request an HHE. In July 2008, BWH moved the orthopedic OR suite into an area equipped with laminar airflow and discontinued the use of UVGI for intraoperative infection control.

Background

UVGI systems have been used in several types of applications to control or eradicate microbes, including wastewater treatment facilities, air handling unit cooling coils and filter assemblies, pharmaceuticals, biohazard control, medical equipment, food (e.g., meats) [IESNA 2000; Kowalski and Bahnfleth 2004], and healthcare facilities. In healthcare facilities, three types of UVGI systems are generally used to inactivate airborne microorganisms such as *M. tuberculosis*: (1) duct irradiation, (2) UVGI lamps incorporated into room air-recirculation units, or (3) upper-room irradiation [NIOSH 2009].

Use of direct UVGI as an air-cleaning method for intraoperative infection control is a relatively uncommon application that has been used by some surgeons since the 1930s. [Berg-Périer et al. 1992; Miner et al. 2005]. Some evidence suggests that use of UVGI in this manner may reduce surgical wound, as well as airborne, bacterial contamination [Taylor et al. 1995; Miner et al. 2005]. The

efficacy of UVGI for intraoperative infection control is not well defined, largely because studies that examined its use did so at a variety of UV intensities in association with other infection control methods and surgical techniques. Nevertheless, some studies concluded that UVGI appears to be effective in reducing the risk of surgical site infections [Brown et al. 1996; Goldner 2000; Ritter et al. 2007]. Investigators have reported that UVGI is usually not used alone, but is used in conjunction with laminar airflow or body exhaust techniques [Miner et al. 2005]. Although assessment of, and recommendations for, infection control methods are outside the scope of this HHE, it should be noted that CDC recommends against using UVGI to prevent surgical site infections [CDC 2003].

Orthopedic surgeons started using UVGI at Peter Bent Brigham Hospital (a forerunner of BWH) in 1973 [Lowell and Kundsin 1978]. At the time of the NIOSH site visits, UVGI was used in six BWH orthopedic ORs for infection control, primarily during joint replacement surgery. According to management, UVGI use was to continue until spring 2008 when the orthopedic suite was scheduled to move to a location equipped with vertical laminar airflow ventilation. In July 2008, the orthopedic suite moved into the new location, and use of UVGI was terminated at BWH [Bloom S, personal communication 2008].

Each UV-equipped OR had eight ceiling-mounted UV lamps (one in each corner of the room and four in a rectangular pattern above the surgical table) that directly irradiated the upper and lower room air and surfaces throughout the OR. The lamps, manufactured by American Ultraviolet Company, emitted germicidal UV predominantly at a wavelength of 254 nm (UV-C wavelength) to reduce airborne transmission of infectious agents and to help maintain a sterile field during specialized orthopedic surgeries. Irradiance at 254 nm was set at 24 to 30 $\mu W/cm^2$ at a height of 1 meter above the floor. BWH Health Physics staff measured UV-C irradiance in each OR weekly, and adjusted irradiance levels as needed. Lamps were turned on with a switch outside each OR; the intensity of the lamps was set using a rheostat in a locked plastic box on a wall in each OR. A warning light near the OR doorway indicated when UVGI was in use, and written warnings were posted on OR doors and next to the warning lights.

Prior to July 2008, UVGI was used at least several times each week. The lamps were typically illuminated for 2 to more than 6 hours during each surgery, where eight to ten medical staff were present.

Approximately 40 to 50 hospital staff worked in the orthopedic ORs, as well as transient staff such as x-ray technicians and floating nurses who could be present for 15 to 60 minutes during a surgical procedure.

In 2003, BWH determined that PPE used by OR staff did not provide adequate protection against UVGI. To address this problem, Health Physics staff used a radiometer to identify combinations of surgical masks, scrubs, jackets, gloves, togas, and head coverings that could attenuate the maximum UVGI that the lamps could generate at one meter above the floor (66–85 $\mu W/cm^2$) to 0.2 $\mu W/cm^2$ [Castronovo 2003]. OR staff were instructed to wear one of three combinations of surgical apparel that were approved as PPE by Health Physics staff. Nevertheless, it appears that compliance with PPE requirements and other work practices had been problematic since 2003. Reasons for incomplete compliance included employee discomfort, waning PPE supplies at the end of the day, difficulty with using sunscreen lotion when wearing gloves and handling instruments, and insufficient time to don PPE, especially for intermittent or brief entries into an OR.

In addition to changes in the PPE program, BWH established the Operating Room UV-C Light Surveillance Program in 2003 at the request of the MNA. The medical surveillance program consisted of annual dermatologic and eye screening exams by BWH dermatologists and ophthalmologists looking for possible effects of UV-C overexposure (i.e., keratoconjunctivitis, skin erythema, skin cancers, photokeratitis), and was offered to nurses and surgical technicians who worked under UVGI. Also in 2003, tamper-resistant plastic boxes were installed over the rheostats to prevent unauthorized persons from changing UV intensity settings. Prior to installing these boxes, anyone could change rheostat settings. In December 2006, the tamper-resistant box in OR-15 was broken, and the rheostat was reportedly turned up "full blast." According to the MNA, this resulted in at least one OR staff member reporting sunburn-like skin erythema.

Assessment

On October 1–3, 2007, we conducted an initial site visit, which included an opening conference, a walk-through of the orthopedic operating suite, personal dosimetry during a surgical procedure, and employee interviews.

During the opening conference, representatives of BWH management, the MNA, and orthopedic surgical staff discussed the rationale for using UVGI during orthopedic surgeries, concerns of OR staff, PPE, UV training, and UV medical screening. Hospital and union representatives accompanied us on the walk-through of the orthopedic operating suite. Management representatives explained the use, control, and monitoring of the UVGI lamps; MNA representatives pointed out concerns that had been brought to their attention. In OR-15, we used a Gigahertz-Optik X1-1 Optometer equipped with a UV-3718 UV-C detector to measure irradiance (Gigahertz-Optik, Newburyport, MA). On the following day, UV-C measurements were repeated by us and BWH Health Physics staff.

We evaluated UV-C exposure during a typical surgical procedure using Gigahertz-Optik X-2000-6 personal dosimeters (Gigahertz-Optik, Newburyport, MA). Each dosimeter was equipped with a radiometric detector head (UV-C 254 nm effective irradiance). The dosimeters were calibrated by the manufacturer.

UV-C dosimeters were worn by the circulating nurse and the nurse anesthetist during hip surgery in OR-12. The circulating nurse wore two dosimeters: one was facing upward on her right shoulder, outside of all PPE; the second dosimeter, also facing upward, was located beneath one layer of PPE (a warm-up jacket). Because only three dosimeters were available during the initial site visit, the nurse anesthetist wore only one dosimeter, which was placed on top of her right shoulder beneath two layers of PPE. Each dosimeter was oriented with the UV-C detector facing toward the ceiling to measure maximum irradiance.

We conducted confidential employee interviews during the initial site visit; all orthopedic staff who worked in surgical suites with UVGI were invited to participate. Employee medical records and written UVGI policies were reviewed.

On December 10, 2007, personal dosimetry was conducted during orthopedic procedures in three ORs. Two dosimeters were worn by the circulating nurse during each procedure. One dosimeter

ASSESSMENT (CONTINUED)

was attached facing upward on top of a shoulder outside of all PPE; the second was facing upward beneath all prescribed layers of protective garments. An anesthesia resident wore two dosimeters in this manner during one of the three procedures.

PPE was assessed in BWH ORs using the Gigahertz-Optik X1-1 Optometer with UV-3718 UV-C detector. Attenuated irradiance was measured beneath PPE items. Corresponding measurements of ambient UVGI were made when each item was evaluated. PPE items, and hospital-approved combinations of items, were evaluated in this manner, as was other PPE that was worn by orthopedic staff.

RESULTS

Exposure Assessment

Personal dosimetry results are presented in Table 1. Peak irradiance outside PPE during the three procedures ranged from 30 to 41 $\mu W/cm^2$. At this intensity, the permissible exposure time for workers with unprotected eyes and skin is 2.4 to 3.3 minutes. It should be noted, however, that an individual worker's exposure would be affected by orientation (e.g., standing, sitting, looking down) and movement throughout the work environment, the angle of incidence, and the presence of reflective surfaces.

Peak irradiance beneath two layers of PPE (the hospital-approved PPE protocol) was less than half the NIOSH REL of 0.2 $\mu W/cm^2$ as an 8-hour TWA (or 0.006 J/cm^2, expressed as dose). The peak measurement for the circulating nurse in OR-12 was obtained beneath one of two PPE layers (a warm-up jacket); thus, this measurement does not represent the total attenuation provided by protective garments.

Table 1. Personal UVGI Dosimetry

Location	Job Title	Duration of UVGI Exposure (minutes)	Peak Irradiance ($\mu W/cm^2$)		Dose (J/cm^2)	
			Ambient (outside PPE)	Attenuated (beneath PPE)	Ambient (outside PPE)	Attenuated (beneath PPE)
OR-12	Circulating Nurse	94	30	0.30*	0.074	0.00047*
	Nurse Anesthetist		--	0.00049	--	0.0000046
OR-15	Circulating Nurse	195	41	data download failed	0.17	data download failed
	Anesthesia Resident		32†	0.070	0.11†	0.00012
OR-11	Circulating Nurse	44	31	0.089	0.037	0.0000042
OR-14	Circulating Nurse	144	33	0.026	0.094	0.00000047

The NIOSH REL for exposure to UVGI is 0.006 J/cm^2 at 254 nm for a daily 8-hour work shift. This corresponds to a maximum recommended 8-hour TWA exposure to UVGI at a wavelength of 254 nm of 0.2 $\mu W/cm^2$.

*Dosimeter was beneath one of two layers of PPE worn. All other dose measurements in this column were obtained beneath the approved PPE protocol.

† Ambient dosimeter was not pointing straight up throughout the entire sampling period.

The cumulative dose for each individual was well below the NIOSH REL. Dose, reported as J/cm^2, provides a more accurate estimate of personal exposure than peak irradiance because dose integrates radiant flux over the entire sampling period, whereas peaks are measured at a specific point in time. In addition, irradiance is not uniform throughout the ORs, and staff often move between areas where they are exposed to various radiant flux densities.

PPE evaluation results are presented in Table 2. Protective eyewear and the toga face shield reduced UVGI to levels well below 0.2 $\mu W/cm^2$. Similarly, gloves used in orthopedic ORs reduced UVGI below the limit of detection.

Two of three surgical masks did not reduce radiant flux below 0.2 $\mu W/cm^2$, and one mask produced different results on different dates, exceeding 0.2 $\mu W/cm^2$ on one date. Irradiance measurements were made with each mask facing the ceiling-mounted UV lamps, at an angle of incidence of approximately 90 degrees. When worn, the front of a mask is approximately parallel, rather than perpendicular to UVGI emitted from the overhead lamps, which should result in a somewhat lower overall radiant

flux density (energy per unit area) than was measured here. A possible exception might be along the top surface of the mask near the bridge of the nose. Variability of mask orientation does not take into account UV-C that may be reflected from surfaces within the OR.

With the exception of the surgical masks and the reinforced gown, hospital-approved headwear and combinations of protective garments listed in Table 2 attenuated irradiance to less than 0.2 $\mu W/cm^2$. As with the mask evaluation, protective garment material was oriented parallel to the ceiling, which would result in maximum radiant flux on the surface of the material.

Table 2. Evaluation of PPE

PPE	Irradiance ($\mu W/cm^2$)	
	Ambient	Attenuated by PPE
Gloves		
Latex (Biogel)*	30	ND
Nonlatex*	31	ND
Biogel Indicator (green) *	29	ND
Face Masks		
Nonlatex*	30	0.97
Blue molded	30	0.31
	26.4	0.07
Kimberly-Clark fog-free (orange)	30	0.60
Head Wear		
Tyvek hood + Barrier head cover (blue)*	30	0.13
Tyvek hood + "new" blue head cover	30	0.007
Toga hood + helmet + Barrier cap (blue)*	68	ND–0.09
Toga hood + Barrier cap (blue)	30	0.9–1.0
Toga face shield	30	ND
Protective Garments		
Scrub shirt + warm-up jacket†	26.5	ND
Scrub shirt + reinforced gown	26.5	0.04–0.05
Reinforced gown*	29	0.5–0.6
Full toga (all except head)*	33	ND
Eye Protection		
Jones Protective eyewear*	33	ND–0.01

ND – Radiant flux density was below the detection limit of the radiometer.
* Approved by Health Physics Department. Where more than one item is listed, all items must be worn in layers to provide adequate protection.
† Approved for use in conjunction with SPF-45 sun block.

Medical

We interviewed 21 BWH surgical staff members. Of 23 orthopedic OR nurse and surgical technician employees working at the time of our visit, 14 (six surgical technicians and eight staff nurses) were available and agreed to be interviewed. In addition, one orthopedic OR staff nurse employee who had transferred to another service, one x-ray technician, two physicians, and three nurse managers were interviewed at their request. Of the 21 surgical staff members, 10 were women; the average age was 45 years (range: 22 to 62); the average number of years working at BWH was 15 (range: less than 1 year to 35); and the average number of years worked under UVGI was 11.7 (range: less than 1 year to 28). Five of the 14 orthopedic OR nurses and technicians reported possible UVGI-related conditions; four reported eye irritation (one notified the BWH Occupational Health Services and two others reported seeing their private physician) and two reported skin changes diagnosed as actinic keratoses by BWH Dermatology. One of the five employees reported both eye irritation and actinic keratosis skin changes.

Overall, orthopedic OR employees reported they had had inconsistent training in the safety and health aspects of UV-C, PPE that was not fully UV-C protective prior to 2001, and inadequate PPE supplies in the mid- to late afternoon. Most of the OR employees reported participating in the hospital administration's medical surveillance program. Other information obtained from employee interviews included the following:

- Circulating nurses reported that many observers (students, residents, and visitors) are either unaware, or do not appreciate, the risks from UV-C exposure, and find that they are not only responsible for the patient's protection from UV-C exposure, but also must take the responsibility to educate and provide the observers with adequate PPE.

- Some OR employees reported that the toga PPE was cumbersome, and the air circulator made hearing difficult, while others reported that wearing the toga PPE was not a problem. Some employees reported feeling hot and uncomfortable in UV-C protective clothing.

- Thirteen of the 14 orthopedic OR nurse/technician employees reported not using sunscreen for the following reasons: (1) it is sticky and slippery and makes putting on and taking off gloves and opening packaged sterilized instruments difficult, (2) they need to wash their hands too frequently to keep applying sunscreen, and, (3) it stings badly if it gets in the eyes.

Medical Record Review

We reviewed medical records of 28 BWH OR employees exposed to surgical suite UV-C radiation who had participated in skin and/or eye screening evaluations initiated in 2003 and performed by BWH ophthalmologists and dermatologists.

Twenty-two employees received at least one skin screening examination. Three of these 22 employees had diagnoses listed as melanoma (one with melanoma-in-situ), four had diagnoses of basal cell carcinoma (one did not state a date of diagnosis, but was diagnosed prior to 2005, the employee's first skin screening), and five were diagnosed with actinic keratoses.

Twenty employees received at least one eye screening examination. Four of these 20 employees reported a history of eye discomfort, irritation, or sensitivity; one reported eye discomfort in the UV-C room. Three of the four had normal eye exams; one was diagnosed with a corneal ulcer. Records of another employee stated, "(the patient) has UV exposure and many years ago had a corneal burn." No employee records indicated eye changes from UV-C exposure.

Other Document Review

1. March 3, 2003: BWH document, "Evaluation of UV-C Exposure in the Orthopedic Operating Rooms at Brigham and Women's Hospital"
    - Findings: (1) UV-C light intensities in the ORs were at or below the BWH-recommended germicidal range of 24–30 $\mu W/cm^2$, (2) some of the fabrics of the hoods, gowns, and Stryker T4 Zippered Toga were not adequately protective, and (3) the intensity controls for the UV-C lights were not locked or covered and did not have proper set markings.

- Actions: (1) The Stryker T4 Zippered Toga was eliminated, (2) the UV-C intensity controls were locked, and the Health Physics Department measured UV-C intensity weekly and reset if needed, (3) any new PPE was to be checked to assure adequate exposure protection below the NIOSH REL, (4) educational posters and pamphlets were created as a source of information for staff, and (5) training sessions were held for all orthopedic OR staff on UV-C, associated health effects, and proper use of PPE.

2. November 2003: BWH Ultraviolet Lights Policy document
   - Objective: To ensure employees are adequately protected from exposure to UVR through both maintenance of equipment/sources and proper use of PPE.
   - Includes (1) written procedure for use of UV lamps in the operating room, (2) information on UVR, associated health effects, and what to do in case of injury, and (3) list of approved PPE for use under UV lamps.

3. November 24, 2004: A summary of the dermatologic assessments reported by Marlene Freeley, MS, RN, Occupational Health Service
   - Of the 52 nurses and surgical technicians who were offered skin and eye screening assessments, 15 participated.
   - Skin findings were nonspecific and could not be related specifically to exposure to UV-C from the BWH operating rooms.

4. A summary of the 2006 OR UV-C surveillance program reported by Marlene Freeley
   - Of the 55 affected employees who were offered skin and eye screening assessments, 19 completed skin screenings and 10 completed eye screenings.
   - Skin evaluations found several employees to have benign-appearing skin lesions, two of which had biopsies revealing benign lesions. Plan: repeat annual skin and eye screenings.
   - Eye screenings found no eye damage from UV-C.

RESULTS (CONTINUED)

5. "UV-C in the OR Environment," training presentation
    - Presented to Orthopedic Department Staff by Frank Castronovo, BWH Director of Health Physics and Radiopharmacology

DISCUSSION

NIOSH strongly encourages employers to protect employees using a hierarchy of controls approach [NIOSH 1989, 1990a, 1990b]. The objective of the hierarchy is to minimize the likelihood that preventive measures will fail, resulting in a hazardous exposure. According to the hierarchy, initial efforts should be made to eliminate the hazardous agent or source of exposure. In regard to intraoperative UVGI use, this could be achieved by substituting other infection control methods or technologies, such as vertical laminar air flow (as BWH has done). For facilities that elect to use UVGI in their ORs, the next level in the hierarchy would be to prevent or contain the hazardous emission at its source by shielding the UV-C lamps so that hospital staff are not exposed to hazardous levels of germicidal UV-C. With respect to occupational health, use of UVGI for intraoperative infection control differs from other UVGI applications (e.g., upper-air UVGI) in that engineering controls (i.e., shielding or reflectors) are not used to prevent overexposure of personnel because direct irradiation is desired for infection control purposes. This leaves only PPE and administrative controls. PPE is used to create a barrier between each worker and the hazardous exposure, and administrative controls establish PPE protocols, employee training, and medical surveillance.

Staff must rely on proper selection and use of PPE to prevent keratoconjunctivitis (inflammation of the conjunctiva), skin erythema (reddening of the skin), possible chronic skin effects, and photokeratitis (inflammation of the cornea). Implementing an effective PPE program is often difficult, especially when use of PPE conflicts with other workplace duties, requirements, and demands. PPE items that were approved by the BWH Health Physics Department generally appeared to provide adequate attenuation of UVGI; however, some individual items allowed transmission of variable amounts of UV-C through the material. Regular, periodic evaluations of the attenuation provided by PPE items should help identify any changes in the protection provided by PPE. Periodically checking the attenuation provided by nondisposable

items such as scrubs and warm-up jackets might be useful to determine if UV-C attenuation remains adequate after repeated use and laundering or with manufacturing changes.

Sunscreen was provided to OR staff for use in place of one layer of PPE. Although some sunscreen products claim to provide protection against some portion of the UV-C spectrum, the U.S. Food and Drug Administration has no approval process in place for testing the effectiveness of sunscreens against UV-C [Lushniak, personal communication 2008]. Even if some sunscreens are capable of providing some protection against UV-C, incorrect or inadequate application could decrease whatever protection may be provided. In addition, many OR staff were reluctant to use sunscreen because they found it to be impractical and uncomfortable.

BWH OR employee interviews indicated that staff did not always use complete PPE combinations, including sunscreen, as recommended by the Health Physics Department. OR employee reports of skin erythema and eye discomfort after UV-C exposure, although uncommon, indicate that errors occurred when relying on PPE for UV-C protection. Mishaps may also have occurred due to maladjustment of UVGI system controls as was reported in the December 2006 incident at BWH when a UV-C lamp rheostat was tampered with. Similar problems have likely occurred at other facilities. For example, a recent report described a 90-minute accidental UV-C radiation exposure. Twenty six medical students working at an autopsy table in an unidentified medical teaching institution were exposed when a timer system malfunctioned [Trevisan et al. 2006]. The students subsequently were diagnosed with photokeratitis and skin damage to the face, scalp, and neck including a sunburn-like condition followed by deep skin exfoliation. Eye symptoms lasted 2–4 days.

The BWH OR employee skin screening exams found cases of basal cell carcinoma, melanoma, and actinic keratoses. While IARC and NTP have classified all three bands of the UV spectrum, UV-A, UV-B, and UV-C, as probable human carcinogens [IARC 1997; NTP 2005], most skin cancers have been attributable to the UV-A and UV-B bands [Spencer and Amonette 1998; NTP 2005]. UV-C radiation has been shown to induce DNA damage in mammalian cells in vivo, and exposure to high doses of radiation from devices emitting primarily UV-C caused skin tumors in rats (keratoacanthoma-like tumors) and mice (squamous-cell carcinoma

Discussion (continued)

and fibrosarcoma) [IARC 1997]. Current research has not shown UV-C radiation to cause melanoma or basal cell carcinoma.

The BWH UV-C training presentation stated that UV-C cannot penetrate the dead layer of skin; however, certain studies show that 5%–20% of 250–254 nm UV-C penetrates the stratum corneum, compared with about 30%–60% of 300 nm (UV-B) radiation [CDC 2005; Nardell et al. 2008]. These studies indicate that although there is less risk of UV-C damage to deeper skin cells that could lead to basal cell carcinoma and melanoma, some risk from exposure to UV-C may be present. Skin cancers are relatively common in light-skinned individuals and are known to be caused by UV exposure from the sun. No epidemiologic studies have adequately evaluated UV-C carcinogenicity in humans, although evidence for cancer in animals exists [NTP 2005]. UV-C radiation is considered to be a probable carcinogen in humans by both IARC and NTP [IARC 1997; NTP 2005]. Eliminating the exposure clearly eliminates the potential future risks from UV-C. See Appendix A, Occupational Exposure Limits and Health Effects, for more information on UV-C exposure and health effects.

Conclusions

With the exception of the surgical masks and the reinforced gown, hospital-approved headwear and combinations of protective garments evaluated during this HHE attenuated UV-C irradiance to less than 0.2 µW/cm^2, the NIOSH 8-hour REL for exposures to UVR at 254 nm. Although medical exams of OR employees exposed to UVGI did not document eye or skin changes due to UV-C exposure, employee reports of skin erythema and eye discomfort after UV-C exposure indicate that overexposures may have occurred. The specific skin cancers and actinic keratoses found on skin exams are known to be caused by UV exposure from the sun.

Since the last NIOSH site visit in December 2007, BWH moved the orthopedic OR suite into an area equipped with laminar airflow and discontinued the use of UVGI for intraoperative infection control. Substitution of other infection control technologies such as laminar airflow eliminates the occupational UV hazard in orthopedic ORs. In addition to eliminating the source of the hazard, substitution eliminates the need for UV-C hazard awareness training, PPE training, ongoing supervision of PPE use, and inspection and evaluation of PPE. We view this

Conclusions (continued)

as a positive change. Although PPE programs may be relatively inexpensive to establish, reliance on PPE as the primary means of protecting workers has been proven to be less effective than other methods of hazard control, such as eliminating the hazard entirely, and/or substituting other technologies, equipment, or procedures that reduce or eliminate occupational hazards.

Recommendations

Because BWH has discontinued the use of intraoperative UVGI, we offer the following recommendations:

1. Remove UVGI lamp fixtures to prevent future use of the lamps in the former orthopedic surgical suite.

2. Continue the medical surveillance program for employees who were exposed to UVGI, including periodic skin screening examinations. Screenings should be offered to all OR staff, including surgeons, anesthesiologists, and residents, who regularly worked in the UVGI-equipped OR suites. Employees should be informed that any suspicious lesion that appears on skin exposed to UVGI should be examined by a physician. If a potentially work-related skin disorder is discovered, the employee should be evaluated by an occupational medicine physician.

3. Should BWH reestablish use of UVGI for intraoperative infection control, the hospital will need to address the health and safety deficiencies identified during this HHE. These include improving UVGI training; requiring the proper use of all mandatory PPE; performing routine exposure monitoring; and offering all OR staff, including surgeons, anesthesiologists, and residents, who regularly work in the UV-C equipped OR suites periodic skin and eye screening examinations as part of a medical surveillance program.

References

Berg-Périer M, Cederblad A, Persson U [1992]. Ultraviolet radiation and ultra-clean air enclosures in operating rooms. J Arthroplasty 7(4):457–463.

Bloom S [2008]. Telephone conversation in August 2008, between S. Bloom, Director of Environmental Affairs, Brigham

and Women's Hospital and D. Sylvain, Division of Surveillance, Hazard Evaluations, and Field Studies, National Institute for Occupational Safety and Health, Centers for Disease Control, U.S. Department of Health and Human Services.

Brown IW Jr., Moor GF, Hummel BW, Marshall WG Jr., Collins JP [1996]. Toward further reducing wound infections in cardiac operations. Ann Thorac Surg *62*(6):1783–1789.

Castronovo FP [2003]. Internal memorandum from F.P.Castronovo, Director of Health Physics, Brigham and Women's Hospital, June 19, 2003.

CDC (Centers for Disease Control and Prevention) [2003]. Guidelines for environmental infection control in health-care facilities. MMWR *52*(RR10):1–42.

CDC (Centers for Disease Control and Prevention) [2005]. Guidelines for preventing the transmission of *Mycobacterium tuberculosis* in health-care settings. MMWR *54*(RR17):1–3141.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

Goldner JL [2000]. [letter to the editor]. Surg Infect *1*(3):249–250.

IARC [1997]. IARC monographs on the evaluation of the carcinogenic risk to man: solar and ultraviolet radiation. Vol. 55. Lyon, France: World Health Organization, International Agency for Research on Cancer.

IESNA [2000]. The IESNA lighting handbook, 9th ed. Rea MS, ed. New York, NY: Illuminating Engineering Society of North America. IES HB-9-2000.

Kowalski WJ, Bahnfleth WP [2004]. Proposed standards and guidelines for UVGI air disinfection. IUVA News *6*(1):20–25.

Lowell JD, Kundsin RB [1978]. The operating room and the ultraviolet environment. Med Instrum *12*(3):161–164.

Lushniak B [2008]. E-mail communication from B. Lushniak, Assistant Surgeon General USPHS, to D. Sylvain, August 19.

Miner AL, Losina E, Katz JN, Fossel AH, Platt R [2005]. Infection control practices to reduce airborne bacteria during total knee replacement: a hospital survey in four states. Infect Control Hosp Epidemiol *26*(12):910–915.

Nardell EA, Bucher SJ, Brickner PW, Wang C, Vincent RL, Becan-McBride K, James MA, Michael M, Wright JD [2008]. Safety of upper-room ultraviolet germicidal air disinfection for room occupants: results from the tuberculosis ultraviolet shelter study. Public Health Reports *123*(1):52–60.

NIOSH [1989]. NIOSH comments on the Occupational Safety and Health Administration proposed rule on health standards; methods of compliance: 29 CFR Part 1910. October 2, 1989, OSHA Docket No. H–160. NIOSH policy statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH [1990a]. NIOSH testimony on the Occupational Safety and Health Administration proposed rule on health standards; methods of compliance: 29 CFR Part 1910, May 31, 1990. OSHA Docket No. H–160. NIOSH policy statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH [1990b]. NIOSH posthearing comments on the Occupational Safety and Health Administration proposed rule on health standards; methods of compliance: 29 CFR Part 1910. October 9, 1990, OSHA Docket No. H-160. NIOSH policy statements. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH [2009]. Engineering controls for tuberculosis: upper-room guidelines for ultraviolet germicidal irradiation in healthcare settings. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) 2009-105.

NTP [2005]. Report on Carcinogens, 11th ed. U.S. Department of Health and Human Services, National Toxicology

Program [ntp.niehs.nih.gov/?objectid=035E5806-F735-FE81-FF769DFE5509AF0A]. Date accessed: February 23, 2009.

Ritter MA, Olberding EM, Malinzak RA [2007]. Ultraviolet lighting during orthopedic surgery and the rate of infection. J Bone Joint Surg [Am] *89*(9):1935–1940.

Spencer JM, Amonette R [1998]. Tanning beds and skin cancer: artificial sun + old sol = real risk. Clin Dermatol *16*(4):487–501.

Taylor GJS, Bannister GC, Leeming JP [1995]. Wound disinfection with ultraviolet radiation. J Hosp Infect *30*(2):85–93.

Trevisan A, Piovesan S, Leonardi A, Bertocco M, Nicolosi P, Pelizzo MG, Angelini A [2006]. Unusual high exposure to ultraviolet-C radiation. Photochem Photobiol *82*(4):1077–1079.

Appendix A: Occupational Exposure Limits & Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by Federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. However, not all workers will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended STEL or ceiling values where health effects are caused by exposures over a short period. Unless otherwise noted, the STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2005]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, worker education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the United States include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2007]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2007].

Outside the United States, OELs have been established by various agencies and organizations and include both legal and recommended limits. Since 2006, the Berufsgenossenschaftliches Institut für Arbeitsschutz (German Institute for Occupational Safety and Health) has maintained a database of international OELs

from European Union member states, Canada (Québec), Japan, Switzerland, and the United States at www.hvbg.de/e/bia/gestis/limit_values /index.html. The database contains international limits for over 1250 hazardous substances and is updated annually.

Employers should understand that not all hazardous chemicals, and few physical agents, have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970 (Public Law 91–596, sec. 5(a)(1))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting worker health that focuses resources on exposure controls by describing how a risk needs to be managed. Information on control banding is available at www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement the OELs, when available.

Ultraviolet Radiation

UVR is an invisible radiant energy produced naturally by the sun and artificially by arcs operating at high temperatures with wavelengths between the visible spectrum and the X-ray region. Biological scientists normally define UVR as three defined wavelength regions: UV-A (400–320 nm), UV-B (320–290 nm), and UV-C (290–200 nm), based on their biological effects and presence in terrestrial sunlight [Diffey 2002]. UVR makes up about 5% of the solar radiation that reaches the earth's surface and is predominantly composed of UV-A and UV-B wavelengths; UV-C wavelengths are absorbed by the ozone layer and rarely penetrate the earth's atmosphere. Artificial light sources, such as sunlamps, halogen lamps, and germicidal lamps, are examples of artificially produced UV sources. UV-C tubes (germicidal lamps) have a peak intensity around 254 nm, with most of the radiant energy emitted at this wavelength. UV-C has been shown to be present in uncovered halogen tungsten lamps [De Flora et al. 1990].

Effects of Ultraviolet Radiation on Skin and Eyes

Because the skin and eyes readily absorb UVR, they are particularly vulnerable to injury. The severity of radiation injury depends on exposure time, intensity of the radiation source, distance from the source, wavelength, sensitivity of the individual, and presence of sensitizing agents.

Skin

Acute skin exposure to UVR can result in erythema (reddening). This is a reversible injury, with the time course dependent on the severity of the burn. Erythema results most commonly from UV-B and UV-C overexposure [ACGIH 2001]. The Commission Internationale de L'Eclairage suggests that the skin is most sensitive to UV radiation in the range of 250 nm to 300 nm [McKinlay and Diffey 1987; Diffey 1994].

Chronic skin exposure to solar UVR in light-skinned individuals can result in the formation of actinic keratoses (precursors to skin cancer), basal cell carcinomas, squamous cell carcinomas, and some types of malignant melanoma. IARC and NTP classify broad spectrum UVR as a known human carcinogen, and the three bands of the UV spectrum, UV-A, UV-B, and UV-C, as probable human carcinogens. UV-B is the most potent portion of the UV spectrum for both short- and long-term biological effects [NTP 2005]. The UV-C classification is based on limited evidence from human tissue studies and sufficient evidence for carcinogenicity in experimental animal studies [IARC 1997; NTP 2005]. UV-C radiation induces DNA damage, chromosomal aberrations, sister chromatid exchange and transformation in mammalian and human cells in vitro and induces DNA damage in mammalian skin cells irradiated in vivo [IARC 1997]. Exposure to high doses of radiation from devices emitting primarily UV-C caused skin tumors in rats (keratoacanthoma-like tumors) and mice (squamous-cell carcinoma and fibrosarcoma) [IARC 1997]. Currently, UV-C radiation has not been shown to be associated with melanoma or basal cell carcinoma. Skin penetration of UV-C may be an important factor in whether or not UV-C exposure causes skin cancer. According to certain reports, only 5%–20% of incident 250 nm (UV-C) penetrates the stratum corneum, compared with approximately 30%–60% of 300 nm (UV-B) radiation [CDC 2005; Nardell et al. 2008], thus there is less risk of UV-C radiation damaging deeper skin cells that could lead to basal cell carcinoma and melanoma. No epidemiologic studies have adequately evaluated UV-C carcinogenicity in humans, so the potential for UV-C radiation to cause cancer in humans is unknown [NTP 2005].

Eyes

The cornea and conjunctiva of the eye absorb UVR, especially in the UV-B and UV-C ranges. UV-C radiation is absorbed by the outer cellular layer of the cornea and conjunctiva, and overexposure results in inflammation of the cornea (photokeratitis) or conjunctiva (conjunctivitis) or both (photokeratoconjunctivitis) [NIOSH 1972; Nardell et al. 2008]. Photokeratoconjunctivitis is a reversible injury, lasting about 24–48 hours, but it is a debilitating condition while it runs its course. The effect is intense pain, a feeling of sand in the eyes, redness, and sometimes photophobia (sensitivity to light) and lacrimation (tearing). This condition may also be accompanied by erythema of the skin surrounding the eyelids [ACGIH 2001]. There is a latent period of a few hours, depending upon the dose, so it is sometimes not recognized as an occupational injury by the worker. These effects rarely result in permanent eye injury [ACGIH 2001].

Occupational Exposure Limits for UVR

OSHA does not have a PEL for occupational exposure to UVR. NIOSH and ACGIH have established recommended exposure limits for UVR that are wavelength dependent. These limits are based primarily on studies of acute effects of UVR in humans and animals. NIOSH and ACGIH note that the recommended values do not apply to exposure of photosensitive individuals or to those concomitantly exposed to photosensitizing agents. Hundreds of agents are believed to cause hypersensitivity to UVR including some plants, some antibiotics, some antidepressants, some antipsychotic drugs, as well as some diuretics, cosmetics, dyes, and coal tar products [ACGIH 2001].

In 1972, NIOSH published a REL for UV radiation [NIOSH 1972]. Because the biological effects from exposure to UVR are dependent on the intensity and energy distribution of the source, the NIOSH REL is wavelength-dependent in the spectral region of interest (200–315 nm). For exposure to germicidal lamps that emit predominantly 254 nm radiation, the NIOSH REL and the ACGIH TLV are the same, 0.006 J/cm^2 for a daily 8-hour work shift. To protect workers who are exposed to 254 nm radiation for 8 hours per workday, the measured irradiance should be less than 0.2 $\mu W/cm^2$ for an 8-hour exposure. For other durations of exposure, the permissible exposure time (in seconds), for workers with unprotected eyes and skin, can be calculated by dividing 0.006 J/cm^2 (the NIOSH REL at 254 nm) by the measured irradiance level at 254 nm in W/cm^2.

References

ACGIH [2001]. Documentation of the threshold limit values and biological exposure indices, 7th Edition. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

ACGIH [2007]. 2007 TLVs® and BEIs®: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists.

AIHA [2007]. 2007 Emergency response planning guidelines (ERPG) & workplace environmental exposure levels (WEEL) handbook. Fairfax, VA: American Industrial Hygiene Association.

CDC (Centers for Disease Control and Prevention) [2005]. Guidelines for preventing the transmission of Mycobacterium tuberculosis in health-care settings. MMWR *54*(RR17):1–141.

CFR. Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.

De Flora S, Camoirano A, Izzotti A, Bennicelli C [1990]. Potent genotoxicity of halogen lamps, compared to fluorescent light and sunlight. Carcinogenesis *11*(2):2171–2177.

Diffey BL [1994]. Observed and predicted minimal erythema doses: a comparative study. Photochem Photobiol *60*(4):380–382.

Diffey BL [2002]. Sources and measurement of ultraviolet radiation. Methods *28*(1):4–13.

IARC [1997]. IARC monographs on the evaluation of the carcinogenic risk to man: solar and ultraviolet radiation. Vol. 55. Lyon, France: World Health Organization, International Agency for Research on Cancer.

McKinlay AD, Diffey BL [1987]. A reference action spectrum for ultraviolet induced erythema in human skin. CIE J *6*:17–22.

Nardell EA, Bucher SJ, Brickner PW, Wang C, Vincent RL, Becan-McBride K, James MA, Michael M, Wright JD [2008]. Safety of upper-room ultraviolet germicidal air disinfection for room occupants: results from the tuberculosis ultraviolet shelter study. Public Health Rep *123*(1):52–60.

NIOSH [1972]. Criteria for a recommended standard: occupational exposure to ultraviolet radiation. Cincinnati, OH: U.S. Department of Health, Education, and Welfare, Health Services and Mental Health Administration, National Institute for Occupational Safety and Health; DHEW (NIOSH) Publication No. HSM 73-11009.

NIOSH [2005]. NIOSH pocket guide to chemical hazards. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2005–149. [www.cdc.gov/niosh/npg/]. Date accessed: February 23, 2009.

NTP [2005]. Report on Carcinogens, 11th ed. U.S. Department of Health and Human Services, National Toxicology Program [ntp.niehs.nih.gov/?objectid=035E5806-F735-FE81-FF769DFE5509AF0A]. Date Accessed: February 23, 2009.

Acknowledgments and Availability of Report

The Hazard Evaluation and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found. HETAB also provides, upon request, technical and consultative assistance to federal, state, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH. Mention of any company or product does not constitute endorsement by NIOSH. In addition, citations to websites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these websites. All Web addresses referenced in this document were accessible as of the publication date.

This report was prepared by David Sylvain and Loren Tapp of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Industrial hygiene field assistance was provided by Bradley King (DSHEFS). Medical field assistance was provided by Steven Angerbauer (University of Utah). Health communication assistance was provided by Stefanie Evans. Editorial assistance was provided by Ellen Galloway. Desktop publishing was performed by Robin Smith.

Copies of this report have been sent to employee and management representatives at Brigham and Women's Hospital, and the OSHA Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed from www.cdc.gov/niosh/hhe. Copies may be purchased from the National Technical Information Service at 5825 Port Royal Road, Springfield, Virginia 22161.

Below is a recommended citation for this report:
NIOSH [2009]. Health hazard evaluation report: UV-C exposure and health effects in surgical suite personnel, Boston, MA. By Sylvain D, Tapp L. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA No. 2007-0257-3082.

NIOSH *National Institute for Occupational Safety and Health*

Delivering on the Nation's promise: Safety and health at work for all people through research and prevention.

To receive NIOSH documents or information about occupational safety and health topics, contact NIOSH at:

1-800-CDC-INFO (1-800-232-4636)

TTY: 1-888-232-6348

E-mail: cdcinfo@cdc.gov

or visit the NIOSH web site at: **www.cdc.gov/niosh.**

For a monthly update on news at NIOSH, subscribe to NIOSH eNews by visiting **www.cdc.gov/niosh/eNews.**

SAFER • HEALTHIER • PEOPLE™