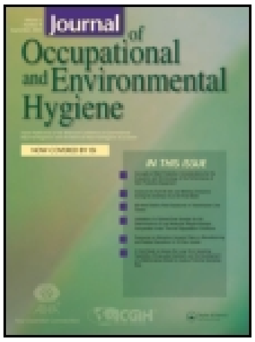


Journal of Occupational and Environmental Hygiene

ISSN: 1545-9624 (Print) 1545-9632 (Online) Journal homepage: http://www.tandfonline.com/loi/uoeh20

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**To cite this article:** Edward A. Gazdik , Frank S. Rosenthal & Wei-Hsung Wang (2004) Determination of the Attenuation Properties of Laboratory Gloves Exposed to an Ultraviolet Transilluminator, Journal of Occupational and Environmental Hygiene, 1:6, 391-402, DOI: 10.1080/15459620490452013

**To link to this article:** https://doi.org/10.1080/15459620490452013

Published online: 17 Aug 2010.

*Journal of Occupational and Environmental Hygiene*, 1: 391–402
ISSN: 1545-9624 print / 1545-9632 online

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# Determination of the Attenuation Properties of Laboratory Gloves Exposed to an Ultraviolet Transilluminator

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*The transmission of ultraviolet radiation (UVR) from an ultraviolet transilluminator through three types of laboratory gloves (latex, nitrile, vinyl) was determined using two independent methods. First, transmittance was measured with a radiometer equipped with UVA and actinic UV detectors. Second, a spectrophotometer was used to determine the UVR transmittance vs. wavelength (250–440 nm); this data was then used to compute the effective attenuation of the glove material. The average UVA percent transmittance using the radiometer method with an unstretched glove was 73.4%, 0.18%, and 1.10% for vinyl, nitrile, and latex, respectively. The average actinic percent transmittance for an unstretched glove was 13.3%, 0.015%, and 0.024% for vinyl, nitrile, and latex, respectively. Slight increases in UVR transmittance resulted from stretching the gloves by 30% or wetting them with saline. Six hours of UVR exposure decreased transmittance of vinyl gloves and increased transmittance by latex gloves. Results from the spectrophotometer method and radiometer methods of determining UVR transmittance agreed that vinyl gloves had the highest transmittance; however, the spectrophotometer method greatly overestimated UV glove attenuation due to the effect of light scattering by the glove material. The study suggests that in some circumstances, vinyl gloves will provide inadequate protection against workplace ultraviolet radiation.*

**Keywords** attenuation, glove, protection, radiation, transilluminator, ultraviolet

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## INTRODUCTION

Occupational exposure to ultraviolet radiation (UVR) occurs from both sunlight and artificial sources. The use of UVR in industry to induce chemical or physical changes in materials allows occupational exposure to occur with a wide range of workers. Potential exposures to UVR also occur in work processes involving sterilization, curing of inks and coatings, leak detection, arc welding, and laboratory research. Exposure to excessive levels of UVR may cause acute photokeratitis of the eye and erythema of the skin, as well as increased risk for chronic skin and eye disease. Some individuals are at increased risk due to photosensitization caused by concurrent exposure to certain chemicals or the use of medications that are photosensitizers.

Although there is a wide selection of laboratory gloves available to workers exposed to UVR, there is little published data on the effectiveness of these gloves in attenuating UVR. A previous study investigating the hazards of a UV transilluminator lists a transmittance of 0.51% for actinic wavelengths of a latex glove when exposed to a UV transilluminator.[(1)] However, many individuals do not use latex gloves due to latex allergy.

Workers in biology laboratories commonly use UV transilluminators to visualize nucleic acids, often after these substances are bound to ethidium bromide (EtBr). Daily occupational exposure times in this procedure can vary from about 1 min for routine photography by assistants to about 20 min for more specialized cutting, manipulating, and photographing.[(2)] Because of the toxicity of substances like EtBr, workers usually wear protective gloves. However, the UVR attenuation of these gloves is usually unknown.

The objectives of this study were (1) to measure the transmission of UVR through commonly used laboratory gloves when exposed to a UV transilluminator; (2) to assess the changes in UVR transmission due to stretching, contact with saline (a surrogate for perspiration), and long-term UVR exposures; (3) to compare two independent methods of determining glove attenuation, one using a radiometer and the other using a spectrophotometer; and (4) to survey the exposure of workers using UV transilluminators to determine which type of gloves would provide adequate protection against UVR for these workers.

## MATERIAL AND METHODS

### UV Transilluminator

Most of the measurements performed in this study were done with a FOTO/UV® 300 UV transilluminator (FOTODYNE®, Hartland, Wis.) with typical peak emission at approximately 308 nm. The emission spectrum of this device was measured with a Spectra Pro-275 spectrograph (Acton Research Corporation, Acton, Mass.). The spectrograph scan plotted data for every 0.3 nm, from 144 to 474 nm.

## Gloves Studied

A survey of laboratory transilluminators at the large university where this study was conducted, found that the most common types of gloves used were latex and nitrile. Recent reports in the scientific literature indicate that from about 1 to 6% of the general population and about 8 to 12% of regularly exposed health care workers are sensitized to latex.[3,4] Since allergies to nitrile also occur, vinyl gloves were also studied. For each type of glove (latex, nitrile, and vinyl), three different glove brands were studied. The large size glove was used because it was the most frequent size worn in the laboratory. The thickness of the gloves was measured with a micrometer. For greater accuracy, a double layer of glove material was measured and the result halved (Table I).

## Transmittance Measurements

The transmittance of UVR, defined as the ratio of ultraviolet radiation passing through the glove to the incident radiation, was determined for both UVA and actinic UV (as defined by the American Conference of Governmental Hygienists, ACGIH®) using two independent measurements. Transmittance was measured directly using a radiometer equipped with UVA and actinic UV detectors. Transmittance of UVA and actinic UV was computed using the transilluminator emission spectrum and UV attenuation vs. wavelength data determined in a spectrophotometer. Our objective in using the two types of measurements was to provide a check on the validity of the measurements. In addition, the data of attenuation versus wavelength obtained from the spectrophotometer could potentially enable the computation of UVR attenuation for a source with an arbitrary emission spectrum.

**TABLE I. Gloves Studied**

| | | Thickness | |
|---|---|---|---|
| Type | Brand | Avg. ($\mu$m) | SD ($\mu$m) |
| Vinyl | Oak (Oak Technical, Stow, Ohio) | 161.0 | 5.2 |
| Vinyl | Moore (Moore Medical Corporation, New Britain, Conn.) | 123.8 | 12.3 |
| Vinyl | Safeskin (Safeskin Corporation, San Diego, Calif.) | 118.8 | 4.6 |
| Latex | N-DEX Original (Best Manufacturing, Menlo, Ga.) | 162.5 | 5.3 |
| Latex | Nx Tech (Safeskin Corporation, San Diego, Calif.) | 162.3 | 4.0 |
| Latex | N-DEX Free (Best Manufacturing, Menlo, Ga.) | 156.8 | 2.9 |
| Nitrile | Perry (Ansell Healthcare, Redbank, NJ) | 129.5 | 3.3 |
| Nitrile | Tex (Safeskin Corporation, San Diego, Calif.) | 122.5 | 2.9 |
| Nitrile | LPE (Safeskin Corporation, San Diego, Calif.) | 105.8 | 3.1 |

## Radiometer Measurements

For actinic UV, effective irradiance measurements were done with a Gigahertz-Optik P 9710 radiometer (Gigahertz-Optik, Newburyport, Mass.) with a 3708-2 actinic detector. The radiometer detectors were placed such that the plane of the detector surface was parallel to the surface of the transilluminator. This was confirmed by the use of a bubble level. The glove material was placed across and in contact with the detectors, with the detector surface completely covered. The detectors had a built-in diffuser to assure a cosine spatial response of the detectors. Irradiance was measured with and without the glove covering the detector. Similar measurements were performed for UVA using the same radiometer with a 3701-2 UVA detector.

The UVA detector has a flat spectral response from 290 to 440 nm, while the actinic detector has a spectral response from 250 to 340 nm, which closely follows the actinic response spectrum as defined by ACGIH (Figure 1). The limits of detection for measurements with the UVA and actinic UV detectors were 0.0017 $\mu W/cm^2$ and 0.01 $\mu W/cm^2$ (effective), respectively. The radiometer and both detectors were calibrated in the manufacturer's laboratory using a Phillips HPA 400/30 UV lamp (Phillips, Eindhoven, Netherlands), having a known output. Before each series of measurements, the radiometer was zeroed by covering the detector with an opaque material.

Using the radiometer, each glove sample was characterized in four scenarios, with five trials repeating each test: unstretched, stretched 30%, one surface wetted with saline, exposed to saline for 24 hours, and then tested after drying. A glove-stretching apparatus allowed a reproducible 30% stretch (Figure 2). The transmission of UVR through the glove material was characterized by the transmittance of the material, defined as the ratio of the irradiance of radiation after passing through the glove material to the incident radiation. Transmittance measurements were made with the detectors in direct contact with the glove sample, thereby minimizing light leaks.

A glove sample (approximately 55 $cm^2$ cut from the palm section of each glove) was secured by the glove-stretching apparatus and placed 2.5 cm above the transilluminator with the glove in contact with the detector. The statistical significance of changes in glove transmittance due to stretching and saline treatments was evaluated using two-tailed paired t-tests.

## Gloves Exposed to UVR

To determine the shielding properties of a glove exposed to UVR over a period of time, glove attenuation was assessed after varying periods of exposure to UVR from the transilluminator. Actinic UV and UVA transmittance was measured in a glove sample at 2.5 cm above the transilluminator surface. Percent transmittance, calculated from incident and transmitted UVR, was noted at 2, 4, and 6 hours. UVR exposure of the gloves during the 6-hour period averaged 1837 $\mu W/cm^2$ for UVA and 786 $\mu W/cm^2$ for actinic UV. These intensities are comparable but somewhat less than exposures found at the surface of the various illuminators surveyed at the University (average

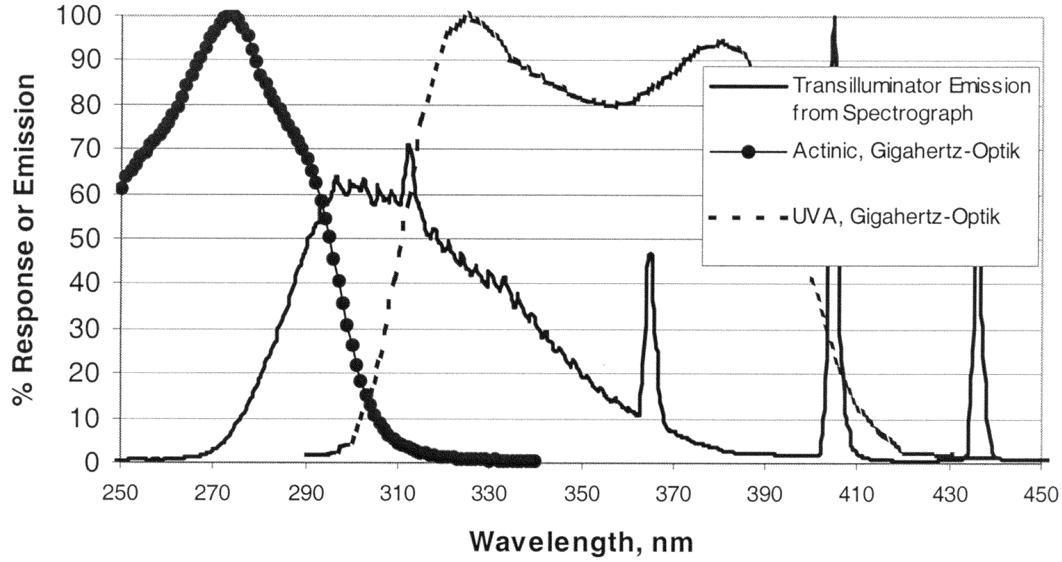


**FIGURE 1.** UVR detector response spectra and transilluminator emission spectrum

of 3352 $\mu$W/cm$^2$ UVA and 960 $\mu$W/cm$^2$ actinic UVB—see Results and Discussion).

### Spectrophotometer Determination of UVR Transmittance

Ordinarily, spectrophotometers direct a light beam through a liquid sample for analysis. For the purposes of this study, adjustments were made to a standard 1.5 mL semimicro plastic cuvette to allow measurement of transmittance through a glove sample. Apertures cut in the front and back of the lower portion of the cuvette allowed the spectrophotometer's UV beam to pass through the glove material unobstructed. A wire band, made from a paper clip, secured the glove sample (approximately 20 × 18 mm$^2$) to the cuvette (Figure 3).

Each glove sample was scanned (200–800 nm) three times in a Cary 400 spectrophotometer (Varian, Inc., Palo Alto, Calif.) in the dual beam mode. Before scanning, the spectrophotometer was calibrated and zeroed using the instrument's internal procedures. Only data between 250 and 440 nm, the upper and lower limits of the wavelength ranges of the radiometer's detectors, were used in a comparison with the transmittances determined by the radiometer method.

UVR attenuation was computed as follows:

$$\text{Transmittance} = \frac{\text{Effective Irradiance Transmitted}}{\text{Effective Irradiance Incident}} = \frac{\sum E_\lambda S_\lambda \Delta\lambda T_\lambda}{\sum E_\lambda S_\lambda \Delta\lambda}$$

where

$E_\lambda$ is the spectral irradiance of the source at the glove surface
$S_\lambda$ is the relative spectral detector response for UVA or actinic UV as specified by the manufacturer
$\Delta\lambda$ is the band width, i.e., the wavelength increment in the spectrophotometer scan
$T_\lambda$ is the transmitted fraction at wavelength $\lambda$, determined from the spectrophotometer.

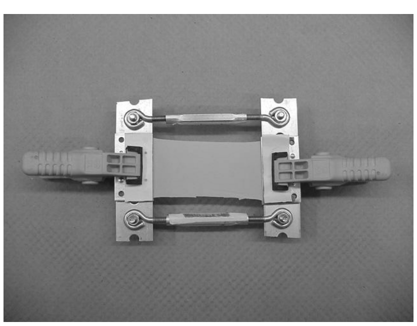

**FIGURE 2.** Glove stretching apparatus

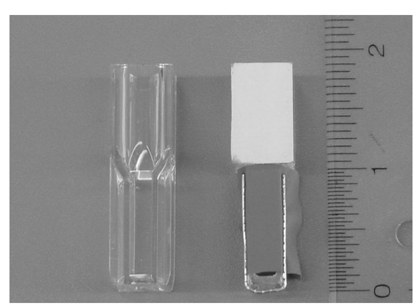

**FIGURE 3.** Experimental design of spectrophotometer cuvette

The summation is taken over the number of wavelength increments in the spectrophotometer scan.

### Survey of UV Transilluminators and Their Users

The protocol for the survey was approved by the Purdue University Human Research Subjects Committee. The survey was administered to laboratory workers and consisted of eight questions about the conditions of use of transilluminators and possible adverse effects. It was conducted in various university laboratories containing a UV transilluminator. While at the worker's laboratory, UVA and actinic irradiance measurements were taken of transilluminators using the Gigahertz-Optik radiometer with UVA and actinic UV detectors. Measurements were made at a height of 0 cm on the center of the transilluminator filter glass after the transilluminator was warmed 5 min.

## RESULTS AND DISCUSSION

### Radiometer Results

Measurements using the radiometer method found that UVA transmittance of unstretched vinyl, latex, and nitrile gloves averaged 73.7%, 1.12%, and 0.17% transmittance, respectively (Table II). Transmittance of actinic UV averaged 13.6%,

**TABLE II. Percent Transmittance for Stretching Test Using the Radiometer**

| Glove Brand by Material | Number of Paired Samples | Unstretched | | Stretched | | | | Paired Sample |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | SD | Avg. | SD | Difference[A] | % Difference[B] | P-Value[C] |
| UVA detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 66.4 | 1.3 | 71.2 | 1.1 | 4.8 | 7.3 | 0.002 |
| Moore | 5 | 80.8 | 1.9 | 85.1 | 1.2 | 4.3 | 5.3 | 0.001 |
| Safeskin | 5 | 73.8 | 1.2 | 77.1 | 0.9 | 3.3 | 4.5 | 0.003 |
| Avg. | | 73.7 | | 77.8 | | 4.2 | 5.7 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.08 | 0.02 | 0.11 | 0.02 | 0.04 | 47.0 | 0.002 |
| Nx Tech | 5 | 0.38 | 0.10 | 0.62 | 0.15 | 0.23 | 60.4 | 0.001 |
| N-DEX Free | 5 | 0.04 | 0.03 | 0.07 | 0.03 | 0.02 | 49.0 | 0.229 |
| Avg. | | 0.17 | | 0.26 | | 0.10 | 52.1 | |
| Latex | | | | | | | | |
| Perry | 5 | 1.97 | 0.30 | 2.51 | 0.23 | 0.54 | 27.7 | 0.002 |
| Tex | 5 | 0.70 | 0.18 | 1.16 | 0.16 | 0.47 | 66.6 | 0.000 |
| LPE | 5 | 0.68 | 0.09 | 0.85 | 0.12 | 0.17 | 25.1 | 0.024 |
| Avg. | | 1.12 | | 1.51 | | 0.39 | 39.8 | |
| Actinic detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 9.5 | 1.5 | 10.0 | 1.0 | 0.5 | 5.6 | 0.099 |
| Moore | 5 | 16.8 | 0.7 | 18.3 | 0.8 | 1.5 | 8.8 | 0.000 |
| Safeskin | 5 | 14.4 | 0.6 | 15.5 | 0.7 | 1.1 | 7.7 | 0.002 |
| Avg. | | 13.6 | | 14.6 | | 1.0 | 7.3 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.001 | 0.001 | 0.001 | 0.001 | 0.000 | 0.0 | 1.000 |
| Nx Tech | 5 | 0.026 | 0.018 | 0.032 | 0.013 | 0.006 | 23.3 | 0.667 |
| N-DEX Free | 5 | 0.005 | 0.001 | 0.012 | 0.005 | 0.007 | 131.6 | 0.022 |
| Avg. | | 0.011 | | 0.015 | | 0.004 | 51.6 | |
| Latex | | | | | | | | |
| Perry | 5 | 0.012 | 0.002 | 0.027 | 0.007 | 0.015 | 126.4 | 0.004 |
| Tex | 5 | 0.012 | 0.008 | 0.025 | 0.012 | 0.013 | 114.9 | 0.009 |
| LPE | 5 | 0.008 | 0.005 | 0.013 | 0.005 | 0.004 | 52.3 | 0.020 |
| Avg. | | 0.011 | | 0.022 | | 0.011 | 97.8 | |

[A] Avg. stretch – avg. unstretch.
[B] ([Avg. stretch – avg. unstretch]/avg. unstretch) ∗ 100.
[C] P-value for paired t-test of stretched vs. unstretched results for each glove type.

0.011%, and 0.011% transmittance, respectively. The UVA and actinic transmittance of gloves when stretched 30% increased slightly. However, for N-DEX Free gloves in the UVA, and Oak, N-DEX Orig, and Nx Tech gloves in actinic UV, the increase in transmittance was not statistically significant ($p > 0.05$). The increase in transmittance for stretched gloves was probably due to the change in glove thickness when stretched.

There was a slight increase in transmittance for both UVA and actinic UV in all gloves except Oak when a glove was wetted with saline (Table III). When wetted, Oak transmittance of UVA significantly decreased. Although all other gloves increased in percent transmittance, none of the nitrile gloves nor Safeskin increased significantly using the UVA detector, and only N Reg and Safeskin increased significantly using the actinic detector. These results were generally consistent with a fabric spectroradiometer study[(5)] that concluded that the effectiveness of the UVR protection was reduced when wetting fabrics (cotton, nylon, lycra, and polyester). When a fabric gets wet, light scattering is reduced, which leads to an increase of UV penetration.[(6)]

For most gloves, there was no significant change in transmittance due to 24-hr saline treatment (Table IV). However, there were small, statistically significant differences in UVA transmittance for Perry and Safeskin gloves. In the actinic range, Oak transmittance decreased slightly with saline treament ($p < 0.05$).

**TABLE III. Percent Transmittance for Wet Saline Test Using the Radiometer**

| Glove Brand by Material | Number of Paired Samples | Dry | | Wet w/Saline | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | SD | Avg. | SD | Difference[A] | % Difference[B] | Paired Sample P-Value[C] |
| UVA detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 65.5 | 1.8 | 64.5 | 1.6 | −1.0 | −1.5 | 0.000 |
| Moore | 5 | 78.8 | 1.7 | 82.2 | 0.9 | 3.4 | 4.3 | 0.002 |
| Safeskin | 5 | 74.6 | 1.4 | 75.7 | 2.6 | 1.0 | 1.4 | 0.296 |
| Avg. | | 73.0 | | 74.1 | | 1.1 | 1.4 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.08 | 0.01 | 0.09 | 0.01 | 0.00 | 1.1 | 0.642 |
| Nx Tech | 5 | 0.41 | 0.06 | 0.43 | 0.07 | 0.02 | 5.3 | 0.060 |
| N-DEX Free | 5 | 0.08 | 0.06 | 0.10 | 0.07 | 0.01 | 12.5 | 0.085 |
| Avg. | | 0.19 | | 0.20 | | 0.01 | 6.3 | |
| Latex | | | | | | | | |
| Perry | 5 | 2.02 | 0.37 | 2.18 | 0.41 | 0.16 | 7.8 | 0.012 |
| Tex | 5 | 0.64 | 0.08 | 0.74 | 0.08 | 0.09 | 14.3 | 0.007 |
| LPE | 5 | 0.67 | 0.08 | 0.74 | 0.08 | 0.07 | 9.9 | 0.037 |
| Avg. | | 1.11 | | 1.22 | | 0.11 | 10.7 | |
| Actinic detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 10.0 | 0.7 | 10.0 | 0.6 | −0.1 | −0.6 | 0.572 |
| Moore | 5 | 14.8 | 2.4 | 17.1 | 0.5 | 2.3 | 15.4 | 0.110 |
| Safeskin | 5 | 14.3 | 0.9 | 15.2 | 1.1 | 0.8 | 5.8 | 0.002 |
| Avg. | | 13.1 | | 14.1 | | 1.0 | 6.9 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.001 | 0.001 | 0.004 | 0.003 | 0.003 | 357.9 | 0.035 |
| Nx Tech | 5 | 0.020 | 0.005 | 0.024 | 0.008 | 0.003 | 16.5 | 0.189 |
| N-DEX Free | 5 | 0.020 | 0.016 | 0.029 | 0.021 | 0.009 | 46.1 | 0.208 |
| Avg. | | 0.014 | | 0.019 | | 0.005 | 140.2 | |
| Latex | | | | | | | | |
| Perry | 5 | 0.017 | 0.004 | 0.019 | 0.004 | 0.002 | 11.3 | 0.071 |
| Tex | 5 | 0.016 | 0.013 | 0.038 | 0.030 | 0.022 | 134.2 | 0.079 |
| LPE | 5 | 0.035 | 0.022 | 0.084 | 0.058 | 0.049 | 138.6 | 0.164 |
| Avg. | | 0.023 | | 0.047 | | 0.024 | 94.7 | |

[A] Wet – dry.
[B] ([Avg. wet – avg. dry]/avg. dry) ∗ 100.
[C] P-value for paired t-test of wet vs. dry results for each glove type.

**TABLE IV. Percent Transmittance for Saline Treatment Test Using the Radiometer**

| Glove Brand by Material | Number of Paired Samples | Untreated | | Treated w/Saline | | | | Paired Sample |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | SD | Avg. | SD | Difference^A | % Difference^B | P-Value^C |
| UVA detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 65.3 | 2.7 | 62.0 | 2.3 | −3.3 | −5.1 | 0.170 |
| Moore | 5 | 81.9 | 2.1 | 78.5 | 7.2 | −3.4 | −4.2 | 0.302 |
| Safeskin | 5 | 73.4 | 1.9 | 67.4 | 6.3 | −6.0 | −8.1 | 0.050 |
| Avg. | | 73.5 | | 69.3 | | −4.2 | −5.8 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.09 | 0.03 | 0.10 | 0.03 | 0.01 | 10.4 | 0.649 |
| Nx Tech | 5 | 0.41 | 0.11 | 0.35 | 0.08 | −0.06 | −14.6 | 0.279 |
| N-DEX Free | 5 | 0.03 | 0.02 | 0.17 | 0.10 | 0.14 | 389.7 | 0.051 |
| Avg. | | 0.18 | | 0.21 | | 0.03 | 128.5 | |
| Latex | | | | | | | | |
| Perry | 5 | 1.91 | 0.24 | 2.38 | 0.17 | 0.47 | 24.4 | 0.004 |
| Tex | 5 | 0.66 | 0.09 | 0.71 | 0.14 | 0.05 | 6.8 | 0.191 |
| LPE | 5 | 0.60 | 0.12 | 0.67 | 0.15 | 0.07 | 11.8 | 0.443 |
| Avg. | | 1.06 | | 1.25 | | 0.19 | 14.3 | |
| Actinic detector | | | | | | | | |
| Vinyl | | | | | | | | |
| Oak | 5 | 9.6 | 0.9 | 9.4 | 0.8 | −0.3 | −2.8 | 0.043 |
| Moore | 5 | 16.4 | 1.4 | 16.2 | 1.7 | −0.2 | −1.0 | 0.724 |
| Safeskin | 5 | 14.0 | 0.8 | 13.5 | 0.9 | −0.5 | −3.4 | 0.117 |
| Avg. | | 13.3 | | 13.0 | | −0.3 | −2.4 | |
| Nitrile | | | | | | | | |
| N-DEX Orig | 5 | 0.002 | 0.001 | 0.011 | 0.010 | 0.009 | 524.2 | 0.093 |
| Nx Tech | 5 | 0.017 | 0.002 | 0.032 | 0.031 | 0.015 | 91.7 | 0.319 |
| N-DEX Free | 5 | 0.027 | 0.029 | 0.058 | 0.057 | 0.031 | 113.7 | 0.168 |
| Avg. | | 0.015 | | 0.034 | | 0.019 | 243.2 | |
| Latex | | | | | | | | |
| Perry | 5 | 0.065 | 0.038 | 0.027 | 0.009 | −0.037 | −57.7 | 0.078 |
| Tex | 5 | 0.040 | 0.036 | 0.014 | 0.008 | −0.027 | −66.0 | 0.188 |
| LPE | 5 | 0.010 | 0.003 | 0.010 | 0.002 | 0.000 | −0.8 | 0.943 |
| Avg. | | 0.038 | | 0.017 | | −0.021 | −41.5 | |

^A Avg. treated – avg. untreated.
^B ([Avg. treated – avg. untreated]/avg. untreated) ∗ 100.
^C P-value for paired t-test of treated vs. untreated results for each glove type.

## Effect of UVR Exposure on Glove Transmittance

Transmittance of UVA and actinic UV through vinyl gloves decreased at 4 hours and 6 hours compared to transmittance after 2 hours of exposure. For latex gloves, UVA and actinic transmittance increased at 4 hours and 6 hours of exposure compared to 2 hours of exposure (Table V). Comparison of this data with the data for UVR transmittance through unexposed gloves (Table II) suggests that 6 hours of UV exposure can reduce UVA and actinic UV transmittance through vinyl gloves by 15–49% and 15–28%, respectively. Six hours UVR exposure of latex gloves resulted in a several-fold increase in actinic UV transmittance and, in general, a less dramatic and less consistent increase in UVA transmittance.

## Spectrophotometer Results

The spectrophotometer scans indicated that all gloves increased in transmittance with wavelength. For vinyl gloves, this increase was particularly marked between 295 and 305 nm (Figure 4). Although there were some differences between brands, the scans indicated a maximum transmittance for vinyl gloves, over the range of 200–400 nm, of approximately 10%. Scans for latex and nitrile gloves indicated maxima transmittances of approximately 0.6% and 0.3%, respectively, over the same wavelength range.

In most cases, the transmission through the gloves of either UVA or actinic UV, as determined from the spectrophotometer data, was considerably less than that determined by radiometer

**TABLE V. Percent Transmittance for UVR Exposure Test Using the Radiometer**

| Glove Brand by Material | 2 Hours | 4 Hours | 6 Hours |
|---|---|---|---|
| | Transmittance for specified exposure duration | | |
| UVA detector | | | |
| Vinyl | | | |
| Oak | 51.7 | 48.9 | 44.5 |
| Moore | 72.3 | 68.7 | 65.6 |
| Safeskin | 62.1 | 59.9 | 55.9 |
| Avg. | 62.0 | 59.2 | 55.4 |
| Nitrile | | | |
| N Reg | 0.10 | 0.10 | 0.11 |
| Nx Tech | 0.29 | 0.28 | 0.28 |
| N Free | 0.26 | 0.24 | 0.25 |
| Avg. | 0.22 | 0.21 | 0.21 |
| Latex | | | |
| Perry | 1.31 | 1.75 | 2.96 |
| Tex | 0.93 | 0.96 | 1.03 |
| LPE | 0.38 | 0.39 | 0.41 |
| Avg. | 0.9 | 1.0 | 1.5 |
| | Exposure duration | | |
| Actinic detector | | | |
| Vinyl | | | |
| Oak | 9.8 | 9.2 | 8.2 |
| Moore | 14.6 | 13.6 | 12.5 |
| Safeskin | 13.0 | 12.3 | 11.2 |
| Avg. | 12.4 | 11.7 | 10.6 |
| Nitrile | | | |
| N Reg | 0.011 | 0.015 | 0.011 |
| Nx Tech | 0.009 | 0.011 | 0.009 |
| N Free | 0.002 | 0.010 | 0.010 |
| Avg. | 0.007 | 0.012 | 0.010 |
| Latex | | | |
| Perry | 0.023 | 0.035 | 0.062 |
| Tex | 0.039 | 0.042 | 0.045 |
| LPE | 0.015 | 0.017 | 0.020 |
| Avg. | 0.026 | 0.032 | 0.042 |

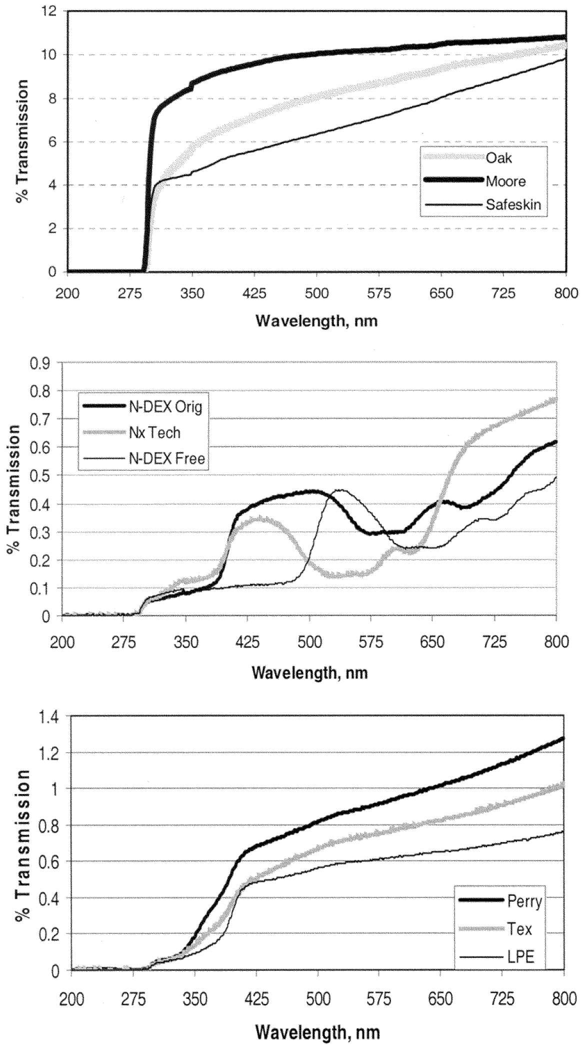


**FIGURE 4.** Average transmittance from spectrophotometer through 3 vinyl, 3 nitrile and 3 latex brands, (each curve represents the average of 3 trials per brand)

method (Table VI). For the nine glove brands studied, the mean ratio of transmittance determined by the radiometer to that determined by the spectrophotometer method was 8.1 for UVA and 5.7 for actinic UV. These ratios were similar between each material grouping and between the UVA and actinic detectors. In general, the ratio of radiometer to spectrophotometer transmittance was greatest for vinyl gloves. For vinyl gloves, the ratio was similar for UVA and actinic UV measurements, whereas for nitrile (except N-DEX free) and latex, the ratios were greater for UVA measurements as compared with actinic UV measurements (Table VI).

### Differences Between Radiometer and Spectrophotometer Results

Several possible explanations for the greater transmittance detected with the radiometer method were considered, including (1) undetected light scattered out of the spectrophotometer beam by the glove material, and (2) uncertainties in the emission and detector response spectra used to calculate glove transmittance from the spectrophotometer data. Given the large ratio between transmittance results from the radiometer and spectrophotometer methods, and the fact that all instruments were calibrated using standard methods, it was considered unlikely that uncertainties in source emission spectra and response spectra could be responsible for the disparity between the observed results. Therefore, additional study focused on the possibility of light scattering as a cause of the disparity.

**TABLE VI. Comparison of Percent UVR Transmittance Obtained with Spectrophotometer and Radiometer**

| | | Spectrophotometer Method[A] | | Radiometer Method[B] | | |
|---|---|---|---|---|---|---|
| **Brand** | **Region** | **Avg.** | **SD** | **Avg.** | **SD** | **Ratio[C]** |
| Vinyl | | | | | | |
| Oak | UVA | 4.98 | 0.39 | 65.74 | 1.92 | 13.2 |
| | Actinic | 0.63 | 0.04 | 9.73 | 1.04 | 15.4 |
| Moore | UVA | 8.14 | 0.76 | 80.51 | 2.22 | 9.9 |
| | Atinic | 1.56 | 0.12 | 16.02 | 1.75 | 10.2 |
| Safeskin | UVA | 4.42 | 0.33 | 73.93 | 1.50 | 16.7 |
| | Actinic | 0.81 | 0.07 | 14.26 | 0.72 | 17.5 |
| Nitrile | | | | | | |
| N Reg | UVA | 0.079 | 0.003 | 0.084 | 0.024 | 1.1 |
| | Actinic | 0.014 | 0.000 | 0.006 | 0.020 | 0.5 |
| Nx Tech | UVA | 0.103 | 0.004 | 0.403 | 0.087 | 3.9 |
| | Actinic | 0.015 | 0.001 | 0.021 | 0.011 | 1.4 |
| N Free | UVA | 0.082 | 0.027 | 0.055 | 0.044 | 0.7 |
| | Actinic | 0.017 | 0.007 | 0.017 | 0.020 | 1.0 |
| Latex | | | | | | |
| Perry | UVA | 0.140 | 0.007 | 1.967 | 0.289 | 14.0 |
| | Actinic | 0.014 | 0.001 | 0.031 | 0.032 | 2.3 |
| Tex | UVA | 0.112 | 0.022 | 0.669 | 0.117 | 6.0 |
| | Actinic | 0.013 | 0.003 | 0.023 | 0.024 | 1.8 |
| LPE | UVA | 0.085 | 0.032 | 0.652 | 0.101 | 7.7 |
| | Actinic | 0.011 | 0.006 | 0.018 | 0.018 | 1.6 |

[A] Average of 3 trials.
[B] Average of 15 trials.
[C] Percent transmittance by radiometer method/percent transmittance by spectrophotometer.

In the spectrophotometer, the detector is positioned approximately 11 inches from the cuvette, compared with the radiometer where the detector is positioned in contact with the sample. In the spectrophotometer, part of the light passing through the glove material may be scattered away from the direction of the incident beam, as shown in Figure 5, possibly resulting in the total transmitted radiation not being detected.

Additional experiments were conducted to test the hypothesis that undetected light scattered out of the spectrophotometer beam was responsible for the lower transmittance of the

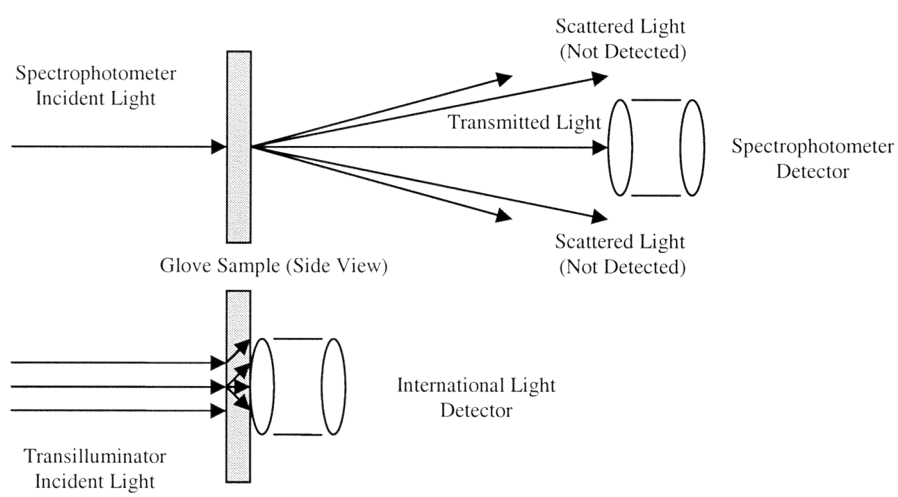


**FIGURE 5.** Detection of transmitted light in spectrophotometer vs. radiometer

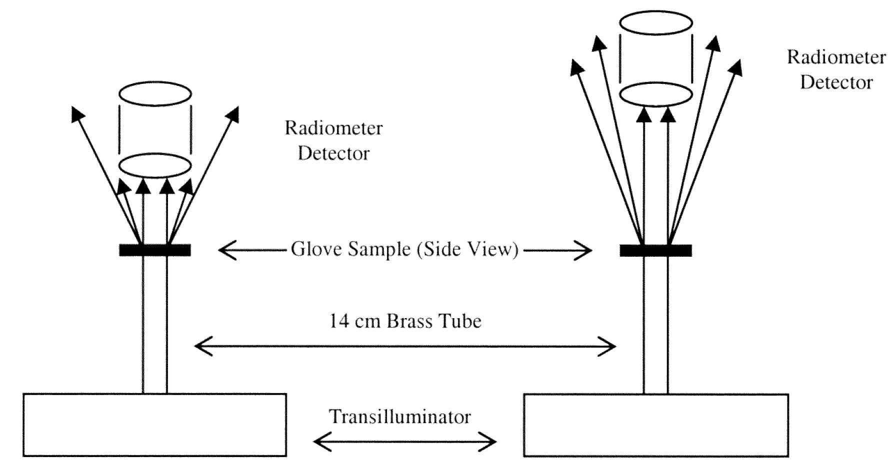


**FIGURE 6.** Experiment distancing radiometer detector from sample

gloves determined by the spectrophotometer method. To simulate the scattering effect in the spectrophotometer, UVR from the transilluminator was collimated by placing a brass tube (diameter = 0.5 cm, length = 14 cm) over a hole cut in an opaque covering of the transilluminator surface and measuring the transmittance as a function of sample to detector distance (Figure 6). Transmittance measurements with the glove material (Safeskin vinyl) in contact with or close to the detector were similar to those found with uncollimated light. (In these measurements, incident UVA was measured with the same configuration but without the glove sample in position.)

As the detector-glove distance increased, transmittance steadily decreased, indicating the effect of scattering light not reaching the detector (Figure 6, Table VII). UVA measurements with detector-glove distances >12 cm approached the transmittance values determined with the spectrophotometer. For actinic UV, measurements at distances >4 cm were not possible because the reduced UVR emission through the collimating tube approached the detection limit of the detector.

The results of the experiments with collimated UVR support our hypothesis that the difference between radiometer and spectrophotometer results was most likely due to the loss of scattered light out of the spectrophotometer beam.

### Survey of UV Transilluminators and Their Users

Nineteen subjects were interviewed in the user survey. The average time the subjects used the transilluminator was 3.7 days per week (ranging from 1 to 7 days) for 7.8 min per day (ranging from 1 to 18 minutes). All subjects reported that their hands hovered at a working distance of approximately 0 to 1 inch from the transilluminator. Although all subjects reported wearing protection for the eyes and hands, only 6 of

**TABLE VII. Transmittance Measured with UVR Collimated Through a Brass Tube**[A]

| | UVA, $\mu$W/cm$^2$ | | | Actinic, $\mu$W/cm$^2$ | | |
|---|---|---|---|---|---|---|
| Distance,[B] cm | Transmitted | Incident | % Transmittance | Transmitted | Incident | % Transmittance |
| 0 | 0.90 | 1.05 | 86.07 | 0.10 | 0.61 | 15.57 |
| 2 | 0.28 | 0.94 | 29.44 | 0.03 | 0.57 | 5.26 |
| 4 | 0.10 | 0.73 | 14.20 | 0.01 | 0.48 | 2.08 |
| 6 | 0.05 | 0.55 | 9.42 | 0.00 | 0.38 | 0.00 |
| 8 | 0.03 | 0.41 | 7.54 | | | |
| 10 | 0.02 | 0.31 | 6.32 | | | |
| 12 | 0.015 | 0.25 | 5.90 | | | |
| 14 | 0.011 | 0.20 | 5.41 | | | |
| 16 | 0.009 | 0.16 | 5.29 | | | |
| 18 | 0.007 | 0.13 | 5.05 | | | |
| 20 | 0.006 | 0.11 | 4.93 | | | |

[A] See text for details.
[B] Distance between the end of the tube and the detector.

**TABLE VIII. Predicted Daily UVA Exposure for Subjects Wearing Specified Glove 0 Inch from Source**

| | Incident Irradiance | | | | Transmitted Irradiance Through Glove[C] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Vinyl | | Nitrile | | Latex | |
| Subject # | Time Exposed (min) | UVA Irradiance ($\mu W/cm^2$) | Radiant Exposure ($J/cm^2$)[A] | Overexposed[B] | Radiant Exposure ($J/cm^2$)[A] | Overexposed[B] | Radiant Exposure ($J/cm^2$)[A] | Overexposed[B] | Radiant Exposure ($J/cm^2$)[A] | Overexposed[B] |
| 1 | 18 | 3296 | 3.56 | Yes | 2.88 | Yes | 0.014 | No | 0.071 | No |
| 2 | 1 | 3296 | 0.20 | No | 0.16 | No | 0.001 | No | 0.004 | No |
| 3 | 10 | 4185 | 2.51 | Yes | 2.03 | Yes | 0.010 | No | 0.050 | No |
| 4 | 10 | 2282 | 1.37 | Yes | 1.11 | Yes | 0.005 | No | 0.027 | No |
| 5 | 5 | 2282 | 0.68 | No | 0.55 | No | 0.003 | No | 0.014 | No |
| 6 | 10 | 2282 | 1.37 | Yes | 1.11 | Yes | 0.005 | No | 0.027 | No |
| 7 | 10 | 4058 | 2.43 | Yes | 1.97 | Yes | 0.010 | No | 0.049 | No |
| 8 | 15 | 4087 | 3.68 | Yes | 2.98 | Yes | 0.015 | No | 0.074 | No |
| 9 | 10 | 3086 | 1.85 | Yes | 1.50 | Yes | 0.007 | No | 0.037 | No |
| 10 | 5 | 149.7 | 0.04 | No | 0.04 | No | 0.000 | No | 0.001 | No |
| 11 | 5 | 149.7 | 0.04 | No | 0.04 | No | 0.000 | No | 0.001 | No |
| 12 | 10 | 149.7 | 0.09 | No | 0.07 | No | 0.000 | No | 0.002 | No |
| 13 | 10 | 149.7 | 0.09 | No | 0.07 | No | 0.000 | No | 0.002 | No |
| 14 | 5 | 3271 | 0.98 | No | 0.79 | No | 0.004 | No | 0.020 | No |
| 15 | 5 | 4335 | 1.30 | Yes | 1.05 | Yes | 0.005 | No | 0.026 | No |
| 16 | 5 | 4773 | 1.43 | Yes | 1.16 | Yes | 0.006 | No | 0.029 | No |
| 17 | 10 | 4773 | 2.86 | Yes | 2.32 | Yes | 0.011 | No | 0.057 | No |
| 18 | 2 | 4773 | 0.57 | No | 0.46 | No | 0.002 | No | 0.011 | No |
| 19 | 2 | 4773 | 0.57 | No | 0.46 | No | 0.002 | No | 0.011 | No |
| Number overexposed | | | | 10 | | 10 | | 0 | | 0 |

[A]Radiant exposure = (time, sec * irradiance, $\mu W/cm^2$)/1,000,000.
[B]Overexposure is > 1.0 $Joule/cm^2$ radiant exposure for periods lasting < 1000 sec, ACGIH 2002.
[C]Experimental UVA transmission through glove: vinyl at 81%, nitrile at 0.4%, latex at 2%.

**TABLE IX. Predicted Daily Actinic Exposure for Subjects Wearing Specified Glove 0 Inch from Source**

| | Incident Irradiance | | | | Transmitted Irradiance Through Glove[C] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Vinyl | | Nitrile | | Latex | |
| Subject # | Time Exposed (min) | Actinic Irradiance ($\mu W/cm^2$) | Radiant Exposure ($mJ/cm^2$)[A] | Permitted Time (sec)[B] | Actinic Irradiance ($\mu W/cm^2$) | Permitted Time (sec)[B] | Actinic Irradiance ($\mu W/cm^2$) | Permitted Time (sec)[B] | Actinic Irradiance ($\mu W/cm^2$) | Permitted Time (sec)[B] |
| 1 | 18 | 687 | 742 | 4 | 110 | 27 | 0.14 | 20794 | 0.21 | 14086 |
| 2 | 1 | 687 | 41 | 4 | 110 | 27 | 0.14 | 20794 | 0.21 | 14086 |
| 3 | 10 | 1210 | 726 | 2 | 194 | 15 | 0.25 | 11806 | 0.38 | 7998 |
| 4 | 10 | 450 | 270 | 7 | 72 | 42 | 0.09 | 31746 | 0.14 | 21505 |
| 5 | 5 | 450 | 135 | 7 | 72 | 42 | 0.09 | 31746 | 0.14 | 21505 |
| 6 | 10 | 450 | 270 | 7 | 72 | 42 | 0.09 | 31746 | 0.14 | 21505 |
| 7 | 10 | 1186 | 712 | 3 | 190 | 16 | 0.25 | 12045 | 0.37 | 8160 |
| 8 | 15 | 1157 | 1041 | 3 | 185 | 16 | 0.24 | 12347 | 0.36 | 8364 |
| 9 | 10 | 361 | 217 | 8 | 58 | 52 | 0.08 | 39573 | 0.11 | 26807 |
| 10 | 5 | 1696 | 509 | 2 | 271 | 11 | 0.36 | 8423 | 0.53 | 5706 |
| 11 | 5 | 1696 | 509 | 2 | 271 | 11 | 0.36 | 8423 | 0.53 | 5706 |
| 12 | 10 | 1696 | 1018 | 2 | 271 | 11 | 0.36 | 8423 | 0.53 | 5706 |
| 13 | 10 | 1696 | 1018 | 2 | 271 | 11 | 0.36 | 8423 | 0.53 | 5706 |
| 14 | 5 | 424 | 127 | 7 | 68 | 44 | 0.09 | 33693 | 0.13 | 22824 |
| 15 | 5 | 1199 | 360 | 3 | 192 | 16 | 0.25 | 11915 | 0.37 | 8071 |
| 16 | 5 | 1234 | 370 | 2 | 197 | 15 | 0.26 | 11577 | 0.38 | 7842 |
| 17 | 10 | 1234 | 740 | 2 | 197 | 15 | 0.26 | 11577 | 0.38 | 7842 |
| 18 | 2 | 1234 | 148 | 2 | 197 | 15 | 0.26 | 11577 | 0.38 | 7842 |
| 19 | 2 | 1234 | 148 | 2 | 197 | 15 | 0.26 | 11577 | 0.38 | 7842 |
| Number overexposed | | | | 19 | | 19 | | 0 | | 0 |

[A] Radiant exposure ($mJ/cm^2$) = (time, sec $*$ irradiance, $\mu W/cm^2$)/1000.
[B] Permitted time (sec) = (0.003 Joule/$cm^2$/irradiance, $\mu W/cm^2$) $*$ 1,000,000, ACGIH 2002.
[C] Experimental actinic transmission through glove: vinyl at 16%, nitrile at 0.02%, latex at 0.03%.

the 19 subjects interviewed said they wore a lab coat when using the transilluminator. Lab coats are used to shield the forearms from the intense UVR.

Sixteen of the 19 subjects reported using latex gloves, while the other 3 reported using nitrile gloves. One subject reported having an allergy to latex and therefore specifically used nitrile gloves. Gloves worn were probably associated with what glove was available for use in the lab, what the lab director chose, or what was chosen by the university to be sold in the university stores.

Tables VIII and IX show the predicted UVA and actinic exposures at 0 inch from the UV transilluminator surface when a worker is wearing the specified glove. The predicted irradiance of UVR transmitted through a glove of a given type was calculated by multiplying the irradiance measured at the transilluminator surface by the experimentally determined transmittance. In this calculation the average of all untreated, unstretched measurements for the glove brand with the highest transmittance within each type was used.

With UVA (Table VIII), this method predicts that 10 of the 19 workers wearing vinyl gloves would be overexposed; however, no workers would be overexposed if wearing nitrile or latex. With actinic (Table IX), the prediction is that all 19 workers wearing vinyl would be overexposed, while all workers wearing nitrile and latex would not. Although no transilluminator workers were found wearing vinyl gloves, the potential exists for UV overexposure to occur if these gloves are chosen for protection.

## CONCLUSIONS AND RECOMMENDATIONS

The investigation of nine different glove brands using the radiometric method of measuring transmittance concluded that the most important factor in determining the amount of UVR transmitted through a glove was the composition of the glove.

Measurements with the radiometer found that the UVR protection was reduced when all gloves were stretched 30%. Wetting a glove with saline slightly reduced transmittance in Oak gloves while the transmittance of all other gloves increased slightly. Treating gloves for 24 hours with saline was shown to cause no significant increase in UVR transmittance when compared with nontreated gloves. Exposure to 6 hours of UVR at an intensity comparable to that of laboratory transilluminators caused a decrease in UVR transmittance for vinyl gloves and an increase in UVR transmittance for latex gloves.

The effects of both glove type and glove thickness on UV transmittance were identified in this study. For example, for vinyl gloves, the thickest glove (Oak) had the least transmission for both UVA and actinic UV. The effect of thickness on UV transmission within the latex and nitrile glove types was not consistent; however, for these glove types the range of thickness for the three brands was small. It is evident that glove type can be more important than glove thickness in determining UV transmittance. For example, comparing average results for the vinyl and nitrile, although vinyl gloves were thicker, the UVR transmission through them was orders of magnitude greater.

In the wavelengths studied between 250 and 440 nm, the spectrophotometer and radiometer methods agreed that vinyl provided the least UVR attenuation, and nitrile gloves provided the best UVR attenuation. The spectrophotometer was originally thought to be an ideal method because of its ability to characterize UVR transmittance for individual wavelengths; however, in this study, the spectrophotometer did not detect UVR scattered out of its beam, resulting in a substantial underestimation of UV transmittance.

Correcting spectrophotometer measurements for the effect of scattered light is complicated because the scattering effect appears to vary with both wavelength and glove material as evidenced by the varied ratios of spectrophotometer to radiometer measurements of glove transmittance observed in this study. Measurements with a spectrophotometer equipped with an integrating sphere (designed to capture scattered light) or with a spectral radiometer might correct this problem. However, this was not attempted in this study. In principle, valid data of transmittance versus wavelength would allow the prediction of glove attenuation of UVR for an arbitrary source spectrum.

Combining UVR irradiance measurements taken from 19 transilluminators, the stated time the transilluminator was used each day, and the experimental glove transmittance values, latex and nitrile gloves provided adequate protection for work with the transilluminators surveyed, while vinyl gloves did not. Although no surveyed worker wore vinyl gloves, predicted exposures wearing such gloves greatly exceed the ACGIH 8-hour threshold limit value for actinic UVR.

## ACKNOWLEDGMENTS

This research was supported by a Centers for Disease Control and Prevention (CDC)/National Institute for Occupational Safety and Health (NIOSH) traineeship (Grant No. T01/CCT510467) and a pilot project research training grant from the CDC/NIOSH-supported University of Cincinnati Education and Research Center (Grant No. T42/CCT510420).

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