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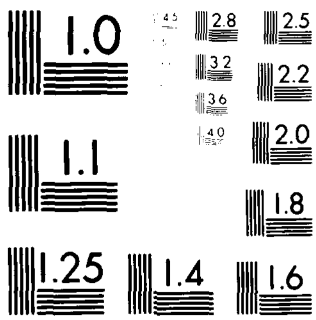

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UNITED STATES ARMY ENVIRONMENTAL HYGIENE AGENCY

ABERDEEN PROVING GROUND, MD 21010

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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 25-42-0318-80
ARDROX HAND HELD ULTRAVIOLET INSPECTION LAMP BCI 90/2
MARCH-APRIL 1980

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The Ardrox inspection light emits potentially hazardous levels of UV-A and UV-B radiation; however, considering its normal application where direct, intrabeam viewing does not occur, there is no actual hazard to the nonphotosensitive user.

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DEPARTMENT OF THE ARMY
U. S. ARMY ENVIRONMENTAL HYGIENE AGENCY
ABERDEEN PROVING GROUND, MARYLAND 21010

Mr. Krial/jg/AUTOVON
584-3932

HSE-RL/WP

20 JUN 1980

SUBJECT: Nonionizing Radiation Protection Special Study No. 25-42-0319-80, Ardrox Hand Held Ultraviolet Inspection Lamp BCI 90/2, March-April 1980

Commander
Air Force Wright Aeronautical Laboratories
ATTN: AFWAL/MLTM (Mr. Gulley)
Wright-Patterson Air Force Base, OH 45433

A summary of the pertinent findings and recommendations of this subject study follows:

The Ardrox inspection light emits potentially hazardous levels of UV-A and UV-B radiation; however, considering its normal application where direct, intrabeam viewing does not occur, there is no actual hazard to the nonphotosensitive user. It is recommended that a warning label be placed on the device and that photosensitive individuals not use the device.

FOR THE COMMANDER:

Frank E. McDermott

FRANK E. McDERMOTT
COL, MSC
Director, Radiation and
Environmental Sciences

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ABERDEEN PROVING GROUND, MARYLAND 21010

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NONIONIZING RADIATION PROTECTION SPECIAL STUDY NO. 25-42-0319-80
ARDROX HAND HELD ULTRAVIOLET INSPECTION LAMP BCI 90/2
MARCH-APRIL 1980

1. AUTHORITY.

a. AR 40-5, Health and Environment, 25 September 1974.

b. AR 40-441, Joint Utilization of Certain Armed Forces Medical Laboratory Facilities, 12 July 1976.

c. Letter, AFML/MXA, Wright-Patterson AFB, 19 December 1979, subject: Evaluation of Ardrox (Brent Chemicals) Hand Held Ultraviolet Inspection Lamp BCI 90/2.

2. REFERENCES.

a. AR 40-46, Control of Health Hazards from Lasers and Other High Intensity Optical Sources, 6 February 1974.

b. Report, HSE-RL, this Agency, 29 March 1979, Nonionizing Radiation Protection Special Study No. 25-42-0388-79, Ultraviolet Radiation Sources Used in Dermatology, September-December 1978.

c. Technical Guide, HSE-RL, this Agency, Hazard Analysis of Broad-Band Optical Sources, December 1977, Technical Guide 085 (ADA 054-802/4GI).

3. PURPOSE. To evaluate potential health hazards associated with the use of the Ardrox Hand-Held UV Inspection Lamp BCI 90/2 used in nondestructive inspection (NDI) and to make recommendations necessary to preclude hazardous exposure of personnel during use of the lamp.

4. GENERAL.

a. Background. In accordance with a letter of request (paragraph 1c), a series of radiometric measurements and a hazard evaluation was performed on one Ardrox UV Inspection Light, by USAEHA during March and April 1980. Concern had been expressed about the use of the lamp by Air Force personnel should such lamps be procured for depot and for field inspection. Air Force maintenance personnel would use the lamp to inspect the structural integrity of metal structures through the use of fluorescent dye penetrants and dye-impregnated magnetic particles which would fluoresce by means of the lamp's UV output. Dye concentrations would be greatest at cracks in the structure.

b. Description. The Ardrox BCI 90/2 (Figure 1) is marketed in the US by Brent Chemicals Corp., Glastonburg, CT. At the time of the study a Philips Type HPW 125-W, E/70/2 "black-light", high-pressure, mercury-vapor lamp was employed in the system. This lamp emits principally near-UV radiation (UV-A) from about 310 nm to about 400 nm. Over 90 percent of the output energy is concentrated in the 365-nm mercury emission line according to the relative spectral energy distribution presented in the manufacturer's specifications. The lamp is positioned in a parabolic reflector.

c. Instrumentation.

(1) EG&G Model 585 Spectroradiometer System with High-sensitivity detector head, Model 585-64, UV solar-blind detector S/N 821, and Bausch and Lomb monochrometer catalogue number 33-86-75.

(2) Ultraviolet Products Inc. J-260 Digital Radiometer, S/N 14311 with 365-nm sensor model J-260 2A S/N 0113.

(3) Hewlett-Packard Radiant Flux Meter model 8330A, S/N 1206A, with H-P detector model 8334 A, S/N 00245.

d. Abbreviations. A table of photometric and radiometric terms and units is provided in Appendix A.

5. FINDINGS.

a. Radiance. The radiance of the lamp was approximately 1.3 W/(cm^2 - sr). The blue-light effective radiance was 1.6 mW/(cm^2 - sr). Figure 2 shows two intra-beam photographs of the radiance distribution. The parabolic reflector at the time of the evaluation was slightly deformed. This may account for the irregular source radiance pattern which is shown in Figure 2. A slight difficulty was also experienced on several occasions with starting the lamp in the vertical position. For this reason some measurements were taken with the lamp positioned in the horizontal position.

b. Spectro-radiometric Measurements. Figure 3 provides the UV spectral irradiance of the lamp from approximately 250 nm to 800 nm at an axial distance of 50 cm from the center of the lamp. Both semilogarithmic and linear scales are shown. The linear plot shows that most energy is in the UV-A. Table 1 of Appendix B lists the continuum spectral irradiance values for the spectral region considered. Table 2 of Appendix B lists the spectral irradiance values of individual spectral lines.

c. Irradiance vs Distance Measurements. The relative irradiance as a function of distance is illustrated in Figure 4 along with the effective actinic UV irradiance. The effective irradiance reaches 0.1 $\mu W/cm^2$ at a distance of 1.5 m.

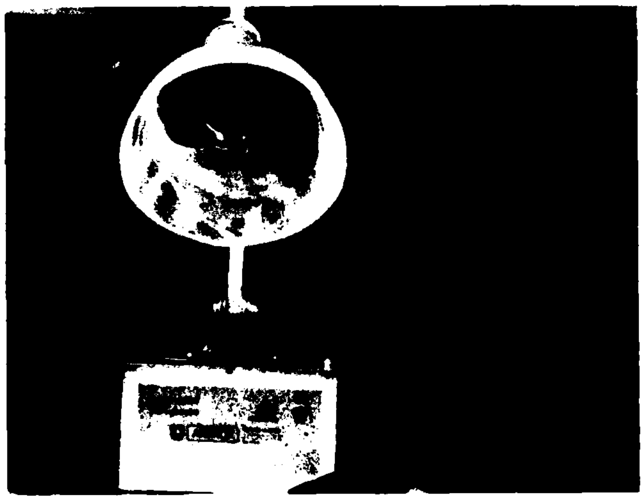


Figure 1. Photograph of Ardrox Model 90/2 Hand-Held UV Inspection Lamp

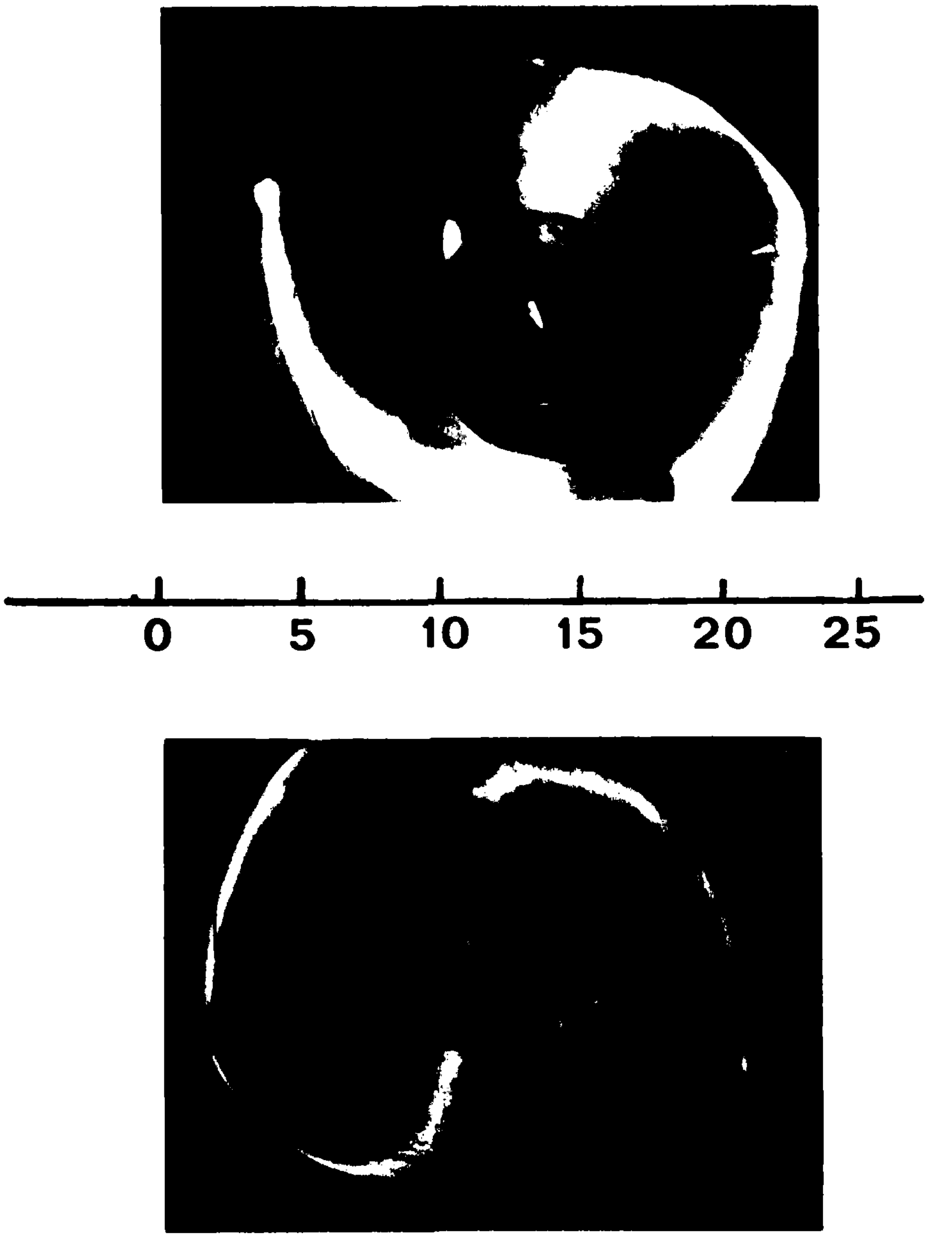


Figure 2. Radiance Pattern of Ardrox Lamps and Reflector. Scale is in cm. Photos are on-axis at two exposure values to show bright area in pattern.

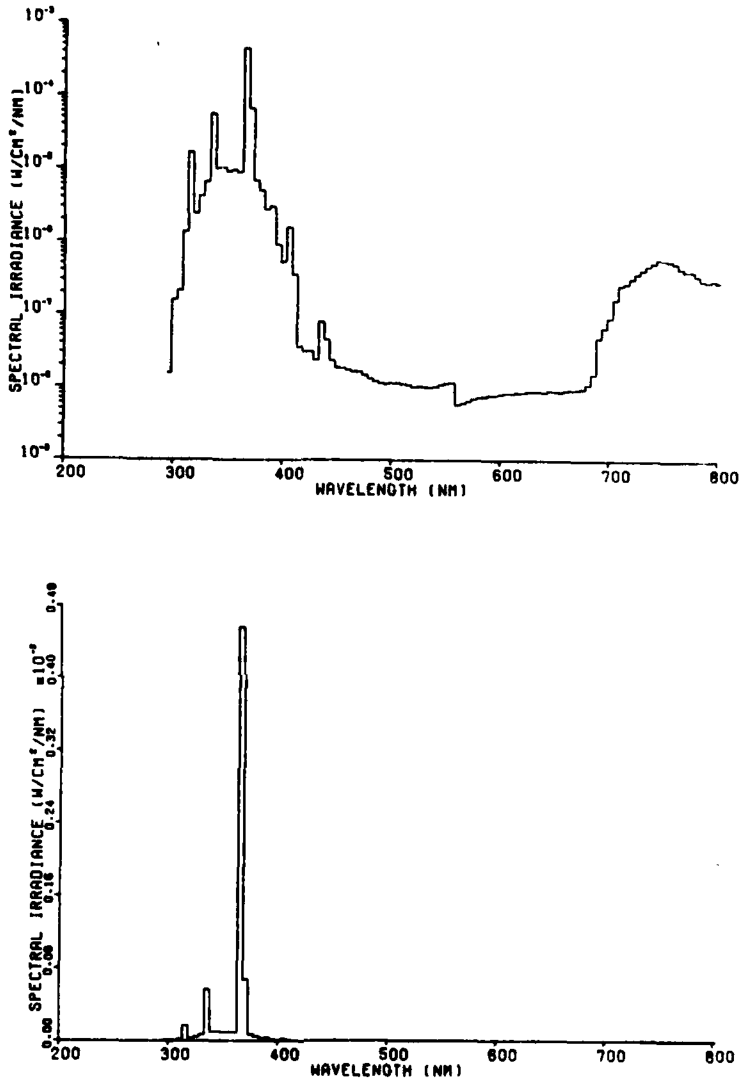


Figure 3. Spectral Irradiance of Lamp System in the Central Beam Axis at 50 cm from the Reflector Edge. Two plots are shown: semilogarithmic and linear. The linear plot shows that the major output is UV-A. The semilogarithmic plot shows the unnecessary radiation in the UV-B and IR-A spectral bands.

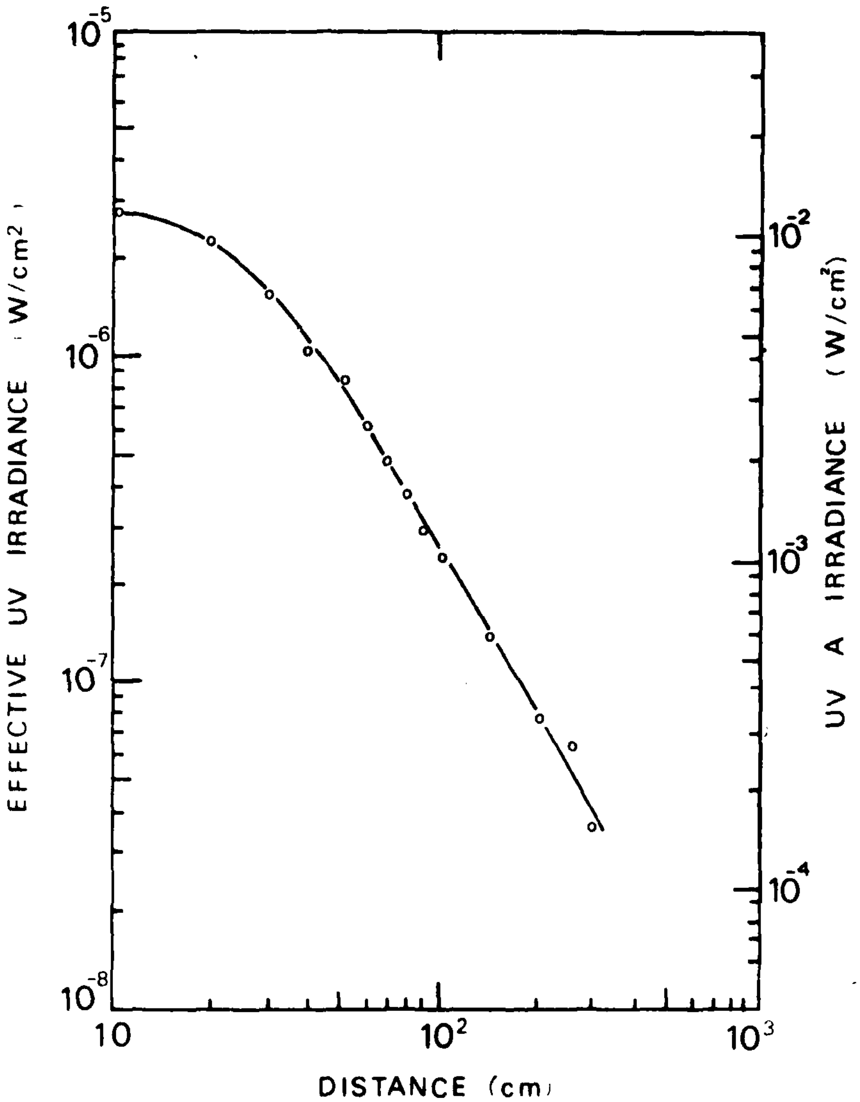


Figure 4. Effective Actinic (UV-B) Irradiance Values in the Direct Beam and UV-A Irradiance. Left ordinate is for spectrally weighted actinic UV-B effective irradiance. Right ordinate gives absolute measured values of UV-A irradiance.

d. Reflection Measurements. Measurements of reflected energy as shown in Figure 5 were made to determine levels at an observer's eye. Worst-case reflection measurements were taken with the lamp in the vertical position. Stainless steel, aluminum and regular white cardboard were used as representative reflecting surfaces.

6. DISCUSSION.

a. UV Spectral Bands. For the purpose of discussing the biological effects of UV radiation on the skin and eye, the CIE (International Commission on Illumination) defines three UV spectral bands:

(1) UV-A: 315-320 nm to 380-400 nm (this radiation is also termed "black-light", "longwave", or "near" UV radiation).

(2) UV-B: 280 nm to 315-320 nm (also termed "actinic", "shortwave", or "erythemal" UV radiation).

(3) UV-C: 100 nm to 280 nm (also termed "germicidal", "actinic", "shortwave", or "far" UV radiation). Radiation at wavelengths below 180-200 nm is also termed "vacuum UV" because it does not propagate through air. These shorter UV wavelengths generate ozone in the air.

b. Black-light Sources. Sources such as the Ardrox Inspection Light make use of mercury lamps designed to emit principally in the UV-A band. The glass envelope is intended to filter out most UV-C, UV-B and visible radiation. As seen in Figure 3, some IR-A (760-780 nm to 1400 nm) also passes through the glass filter envelope of the lamp.

c. Optical Radiation Hazards. Although UV-B and UV-C radiation is normally called the "actinic UV", exposure to UV-A is not without potential hazard. Ultraviolet photokerititis ("welders' flash") and skin erythema ("sunburn") can also be produced by UV-A, albeit at levels thousands of times greater than levels of UV-B and UV-C which elicit such a response. The present exposure limit for "effective" UV-B and UV-C is 3 mJ/cm^2 within 1 workday period less than 30,000 sec or 0.1 $\mu W/cm^2$ continuously (reference 2a). Short-wavelength light (blue and violet) can cause photochemically induced retinal injury. The radiance of gas discharge lamps and incandescent lamps are insufficient to present a potential retinal thermal injury hazard. The blue-light radiance of the lamp was 1.6 $mW/(cm^2 - sr)$ which is below the presently recommended limit of 10 $mW/(cm^2 - sr)$ for long-term (greater than 2.8 hr) exposure.

d. Hazard Evaluation. The UV-A irradiance exceeds the present recommended exposure limit for periods greater than 1000 sec, of 1 mW/cm^2 at direct viewing distances less than 100 cm (3.3 feet). However, such viewing

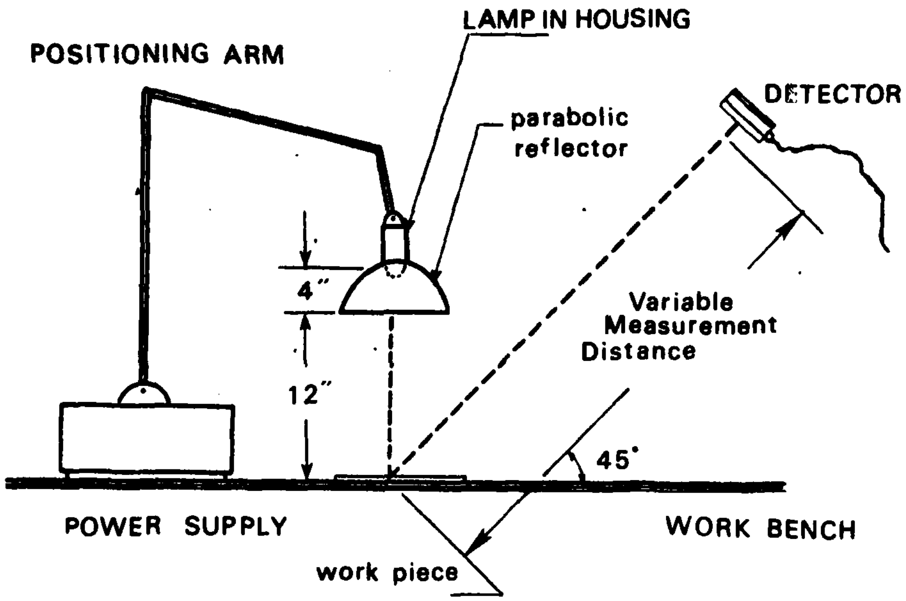


Figure 5. Arrangement for Measuring Reflected Levels of UV-A and UV-B from Surfaces Under Inspection.

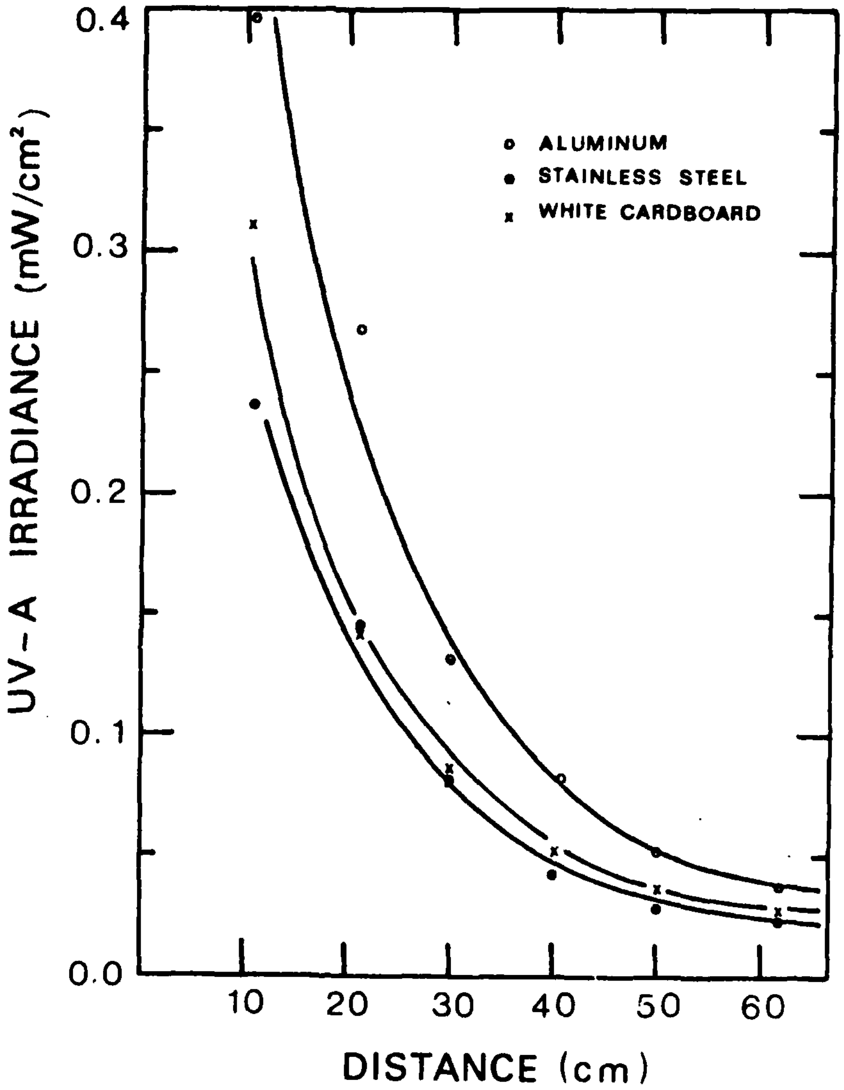


Figure 6. Reflected UV-A Irradiance Values from Three Representative Surfaces. Lamp reflector was approximately 30 cm from surface. Aluminum was chosen because it characteristically has the highest reflectance in the UV-B and UV-A. Reflected effective irradiance values of UV-B radiation were at least 4,000 times less than the UV-A levels shown above. Hence 0.4 mW/cm^2 of UV-A corresponds to a maximum reflected level of 10^{-7} W/cm^2 of effective UV-B.

conditions would not exist in actual use of the lamp. Only momentary direct ocular exposures would be contemplated. However, exposure of the eye to reflected radiation would occur. From Figure 6 the reflected irradiances from even sheet aluminum are far below this continuous exposure limit at any reasonable viewing distance. There is no blue-light retinal hazard from viewing the lamp. The only remaining hazard of concern relates to actinic UV radiation from direct exposure of the hands and from reflected radiation. The direct beam irradiance at 10 cm was 2.7 $\mu W/cm^2$. This level corresponds to a permissible exposure duration of 18.5 minutes. However, reflected radiation at the eye of an observer would be less than 0.1 $\mu W/cm^2$. Hence, UV-B exposure limits are exceeded only for the hand which has a much higher tolerance than the eye. Furthermore, it would not be expected that hands would be this close for periods exceeding 18 minutes in any 1 day.

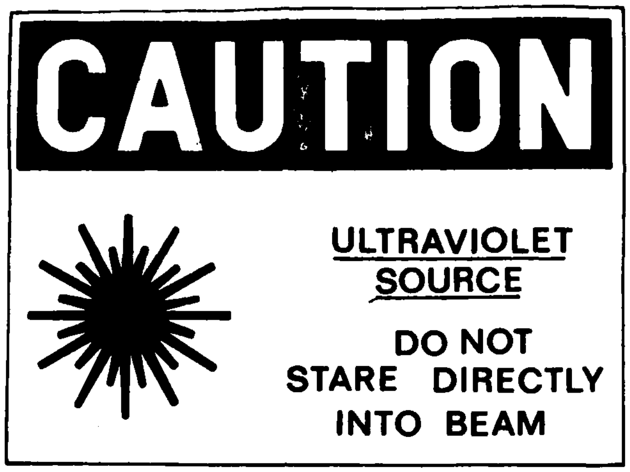
e. Alternate Design. The risk of over-exposure to UV-B radiation could be eliminated by an alternate design. A glass or plastic filter plate (or fresnel lens) which transmitted UV-A radiation but filtered out wavelengths less than 320 nm could be installed in front of the lamp. However, an examination of the lamp fixture revealed that airflow over the lamp bulb was necessary for cooling, hence the addition of such a filter would present a design problem. Inasmuch as the Ardrox lamp would be used only for a few minutes for each inspection, a cumulative daily exposure to reflected UV-B at the very close distances of concern is virtually inconceivable. Therefore, a redesignof the lamp system appears unnecessary for the presently intended application by the US Air Force.

f. Photosensitive Individuals. Optical radiation emitted by the Ardrox lamp may cause a photosensitive skin response in certain individuals who are naturally photosensitive or who are photosensitive as the result of taking certain photosensitizing medications (e.g., tetracycline). However, exposure to UV radiation emitted by one Ardrox lamp source would not be a unique cause for such an effect. Sunlight could also cause the same effect.

7. CONCLUSION. Although the Ardrox UV inspection light emits radiation exceeding current exposure limits for lengthy exposure durations, the system can be used as intended with only minor precautions, since the actual cumulative operator exposure time in any 1 day would normally be less than 2 hours.

8. RECOMMENDATIONS.

a. Place a warning label on the lamp that reads as follows:



(in accordance with para 1-5a, AR 40-46).

b. Indicate in instruction manuals that photosensitive individuals or those taking medications which photosensitize the skin should not use the device (para 1-5a, AR 40-46).

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APPENDIX A

USEFUL CIE RADIOMETRIC AND PHOTOMETRIC TERMS AND UNITS[1,2]

RADIOMETRIC				PHOTOMETRIC			
Term	Symbol	Defining Equation	SI Unit and Abbreviation	Term	Symbol	Defining Equation	SI Units and Abbreviation
Radiant Energy	Q_e		Joule (J)	Quantity of Light	Q_v	$Q_v = \int \Phi_v dt$	lumen-second (lm·s) (talbot)
Radiant Energy Density	W_e	$W_e = \frac{dQ_e}{dV}$	Joule per cubic meter (J·m^{-3})	Luminous Energy Density	W_v	$W_v = \frac{dQ_v}{dV}$	talbot per square meter (lm·s·m^{-3})
Radiant Power (Radiant Flux)	Φ_e, P	$\Phi_e = \frac{dQ_e}{dt}$	Watt (W)	Luminous Flux	Φ_v	$\Phi_v = 680 \int \frac{d\Phi_e}{d\lambda} V(\lambda)\, d\lambda$	lumen (lm)
Radiant Exitance	M_e	$M_e = \frac{d\Phi_e}{dA} = \int L_e \cdot \cos\theta \cdot d\Omega$	Watt per square meter (W·m^{-2})	Luminous Exitance	M_v	$M_v = \frac{d\Phi_v}{dA} = \int L_v \cdot \cos\theta \cdot d\Omega$	lumen per square meter lm·m^{-2}
Irradiance or Radiant Flux Density (Dose Rate in Photobiology)	E_e	$E_e = \frac{d\Phi_e}{dA}$	Watt per square meter (W·m^{-2})	Illuminance (luminous flux density)	E_v	$E_v = \frac{d\Phi_v}{dA}$	lumen per square meter (lm·m^{-2}) lux (lx)
Radiant Intensity	I_e	$I_e = \frac{d\Phi_e}{d\Omega}$	Watt per steradian (W·sr^{-1})	Luminous Intensity (candlepower)	I_v	$I_v = \frac{d\Phi_v}{dr}$	lumen per steradian (lm·sr) or candela (cd)
Radiance	L_e	$L_e = \frac{d^2\Phi_e}{d\Omega \cdot dA \cdot \cos\theta}$ [5]	Watt per steradian and per square meter (W·sr^{-1}·m^{-2})	Luminance	L_v	$L_v = \frac{d^2\Phi_e}{dr \cdot dA \cdot \cos\theta}$ [5]	candela per square meter (cd·m^{-1})
Radiant Exposure (Dose, in Photobiology)	H_e	$H_e = \frac{dQ_e}{dA}$	Joule per square meter (J·m^{-2})	Light Exposure	H_v	$H_v = \frac{dQ_v}{dA} = \int E_v dt$	lux-second (lx·s)
				Luminous Efficacy (of radiation)	K	$K = \frac{\Phi_v}{\Phi_e}$	lumen per watt (lm·W^{-1})
				Luminous Efficiency (of a broad band radiation)	V(*)	$V(*) = \frac{K}{K_m} = \frac{K}{680}$	unitless
Radiant Efficiency[3] (of a source)	η_e	$\eta_e = \frac{P}{P_i}$	unitless	Luminous Efficacy[3] (of a source)	η_v	$\eta_v = \frac{\Phi_v}{P_i}$	lumen per watt (lm·W^{-1})
Optical Density[4]	D_e	$D_e = -\log_{10}\tau_e$	unitless	Optical Density[4]	D_v	$D_v = -\log_{10}\tau_v$	unitless
				Retinal Illuminance in Trolands	E_t	$E_t = \frac{L_v}{S_p}$	troland (td) = luminance in cd·m^{-2} times pupil area in mm^2

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word *spectral*, and the unit is then per wavelength interval and the symbol has a subscript λ. For example, spectral irradiance E_λ has units of W·m^{-2}·m^{-1} or more often, W·cm^{-2}·nm^{-1}.

2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the nm or um are most commonly used to express wavelength.

3. P_i is electrical input power in watts.

4. τ is the transmission

5. At the source $L = \frac{dI}{dA \cdot \cos\theta}$ and at a receptor $L = \frac{dE}{d\Omega}$

APPENDIX B

TABLE 1. CONTINUUM SPECTRAL IRRADIANCE OF ARDROX LAMP AT 50 cm

Wavelength (nm)	μW/(cm^2.nm)
295	0.016
300	0.16
305	0.22
310	1.38
315	6.64
320	2.42
325	4.18
330	6.56
335	30.9
340	10.1
345	10.3
350	9.12
355	9.50
360	8.92
365	24.6
370	67.6
375	6.87
380	5.03
385	2.77
390	3.04
395	0.90
400	0.53
405	0.43
410	0.36
415	0.036
420	0.031
425	0.031
430	0.024
435	0.028
440	0.045
445	0.023
450	0.019
455	0.018
460	0.017
465	0.016
470	0.016
475	0.015
480	0.013
485	0.012
490	0.012
495	0.011

Wavelength (nm)	μW/(cm^2.nm)
500	0.012
505	0.012
510	0.011
515	0.011
520	0.010
525	0.010
530	0.010
535	0.010
540	0.010
545	0.011
550	0.012
555	0.012
560	0.0058
565	0.0061
570	0.0065
575	0.0070
580	0.0073
585	0.0076
590	0.0079
595	0.0079
600	0.0082
605	0.0084
610	0.0083
615	0.0086
620	0.0086
625	0.0086
630	0.0089
635	0.0090
640	0.0087
645	0.0091
650	0.0090
655	0.0082
660	0.0092
665	0.0094
670	0.0095
675	0.0097
680	0.011
685	0.016
690	0.049
695	0.067
700	0.092
705	0.17
710	0.26

Wavelength (nm)	µW/(cm².nm)
715	0.28
720	0.32
725	0.38
730	0.43
735	0.49
740	0.54
745	0.60
750	0.59
755	0.57
760	0.53
765	0.45
770	0.42
775	0.41
780	0.36
785	0.31
790	0.30
795	0.31
800	0.21

TABLE 2. IRRADIANCE OF INDIVIDUAL SPECTRAL LINES AT 50 cm FROM ARDROX LAMP

Wavelength (nm)	Line Irradiance ($\mu W/cm^2$)
313	16.7
334	42.6
365	720.0
405	1.13
437	0.051