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AN EVALUATION OF AN ULTRAVIOLET RADIATION SURVEY METER CHARACTE--ETC(U)
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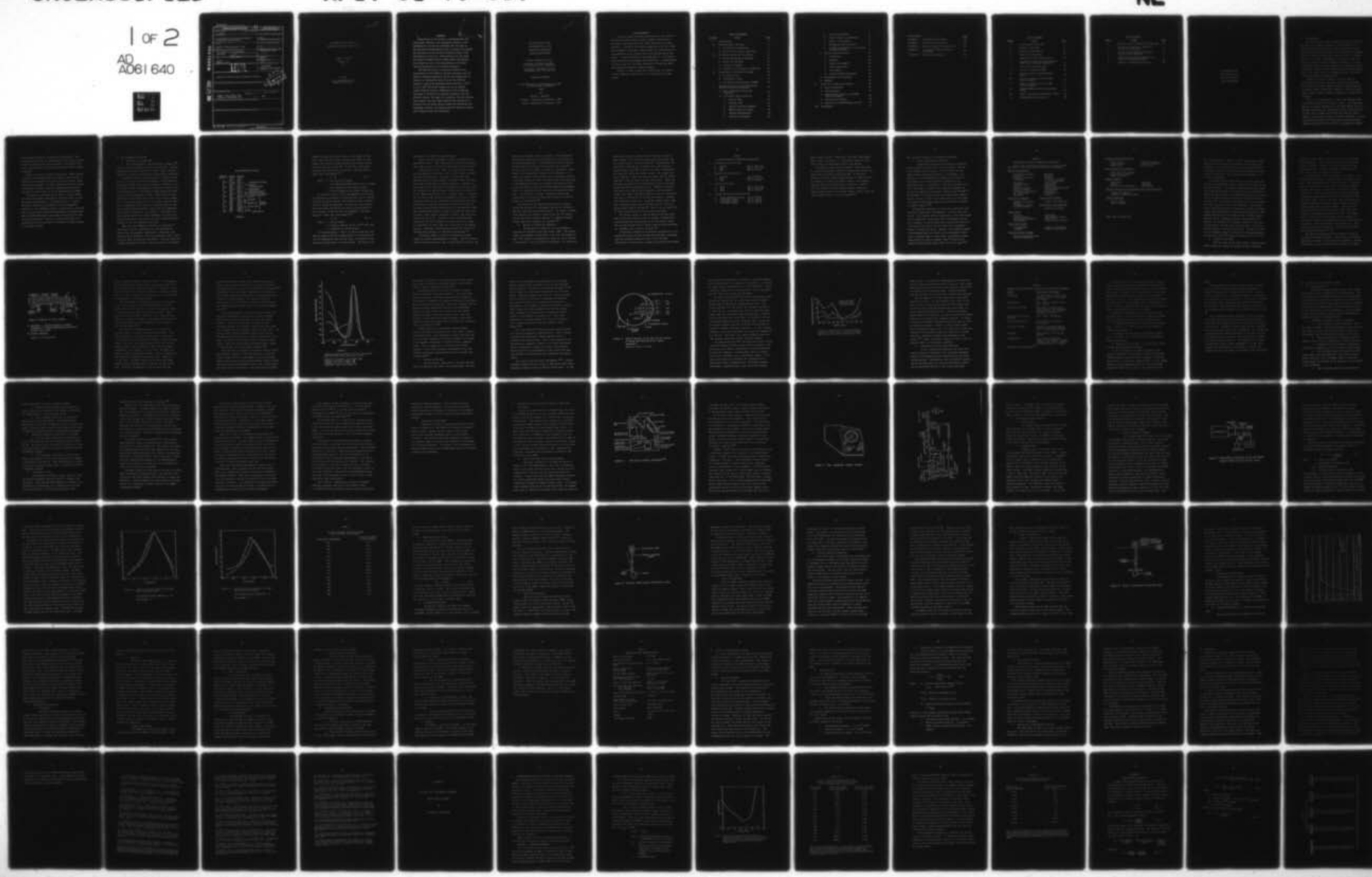

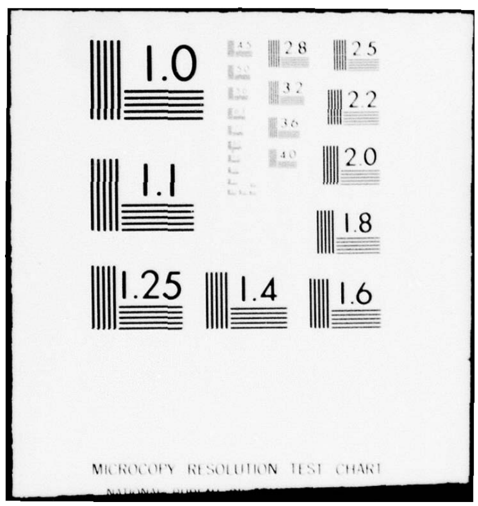
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AN EVALUATION OF AN ULTRAVIOLET RADIATION SURVEY METER CHARACTERISTICS

RONALD L. SCHILLER

CAPTAIN, USAF

1977

92 PAGES

M.S. IN ENVIRONMENTAL HEALTH
UNIVERSITY OF CINCINNATI

ABSTRACT

Discussions of the nature of electromagnetic and ultraviolet radiation, the biological effects of and standards for ultraviolet radiation (UV) and some of the available instrumentation used to measure UV preceded the discussion of the critical evaluation made of the performance and physical characteristics of the NIOSH prototype UV Hazard Monitor (UVHM) dubbed the UVALERT. The evaluation lead to the development of UV hazard survey procedures and an UV Survey Worksheet.

The UVHM was found to basically conform to the requirements of the NIOSH UV Criteria Document with the spectral response peaking at 270 nm with essentially no response to wavelengths above 325 nm. The UVHM was capable of detecting irradiance levels from 0.1×10^{-7} to 3.0×10^{-5} Watts/cm^2 without the use of optical neutral density filters. Discussion of the techniques developed to determine the spectral response, the calibration factor, the angle of acceptance, and the minimum beam diameter for full UVHM response were presented. A problem with the UVHMs optical system was discovered and discussed. Finally, the handling and use during an industrial welding survey were presented.

AN EVALUATION OF THE CHARACTERISTICS OF AN ULTRAVIOLET RADIATION HAZARD SURVEY METER

A Thesis submitted to the

Division of Graduate Studies
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MASTER OF SCIENCE

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of the College of Medicine

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

AN EVALUATION OF THE CHARACTERISTICS OF AN ULTRAVIOLET RADIATION HAZARD SURVEY METER

I. Introduction

As long as man has been exposed to the sun, he has been exposed to ultraviolet radiation. He was unaware of its physical presence because the region classified as ultraviolet lies outside the visible light portion of the electromagnetic spectrum and therefore, man was unable to visually detect it. However, unknowingly he was able to sense its effects because of certain biological responses. It wasn't until 1801, when J.W. Ritter observed the occurrence of the blackening of silver chloride when placed in the dark region beyond the violet end of the visible spectrum, that ultraviolet radiation was discovered.(1)

Within the last half century, there has been a proliferation of devices that emit ultraviolet radiation. Such artificial sources commonly found are germicidal and blacklight lamps, carbon arcs, welding and cutting torches, plasma flame torches, laboratory equipment, and some dental equipment.

Due to this proliferation, concern has developed over ultraviolet radiation's biological effects. The "Radiation Control for Health and Safety Act of 1968" (Public Law (P.L.) 90-602) followed by the "Occupational Safety and Health Act of 1970" (P.L. 91-596) were Federal laws that put legal emphasis on the need to study ultraviolet radiation. In 1972, the National Institute for Occupational Safety and Health (NIOSH) published the "Criteria for a Recommended Standard on Occupational Exposure to Ultraviolet Radiation." The recommended standards and aforementioned legislation created a need for hazard survey meters capable of measuring ultraviolet radiation while assessing the potential risk to exposed workers.

With this need for a hazard survey meter, NIOSH awarded a contract to CBS Laboratories to develop a survey meter to conform to the standards set forth in the Ultraviolet Radiation Criteria Document. In 1973, CBS Laboratories delivered a prototype instrument called the UVALERT Hazard Monitor; referred to in this study as the UV Hazard Monitor (UVHM).

The intent of this work was to make a critical review of various performance and physical characteristics of this prototype hazard monitor. To accomplish this, a limited literature review was performed of the electromagnetic spectrum, of the biological effects of ultraviolet radiation, and of the existing ultraviolet measurement instrumentation. Next the UVHM performance and physical characteristics were critically evaluated. Finally, a hazard evaluation of a welding process was performed to determine the UVHM response in an actual setting.

II. Electromagnetic Spectrum

A. Description of Radiation

The electromagnetic spectrum shown in Figure 1[2] consists of the following six forms of radiation: ionizing radiation, ultraviolet radiation, visible light, infrared radiation, microwave radiation and radiofrequency radiation.

A term more explicit than radiation is radiant energy and it can be used to define the forms of energy which are propogated through space as electromagnetic radiation. In its simplest form, electromagnetic radiation consists of an oscillating electric field moving through space associated with an oscillating magnetic field. These fields are perpendicular to each other and to their direction of propogation. Present day physics bases its current concepts about the electromagnetic spectrum on the quantum theory as proposed by Max Planck and others, and on the electromagnetic wave theory as advanced by J.C. Maxwell. This duality of nature helps explain the various phenomena that have been observed by various experimentors as they conducted investigations of the electromagnetic spectrum.

When the electromagnetic spectrum is considered as wave-like in nature, explanation of such phenomena as diffraction, propogation, interference, refraction, and polarization is possible. With electromagnetic waves, there are three ways in which they can differ: they may differ in strength (intensity of force); they may differ in frequency

THE ELECTROMAGNETIC SPECTRUM

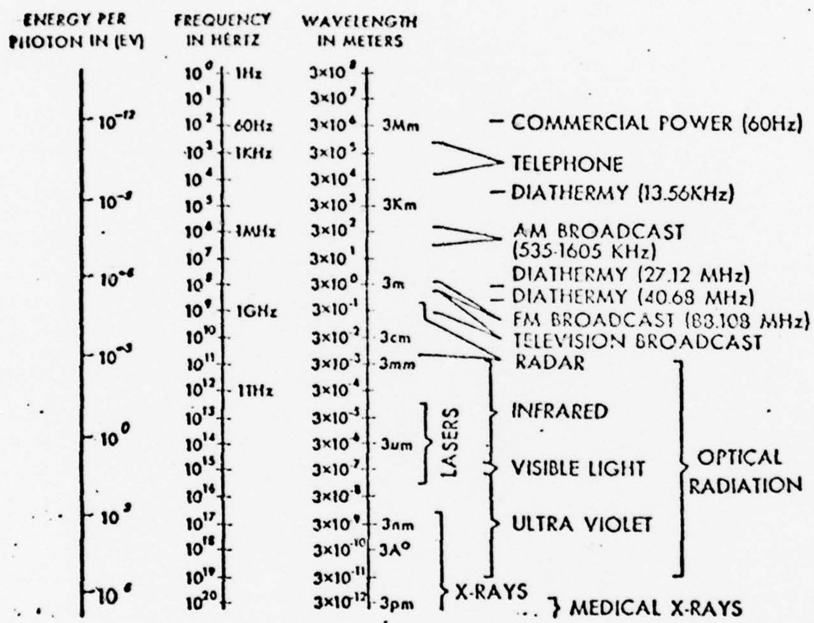

FIGURE 1

(number of times the waves vibrate or the number of complete cycles per unit time); and they may differ in wavelength (the shortest distance between consecutive similar points on the wave train).(3) Two of these differences, frequency and wavelength, are related. Equation (Eq.) 1 shows this relationship:(2)

$$C = f\lambda \qquad \text{Eq. 1}$$

where: C = the velocity of light (3×10^8 meters(m)/second(sec) in a vacuum)

f = the frequency of the radiant energy

λ = the wavelength of the radiant energy wave

As mentioned earlier, the electromagnetic spectrum may be considered to propogate as discrete particles or photons (quanta) of radiant energy, each quantum having a definite value of energy and momentum. In this case, the energies associated with the photons are directly proportional to the frequency of the specific electromagnetic radiation. Equation 2 shows this relationship:(2)

$$E = hf \qquad \text{Eq. 2}$$

where: E = photon energy

h = Planck's constant (6.63×10^{-34} joule-sec)

f = frequency of radiant energy

By rearranging Eqs. 1 and 2, it can be shown that the photon energy is directly proportional to the frequency of the electromagnetic wave and that these two quantities are inversely proportional to the wavelength. The shorter the wavelength, the higher the photon energy.

Radiant energy can produce an effect only when it is absorbed by matter. This absorption of energy will normally cause some atomic or electronic alteration in the material.

As mentioned earlier, there are generally six forms of electromagnetic radiation. One of these forms is called ionizing radiation (i.e., X-rays). In this case, the photonic energy is high enough to dislodge orbital electrons from atoms or molecules to produce ion pairs. However, if the energy is not sufficient to dislodge the electrons, then the region of the spectrum where this occurs is referred to as the nonionizing portion (i.e., visible light). Basically, all the other forms of the electromagnetic spectrum, except ionizing radiation, are classified as nonionizing radiation. A generally recognized cutoff point between the energy of ionizing and nonionizing radiation is 12 electron volts (eV). The minimum photon energies capable of producing ionization in water, atomic oxygen, hydrogen, nitrogen, and carbon are between 12 and 15 eV. Inasmuch as these atoms/molecules constitute the basic elements of living tissue, 12 eV may be considered the lower limit for ionizations in biological systems. Therefore, radiant energy levels less than 12 eV, biologically speaking, are considered nonionizing.[(4)]

The primary modes of action of nonionizing radiant energy are either photochemical or thermal. The basic law of Grotthus and Draper states that no photochemical reaction can occur unless radiant energy is absorbed. Such absorption requires that the energy of the photons be transferred to the absorbing molecules. The nonionizing radiant energies absorbed into the molecule either affect the electronic energy levels of its atoms, or change the rotational, vibrational, and transitional energies of the molecules. In biological systems, their energy transfer produces electron excitation, which can result in dissociation of the molecule if the bonding electrons are involved, dissipation of the excitation energy in the form of fluorescence of phosphorescence, the formation of free radicals and degradation into heat. In the latter situation, absorption changes the vibrational or rotational energy and increases the kinetic energy of the molecule.[4]

The effects of the interaction between the radiant energy and the matter of biological systems are dependent upon the energy of the radiated photons, the degree to which these photons are capable of penetrating into the system, and the ability of specific molecules to undergo chemical changes when these energies are absorbed.[4]

B. Nature of Ultraviolet Radiation

The ultraviolet region of the electromagnetic spectrum lies between X-rays and visible light. The energy range of ultraviolet is from about 3.26 eV at 380 nanometers (nm = 10^{-9} meters) in wavelength to about 12.3 eV at 100 nm in wavelength. From a biological standpoint, the transition between excitation and ionization of molecules occurs at about 100 nm. The separation between the ultraviolet and the visible spectra is about 380 nm.[1] Biologically, the ultraviolet spectrum may be divided into the extreme or vacuum region, from 100 to 190 nm, the range in which both air and water absorb the radiant energy. The region from 190 to 300 nm is called the far ultraviolet and the region from 300 to 380 is called the near ultraviolet. These two divisions are based on the absorption of solar ultraviolet (below 300 nm) by atmospheric ozone. Physicists classify radiation in the 300 to 400 nm region as the near ultraviolet, the region from 200 to 300 nm as the far ultraviolet, and from 4 to 200 nm as the extreme ultraviolet. Another classification is given as: blacklight region (400 to 300 nm), erythemal region (320 to 250 nm), and the ozone producing region (280 to 200 nm).[6] Table 1 is the tabulation of these classifications of ultraviolet radiation.

Ultraviolet energy is emitted whenever excited atoms make transitions from one state to another, concomitantly releasing photons with energies in the ultraviolet range. The two main methods used to excite atoms are the electrical arc, through a gas or vapor, and heat.[1]

Ultraviolet produced in an enclosed incandescent or arc source may or may not pass through the enclosure, depending upon the absorbing characteristics of the envelope. Crystalline or fused quartz transmits ultraviolet wavelengths

TABLE 1

CLASSIFICATIONS OF ULTRAVIOLET RADIATION

A. Biological Classification

1.	Vacuum	100 to 189.9 nm
2.	Far	190 to 299.9 nm
3.	Near	300 to 380 nm

B. Physicists Classification

1.	Extreme	4 to 199.9 nm
2.	Far	200 to 299.9 nm
3.	Near	300 to 400 nm

C. IEC Classification

1.	UV-C	200 to 279.9 nm
2.	UV-B	280 to 314.9 nm
3.	UV-A	315 to 400 nm

D. Another Biological Classification

1.	Ozone production region	170 to 230 nm
2.	Germicidal region	220 to 280 nm
3.	Erythemal region	250 to 320 nm
4.	Blacklight region	300 to 400 nm

down to about 185 nm. Commercially available home window glass, about 2 mm thick, is practically opaque to ultraviolet energy of wavelengths shorter than 300 nm.

Ultraviolet energy may be reflected. The reflection of incident ultraviolet radiation from painted surfaces can range from negligible to more than 90%. A material's ability to reflect visible light provides no indication of its ability to reflect ultraviolet energy. For example, ordinary white wall plaster has a reflection of 46% at 253.7 nm, whereas zinc and titanium oxides, which are equally good reflectors for visible light, reflect only 2.5% and 6% respectively, at this wavelength.(7)

III. Biological Effects of Ultraviolet Radiation

A. Extent and Nature of Exposure

Occupational exposures to ultraviolet radiation occur from both artificial and natural sources. The sun is the primary natural source. The artificial sources either produce ultraviolet energy as a by-product, e.g. welding, or are manufactured to generate the energy for utilization of its various physical properties, e.g. germicidal lamps. According to a 1972 best available estimate, the number of workers with industrial exposure to artificial sources of ultraviolet radiation was 320,000.(7) By 1980 Moss (8) estimates that the occupational exposure may be a factor of 100 or more higher than the 1972 figure. A listing of occupations exposed to ultraviolet radiation is found in Table 2.(9)

Occupational exposures to ultraviolet energy pose two different cause-effect relationships: a direct and an indirect. The indirect effects develop due to the interactions of the ultraviolet energy with other environmental agents. As an example, the solar ultraviolet energy below 300 nm is effectively filtered out by the ozone in the atmosphere before it reaches the earth. However, this absorbed energy can photochemically react with other environmental pollutants to produce what is called smog. Ultraviolet energy below 220 nm is known to produce ozone(7) which has an adopted Threshold Limit Value (TLV) of only 0.1 ppm.(10)

TABLE 2

OCCUPATIONS EXPOSED TO ULTRAVIOLET RADIATION

Some of the occupations potentially associated with ultraviolet radiation exposure include the following:

Outdoor Sun Exposure

- Agricultural workers
- Gardeners
- Construction workers
- Lifeguards
- Fishermen
- Open-pit miners
- Seamen
- Oilfield workers
- Pipeline workers
- Railroad track workers
- Ski Instructors
- Cattlemen
- Military
- Sportsmen
- Postmen
- Policemen (includes crossing guards)
- Road workers
- Landscapers
- Lumberjacks
- Outdoor maintenance men
- Greenskeepers
- Surveyors
- Brick masons
- Farmers

Welding Arc Exposure

- Welders and helpers
- Foremen
- Maintenance workers
- Pipeline workers

Plasma Torch Exposure

- Plasma torch operators

Ultraviolet Laser Exposure

- Laboratory workers

Researchers

- Chemists
- Bacteriologists
- Photo-Bacteriologists
- Microscopist
- Physicists
- Physiological optics
- Lamp tester
- Tissue culture workers

Printing Processes

- Lithographers
- Printers
- Graphic illustrators
- Movie projectionists

Non-destructive Testing

- Metal casting inspectors
- Textile inspectors

<u>Drying and Curing Processes</u>

Paint curers	Food irradiators
Plastic curers	Tobacco irradiators
Wood curers	Meat curers

<u>Environmental Test Chambers</u>

Paint and color testers
Horticultural workers
Space simulators

<u>Medical Sources</u>

Physicians	Dentists
Nurses	Opticians
Phototherapy technicians	Optometrist

<u>Chemical Processing and Manufacturing (Photochemistry)</u>

Production employees
Vitamin D synthesis workers

<u>Sunlamp Exposures</u>

Beauty salons
Bath attendant

Table from reference (9).

As a final example of indirect effects, ultraviolet energy emitted from a welding arc can produce the following contaminants: ozone from ultraviolet energy below 220 nm in wavelength, nitrogen oxides, and phosgene produced by interaction of ultraviolet and a chlorinated hydrocarbon, e.g. carbon tetrachloride.

In considering the direct effects, the most important absorbers in biological tissue of ultraviolet energy are the organic molecules. Ultraviolet radiations injurious effects on living systems appear to be related to the absorption of either the nucleic acid or unconjugated proteins of the cell, and to the photochemical reaction that occurs within some receptors.[4] The lethality on small cells and on bacterial and viral organisms is one effect observed. Other ultraviolet energy caused effects observed in cellular organisms include DNA chain breaking, partial DNA denaturation, cross linking between chains of a DNA molecule, linking between DNA and protein, chromosomal damage and mutagenesis.[1] However, the inability of ultraviolet photons to penetrate any appreciable distance into the body limits the areas of medical concern to the skin and the eye. Extensive reviews of the biomedical aspects of ultraviolet exposure appear in the papers by Leach,[1] Urbach,[12] and Pitts.[13, 14, 15]

B. Effects on the Skin

The fact that in the intact animal, incident ultraviolet energy does penetrate through the skin, makes the response to this energy of primary concern from an occupational viewpoint. Some of the skins responses (acute and chronic) include: erythema, blistering and desquamation, pigment darkening, tanning, epidermal thickening, actinic skin, photosensitization and skin cancer.

Structurally the skin is composed of two layers --- the epidermis and the dermis. Figure 2 shows a diagram of the skin. The epidermis has two essential layers --- an outermost stratified layer of horny cells called the "stratum corneum" and the inner living cells from which the horny cells arise. Stratum corneum cells are continually being sloughed and replaced by cells which are reproduced in the basal cell layer. Between the basal cells are melanocytes (pigment producing cells) which when irradiated by ultraviolet energy produce melanin granules. These granules migrate toward the stratum corneum from the basal cells through the malphigian (prickle cell) layer. The dermal layer is thicker than the epidermis and is composed of elastic and collagen tissue which provide the skin with its resiliency. Other constituents of the dermis are: sweat glands and ducts, hair follicles, sebaceous (oil) glands, blood vessels and nerves.[4, 16]

The degree of penetration by ultraviolet energy influences the response elicited. Below 290 nm, ultraviolet absorption in humans is entirely in the epidermis. Between 290 and 320 nm, less than 10% of the incident ultraviolet

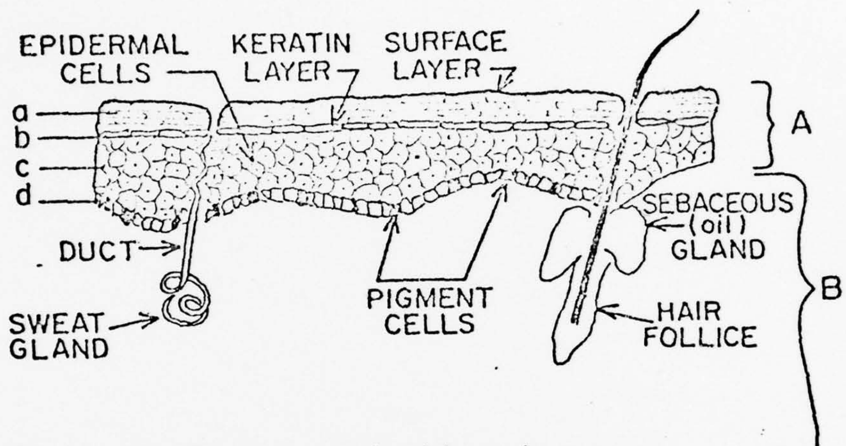

Figure 2. Diagram of skin s layers.

A. EPIDERMIS: a—STRATUM CORNEUM, b—STRATUM GRANULOSUM, c—STRATUM GERMINATIVUM (PRICKLE CELL), d—BASAL CELL LAYER.

B. DERMIS (CORNEUM).

Adopted from reference (4) and (16)

energy reaching the dermis increases until at the beginning of the visible energy range, only a little more than 50% of the incident energy reaches the dermis.[1] Generally, with less than 50% of the incident ultraviolet reaching the dermal layer, the internal organs of the body are not considered to be susceptible to ultraviolet damage.

The development of erythema, defined as the reddening of the skin from the dilation and engorgement of minute blood vessels in the dermis, is the most conspicuous change in the skin brought about by ultraviolet energy. There have been various methods evolved to try to quantitate the degree of erythema to the dose. One method used graded red colored paper which was then compared to the response of exposed individuals.[17]

The degree of erythema produced by a certain dose differs greatly at various ultraviolet wavelengths. With lower wavelengths, a relatively small dose is sufficient to to produce a barely noticeable erythema. With increasing dosage, the degree of erythema produced does not increase proportionally to that produced at equal doses of longer wavelengths. For example, a 3×10^{-5} Watt, 20 minute exposure of 220 nm energy might produce a slight reddening of the skin with a reddening lasting for a day. However, a 3×10^{-5} Watt, 20 minute exposure of 297 nm energy might produce a deep reddening with a reddening lasting several days. From this observation, it can be noted that the shorter wavelengths not only show a minimal long-acting effect, but also that the increase in erythema intensity with increasing dose is less than with longer wavelengths.[17] In addition to the wavelength dependency of ultraviolet, the erythema response of human skin is dependent upon such variables as the following: the angle and spectral characteristics of the incident energy, the thickening of the stratum corneum, and the degree of cutaneous pigmentation.[18]

As mentioned earlier, the relative effectiveness of different wavelengths in eliciting a specific response constitutes the "action spectrum" for that particular response. The "action spectrum" developed for the erythemal response to ultraviolet energy shows that there are two maxima for the erythemal effect in normal skin: one peak at about 297 nm and another peak at about 250 nm. Depending upon the investigator and his experimental technique, the peak at 250 nm could either be major or minor. Figure 3 shows an "action spectrum" developed by a number of investigators for the erythemal response.[19]

Once the skin is exposed to ultraviolet energy and the photochemical response of the skin develops, a period of latency insues prior to an erythemal reaction occurring. During this latency period, melanin granules from the basal cells migrate into the malphigan layer with a thickening of the horny layers of the skin. This migration of melanin,

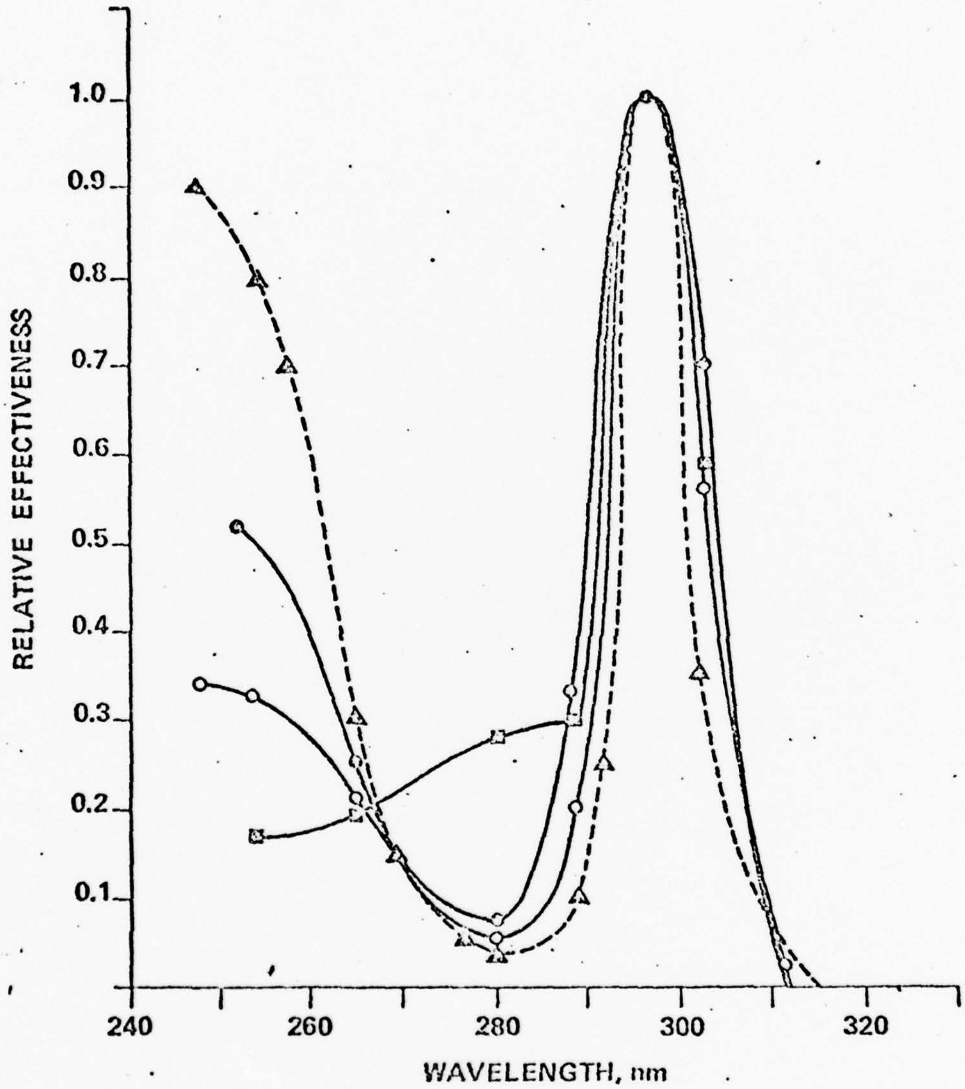

FIGURE 3

ERYTHEMA ACTION SPECTRA (previous observers).
FROM EVERETT, OLSON, and SAYER. (19)

LUCKIESH, HOLLADAY, and TAYLOR - ▲
HAUSSER and VAHLE (1922) - ■
HAUSSER and VAHLE (1927) - ●
COBLENTZ, STAIR, and HOGUE - ○

the pigment responsible for varying degrees of skin coloration, seems to provide an increased degree of protection against repeated ultraviolet insults.(7)

Photosensitization of the skin is another response observed following ultraviolet exposure. Two genetically inherited diseases, xeroderma pigmentosum and congenital erythropoietic prophyria are endogenous disorders exacerbated by ultraviolet energy exposure. There are exogenous factors which can produce photosensitization in the individual. Examples of these factors are certain oral and topical application drugs; many plants such as figs, limes and parsnips contain photosensitizing chemicals; and certain industrial chemicals such as coal tar derivatives and ultraviolet cured inks.(4,7,20)

Chronic exposures to ultraviolet energy produce actinic skin which is manifested by a dry, brown, inelastic and wrinkled skin. The condition of actinic skin does not in itself appear harmful but should be heeded as a warning to susceptible individuals of potential future complications. There is ample data to indicate that chronic exposure to ultraviolet produces carcinogenesis with the primary carcinogenic spectrum believed to be between 280 and 320 nm.(21)

C. Effects on the Eye

The ultraviolet energy that is incident upon the eye is absorbed by the cornea, the aqueous humor, the lens and/or the vitreous humor depending upon its wavelength. Figure 4 presents the structure of the eye and indicates how ultraviolet is absorbed at selected wavelengths.[4,22] In the intact eye, ultraviolet energy does not reach the retina. This is fortunate since the eye, unlike the skin, does not develop a tolerance to subsequent irradiation. The classical effects of ultraviolet on the eyes are: photophobia, pain, epiphora, excessive lacrimation, irritation, congestion of the conjunctiva and ciliary spasms. These symptoms are frequently seen in industry and described as "flash-burn" or "welders eye." This acute phonomenon is incapacitating at the time but disappears after several days with rarely any permanent ocular damage.[23]

Pitts and Tredici[13] investigated threshold intensities for the production of photokeratitis. Their findings concluded that ultraviolet induced photokeratitis is incidious and incapacitating. Most of the symptoms of the photokeratitis appeared in about 4 to 12 hours with about 8 hours elapsing for evidence of visual incapacitation. The keratitis was an inflammation of the cornea with punctate lesions or ulcerations in the superficial epithelial layers.

In a latter report by Pitts and Gibbons,[14] a similar threshold response to ultraviolet at 260 nm and longer wavelengths was shown to exist in rabbits and primates. At 250

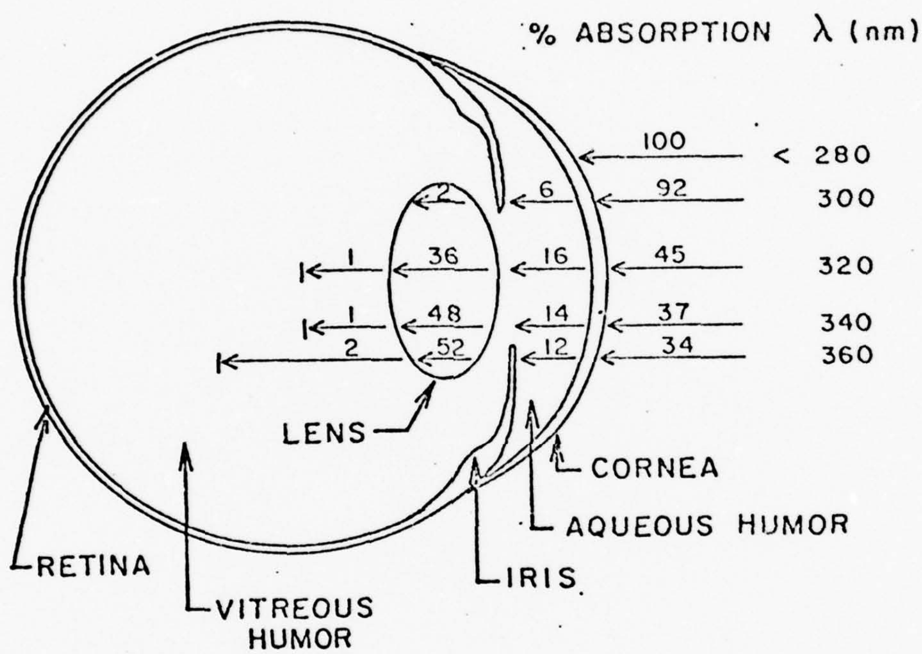

Figure 4. General structure of the eye and the percent of energy (UV) absorbed by the various components.

Modified from reference (4) and (22).

nm and shorter wavelengths, the primates (including humans) were the more sensitive, compared to the rabbits. At 270 nm the human cornea threshold was 0.4×10^{-2} Watts/cm^2. Figure 5 shows the comparison of the ultraviolet "action spectrum" for the rabbit, the primate and the human.

As reported by Pitts(15) most of the wavelengths below 300 nm were absorbed by the cornea while the wavelengths between 310 and 390 nm were absorbed by the lens. The "action spectrum" for the rabbit lens extended from 295 to at least 335 nm. It appears that the most effective wavelength range for producing lenticular opacities, localized areas of opacification in the lens, is from 295 to 315 nm. A surprising finding of Pitts' study was that a relatively low radiant exposure from 295 to 315 nm in wavelength was required to produce lenticular opacities. At lower radiant exposures in the same wavelength, the cornea was damaged but not the lens. Therefore, the cornea threshold should provide adequate protection against lenticular damage.

As reported by Pitts,(23) the human ultraviolet "action spectrum" extends from 220 to 310 nm with a minimum at 270 nm and an energy density threshold of 4.0 milliJoules/cm^2. He based his findings on an experiment where he exposed thirty-nine (39) human eyes to ultraviolet energy. Pitts used seven criteria to determine the threshold level; epithelial debris, epithelial haze, epithelial granules, photophobia, symptomatology, visual acuity and corneal

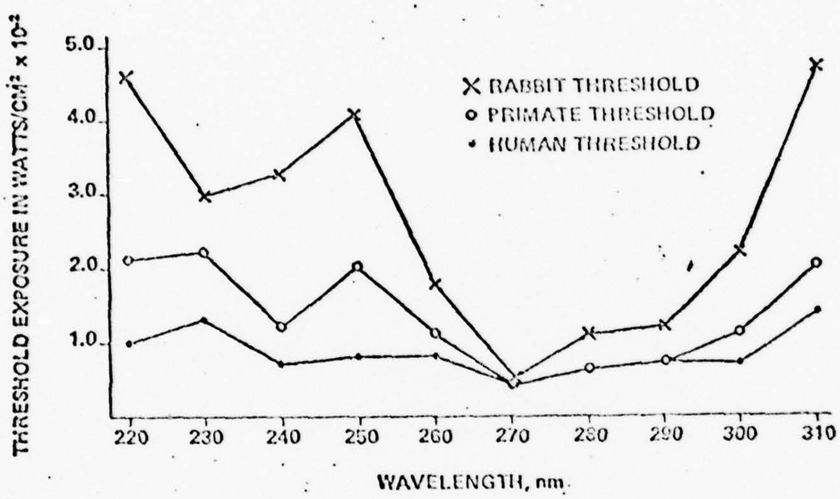

FIGURE 5. COMPARISON OF THE ULTRAVIOLET ACTION SPECTRUM FOR THE RABBIT, PRIMATE AND HUMAN. FROM PITTS AND GIBBONS. (14)

light scatter. Two observers independently determined the criteria status and classification of each eye. The results indicated that the most effective wave band was 270 nm with a threshold of 4.0 milliJoules/cm^2. The most commonly reported symptoms were tearing and a foreign body sensation.

The eye appears to be most sensitive to ultraviolet radiation of 270 nm. At low exposures, the cornea is the first to react to the insults by ultraviolet energy with the effects being delayed depending upon wavelength, exposure duration and exposure rate. With low exposures, these effects are transitory in nature and usually disappear within 24 to 48 hours after exposure cessation. At longer wavelengths and higher irradiance levels the lens may undergo lenticular changes. However, at these higher levels where lenticular changes occur, the cornea may already have developed such permanent damage as stromal haze, stromal opacities, endothelial changes and thickening of the cornea.(23) Table 3 presents a summary of some of the biological effects of ultraviolet radiation.

D. Standards for Ultraviolet Radiation.

As has already been discussed, the direct biological effects of ultraviolet are wavelength dependent. Each of the biological effects mentioned have their own action spectrum. Unfortunately, most ultraviolet sources emit broad band spectra so that the wavelengths emitted may be associated with one or more action spectrums.

TABLE 3

SUMMARY OF SOME BIOLOGICAL EFFECTS OF ULTRAVIOLET RADIATION

EFFECT	ULTRAVIOLET WAVELENGTH
Germicidal	254 nm maximum - effects fall rapidly at shorter or longer wavelengths.
Carcinogenic	200 - 400 nm; maximum effect 290 - 320 nm.
Photosensitization	Wavelengths at which this occurs varies with absorption characteristic of chemical compounds involved.
Thickening of Stratum Corneum	Solar range, 300-400 nm.
Keratoconjunctivitis	Greater effect at shorter wavelengths.
Lenticular damage	Limited to wavebands above 295 nm. Action spectrum for lens: 295 to about 315 nm.
Erythema	Peak effects at 250 nm and 290 nm.
Pigmentation	280 - 320 nm stimulates formation of melanin - little tanning; 300 - 650 nm oxidizes preformed melanin - tanning

Modified from Michaelson[5]

An early attempt at formulating ultraviolet exposure guidance was made in 1948 by the Council on Physical Medicine of the American Medical Association. They recommended criteria for exposure of the eye or skin to ultraviolet energy from germicidal lamps, primarily a monochromatic emitter at 253.7 nm. They proposed a limit for the lamp of 0.1 $\mu W/cm^2$ for a 24 hour exposure and 0.5 $\mu W/cm^2$ for a 7 hour, or shorter, exposure.(24) The criteria were based on a dose which would not produce an erythema.

Matelsky(4) recognized that many paramteres affect threshold values, so he suggested the following threshold doses, weighted on the basis of their action spectra:

1) Minimum erythemal dose for previously nonexposed skin: 2×10^4 - 2.5×10^4 $\mu W\ sec/cm^2$ of erythemally-weighted ultraviolet.

2) Minimum erythemal dose for previously exposed skin: 2.5×10^4 - 3.5×10^4 $\mu W\ sec/cm^2$ of erythemally-weighted ultraviolet.

3) Minimum keratitic dose: 1.5×10^3 $\mu W\ sec/cm^2$ of keratitically-weighted ultraviolet.

In 1971 the Committee on Physical Agents of the American Conference of Governmental Industrial Hygienist (ACGIH) proposed a general TLV for exposure of both the skin and eye to ultraviolet radiation.(25) In 1972, NIOSH published its Recommendation for Ultraviolet Radiation Standard(7) which was the same as that proposed by the

ACGIH.

The recommendation was based on the effects of ultraviolet on skin erythema and photokeratitis production. Sliney[25] compared the action spectra, both for erythema and for photokeratitis, and plotted energy as a function of wavelength for these action spectra. He then drew a minimum hazard curve which conformed to the general distribution of this data. This curve drawn by Sliney was the basis of the recommendation by NIOSH for the standard from 220 to 315 nm.

The recommended standard (Appendix 1) was based upon the action spectra for both erythema and keratoconjunctivitis and was intended to protect the skin and eyes against acute effects. Therefore, separate skin and eye standards were not necessary and were not recommended. The recommended standard was more readily applicable to the eyes since the eye, unlike the skin, does not acquire protective capabilities after repeated exposures. The standard was intended to adequately protect normal individuals so it may not be adequate for photosensitive individuals. Finally, this standard has yet to be given a legal mandate for enforcement.

IV. Measurement of Ultraviolet Energy

A. Design Criteria

Ultraviolet energy normally occurs over a broadband region and not predominately at one wavelength. With the publishing of the NIOSH Ultraviolet Criteria Document, a measuring device that would integrate the ultraviolet intensity over a specified range became a necessity. Problems that had to be considered with such instrumentation were: it effectively had to be non-responsive to the low visible radiant energy wavelengths and it had to be biologically weighted in units of a "hazard factor."

1. Guidelines applicable to all instruments:

a. The instrument should be portable, compact and light in weight. This design guideline would allow the measurement of the ultraviolet energy with little to no interference from the instruments presence in the field.

b. The operation of the instrument should be simple so that it may be operated by a trained technician.

c. Adequate filtration should be provided to eliminate or minimize the out of wavelength band leakage.

d. The instrument should be rugged and stable under normal operating conditions. This feature would permit field use of the instrument without unnecessary concern about the validity of the data due to the frailness of the instrument.

e. The instrument should be calibrated with minimum inconvenience using a reliable standard.

f. Reflection from nearby surfaces should be either eliminated or minimized. This feature would permit true measurements of the ultraviolet source.

g. The instrument should have an acceptance angle of no less than 30 degrees. This characteristic would permit survey work of nonpoint sources. It would also permit a survey of point sources close enough to each other to account for an additive effect upon the exposed individual.

2. Additional guidelines applicable to the UVHM:

a. The instrument should have a sensitivity to 0.05×10^{-6} Watts/cm^2 over the wavelength range of 200 to 315 nm. This sensitivity would permit an evaluation of the ultraviolet energy source to determine compliance with the recommended standard.

b. The instrument should have a spectral response curve peaking at 270 nm with essentially no response to wavelengths above 325 nm. This would permit the evaluation of an ultraviolet energy source in accordance with the recommended standard.

B. Instruments in Use

In measuring ultraviolet energy, there are three main detection methods employed: physical, chemical and biological. The principal disadvantages of chemical (e.g. dosimeters) and biological (e.g. pigmentation) detectors are low sensitivity, relatively long response times and unsuitability for continuous recordings.[26]

Shortly after the publishing of the NIOSH Ultraviolet Criteria Document, a company submitted to NIOSH a proposal for the development of an industrial ultraviolet radiation badge-type dosimeter. The badge would be able to indicate to the user the dose of ultraviolet energy received (8 hour dose = 3 mW sec/cm^2 effective at 270 nm). The basic principle was the use of a photosensitive material that upon exposure to ultraviolet would change color in relation to the dose received. To date, no badge has been developed from this proposal.

In England, Challoner and others[27] used a simple badge dosimeter based on measuring optical absorbance of ultraviolet on a polysulphone film. The optical absorbance was measured before and after each exposure with the dose measurement being converted to the effective erythema dose equivalent of 297 nm in mJ/cm^2. This device may be useful for solar radiation measurements for an epidemiological study but it would not be useful for the measurements required in an industrial environment.

Although attempts have been made to develop a reliable, cheap and simple film badge detector, the problem of low sensitivity and long response times continue to plague the developers. Another problem with these personal type dosimeters is in obtaining a response similar to the NIOSH recommended standard.

The method of physical detection has been the most widely used measurement method because it appears to be the most reliable. The physical method of measurement depends upon photosensitive elements converting electromagnetic emissions into electrical energy. There are two basic types of physical detectors: Radiometric -- those that absorb radiation which is then degraded to heat and Photoelectric -- those which produce electronic displacement or eject electrons from photoemissive materials.

There are a variety of instruments which employ the physical detection method. The simplest device is the barrier or photovoltaic cell. In this method, certain semiconductors such as selenium or copper oxide deposited on a selected metal develop a potential barrier between the layer and the metal. Energy falling upon the surface of the cell causes the flow of electrons from the semiconductor to the metal. A sensitive meter placed in such a circuit will record the intensity of radiation falling on the cell.

Some other instruments developed use vacuum tubes or photomultiplier tubes to achieve the desired sensitivity. Most of the commercially available ultraviolet equipment is wavelength selective. With these instruments, special filters are required to isolate the portion of the ultraviolet spectrum of interest. As a result of this selectivity problem, most of the available ultraviolet instrumentation is designed for and used at very specific wavelengths.

Some examples of the instruments currently being used in the field to measure ultraviolet are: 1) Blak-Ray UV Intensity Meter,[28] 2) a portable spectroradiometer developed by the USAF,[29] 3) the International Light Model IL 700[30] and 4) the NIOSH UVHM.[31]

The Blak-Ray meter is a commercially available, hand-held survey meter that was designed for measuring UV intensities in industrial applications such as under germicidal lamps. It is not the hazard survey meter required for total UV hazard evaluations because it has a limited wavelength sensitivity.

The portable spectroradiometer, developed at Wright-Patterson AFB, is an attempt to satisfy operational requirements for an ultraviolet hazard survey meter. The instrument consists of a miniature tandem grating monochromator with a photomultiplier detector. One of the drawbacks of the instrument is that incremental measurements of the source must be made over the wavelength of interest. The integral of the product of the meter response and the respective wavelength correction factors for the instrument results in the total irradiance corrected for the ACGIH/NIOSH action spectrum. This instrument is not a direct readout, broad-band ultraviolet survey meter.

The IL 700 is a commercially available instrument which has extremely high sensitivity (down to about 1×10^{-10} W/cm^2 with suitable accessary options) but has no biological-weighting function. The instrument utilizes photodiodes, photomultipliers, and solid state detectors thereby allowing an interchange of detectors for continuous measurements of power in various spectral bands from 200 to 1100 nm.

C. Ultraviolet Hazard Meter

NIOSH was furnished a prototype ultraviolet hazard monitor in April 1973. The UVHM is an attempt to develop a direct readout, portable monitor capable of detecting potentially hazardous broadband sources of ultraviolet radiation. The instrument had been designed to respond to the exposure limits set forth in the *NIOSH Criteria Document* for Ultraviolet Exposure. In Section V, the performance and physical characteristics of the UVHM which were operationally evaluated, are discussed.

V. Evaluation of the Ultraviolet Monitor's Operating Parameters

In order to comply with the recommendations set forth in the NIOSH Ultraviolet Criteria Document, NIOSH awarded a contract for the development of an ultraviolet energy monitoring device. This device had to conform to a specified spectral wavelength response curve peaking at 270 nm with essentially no response to wavelengths above 325 nm. In April 1973, CBS Laboratories delivered a prototype instrument (referred to as UVHM) that was intended to meet the specified criteria and enable a determination to be made of the potential risk to workers exposed to ultraviolet energy. In this section, various operating parameters of this prototype instrument will be discussed. This evaluation was performed to determine the performance capabilities and limitations of the UVHM.

A. Basic Instrument Design and Principles

The basic components of the UVHM are shown in Figure 6.[31] The UVHM employs a multilayer interference filter, ultraviolet dichroic mirror and a quartz lens in a folded optical system to achieve the desired spectral response. A metal oxide silicon (MOS) photodiode operates in a biased mode which detects the ultraviolet energy transmitted through the bandpass filter system. To maintain linear dynamic operation on the MOS Photodiode, the maximum input flux is limited on the higher input ranges by means of

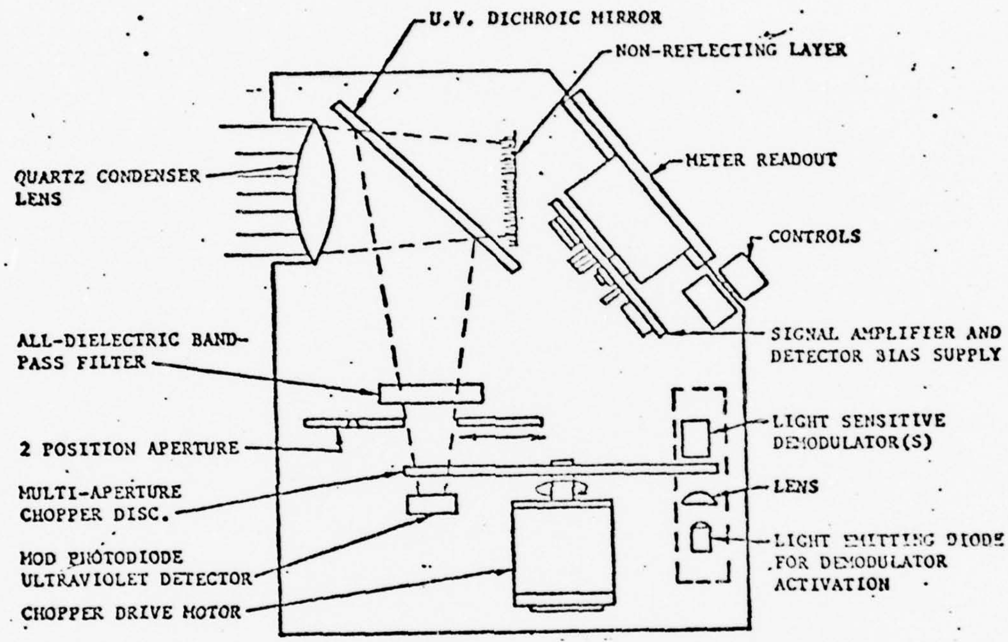

FIGURE 6 UVHM BASIC INTERNAL COMPONENTS(31)

a moveable aperture stop. A rotating optical chopper interrupts the optical signal, thereby allowing separation of the photodiode output signal from the dark current.

The detector output signal is amplified in a two stage alternating current (AC) amplifier. The sensitivity of the instrument is set in the AC amplifier. This AC signal is rectified in a synchronous demodulator consisting of two photoconductive cells coupled to the optical chopper wheel. This synchronous demodulation rejects the nonsynchronous signals, thereby providing a high noise immunity to the system. The detected direct current (DC) is filtered and displayed on a panel meter which also serves to monitor the battery condition.[31]

Figures 7 and 8 show the Ultraviolet Hazard Monitor and a functional diagram of the circuitry of the UVHM respectively. A simple two piece aluminum enclosure contains the components of the meter. The instrument controls consist of the power switch, a charger input jack, a function selector switch (fast or slow response), a 250° deflection indicator meter (range 0 to 3 units) which can also indicate the condition of the battery, and a range switch (selection range from 10^{-7} to 10^{-2} Watts/cm^2). The instrument is powered by a four unit, 6 volt, 750 milliampere/hour rechargeable nickel cadmium battery which allows $\pm$ 12 volts for the electronics and the 24 volts for the motor supply circuit. The battery charger completely replenishes the battery in

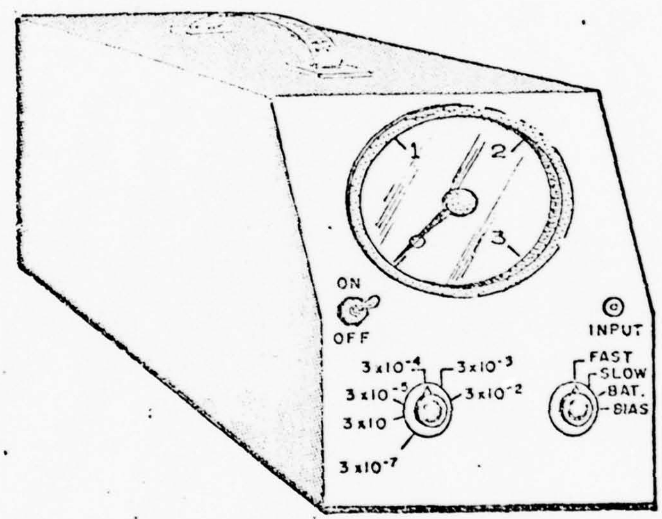

Figure 7. The ultraviolet hazard monitor.

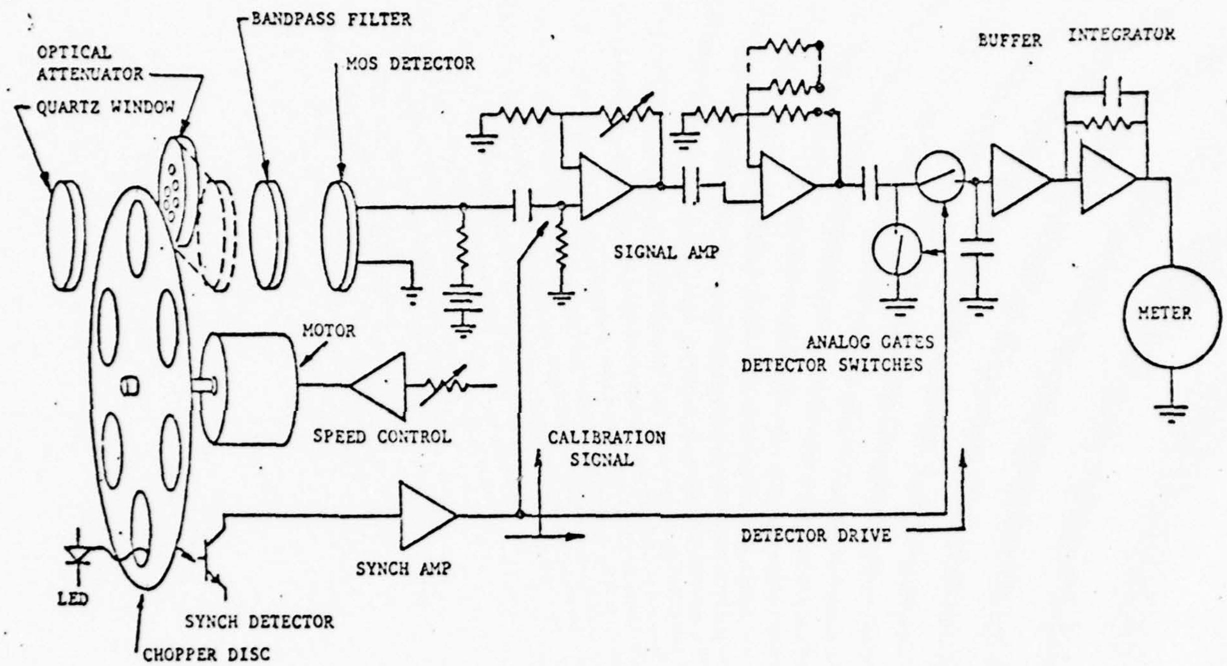

FIGURE 8 CIRCUITRY DIAGRAM OF UVHM(31)

about 14 hours. No damage occurs if the battery becomes moderately overcharged.(31) There is a recorder jack on the face of the UVHM which allows a permanent record of the UVHM response to be obtained when connected to a recorder.

B. Performance Characteristics

a. Warm-up Time

The warm-up time was defined as the elapsed time necessary for the UVHM to meet stated performance specifications after being off for at least 24 hours. During all performance testing, the UVHM was allowed one minute for warm-up. Based on the results of this testing, a one minute warm-up time is satisfactory.

b. Response Time

Response time in this evaluation was the total elapsed time between exposure of the UVHM to a known ultraviolet source and a 100% final response. Knowledge of the response time is important for it provides the operator with information on the ability/inability of the UVHM to adequately detect pulsed or short duration ultraviolet energy. The UVHM's optical window was blocked from a 30 Watt, deuterium, ultraviolet lamp. The time from the UVHM's optical window being exposed to the lamp to the indicator meter's full response was checked using a Sheffield Stopwatch. Ten different trials were made on each response setting. On the fast setting, the final response was achieved in 1.8 ± 0.2 seconds. On the slow

Standard(7) which was the same as that proposed by the

setting, the final response was achieved in 30 $\pm$ 2 seconds. The response time on the slow setting limits the use of this setting to the measurement of ultraviolet energy sources that operate continuously for longer than 32 seconds. The fast response setting can be used for continuous or intermittant sources which operate longer than 2 seconds. The UVHM is limited in its ability to measure pulsed sources to energy pulses longer than 2 seconds.

c. Relative Spectral Response

The relative spectral response was the response of the UVHM to the incident radiant energy of a particular wavelength or wavelength band. The relative spectral response was made to determine how well the response agreed with the published biologically weighted NIOSH standard. The relative response measurements were made using the setup in Figure 9. A 30 watt deuterium ultraviolet lamp was used as the ultraviolet source. After the ultraviolet energy passed through a single converging silica lens, it filled the entrance slit (3 mm x 3 mm) of a Minuteman Model 305-M half-meter, vacuum Monochromator. The monochromator's optical system employed a modified Czerny-Turner system positioned in such a manner that no double diffraction occurred. The exit beam from the 3 mm x 3 mm exit slit was similarly directed through a simple converging silica lens which was positioned in such a manner as to fill less than half of the UVHM detector's quartz condenser lens. The

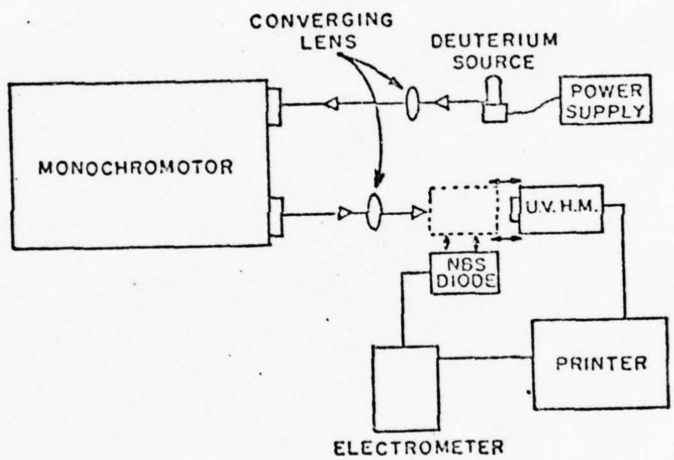

Figure 9. Experimental arrangement for U.V. alert hazard monitor relative spectral response chech.

National Bureau of Standards (NBS) Transfer Standard Photodiode and the UVHM were positioned at the same distance from the converging lens so that the same amount of incident radiant energy impacted upon the photodiode or the UVHM condenser lens. The photodiode's electrical impulses were fed to a Keithley Model 602 Solid State Electrometer which measured the current (10^{-8} Amperes). The current response was recorded as a function of wavelength using a Hewlett-Packard (H-P) 7004B X-Y Recorder. The UVHM response as a function of wavelength was recorded directly using the H-P Recorder.

Using the current measurements from the NBS calibrated transfer standard photodiode, the incident power was determined using the following equation:

$$I.P. = 1.24 \frac{I}{(\lambda)(Q.E.)} \qquad \text{Eq. 3}$$

where I = current in amperes

λ = wavelength in micrometers (μm)

Q.E. = quantum efficiency

I.P. = incident power in microwatts (μW)

The development of equation 3 is shown in Appendix 2. The incident power at each wavelength was then multiplied by the relative spectral effectiveness values listed in the NIOSH Criteria Document for Ultraviolet Radiation, page 1-5, to produce an effective power value.(7) These effective power values were then normalized to a maximum response at 270 nm to match the NIOSH recommended ultraviolet exposure response curve. The two curves were then plotted (Figures 10 and 11) with the UVHM compared to the normalized photodiode curve. The data used to plot Figures 10 and 11 are in Appendix 3.

The UVHM curve (fast response) showed good adherence to the normalized curve from 220 nm to 245 nm and from 265 nm to 300 nm. At 255 nm the UVHM curve was about 40% higher than the normalized curve. The UVHM curve (slow response) did not show good adherence to the normalized curve. The peak UVHM response occurred at 265 nm instead of 270 nm. This was probably due to the relatively fast monochromator speed (100 speed setting) and a slow UVHM response (30 $\pm$ 2 seconds). Therefore, the UVHM did not have the opportunity to adequately respond to the incident energy. The UVHM results below 220 nm and above 310 nm were not discernable because of some internal instrument noise that developed in the instrumental setup. Previous calibration runs indicated that the relative spectral response as a percent of maximum response was less than 2.6% for wavelengths below 220 nm and was less than 3.5% for wavelengths at or above 310 nm.[31] Table 4 lists the relative spectral response of the UVHM (fast setting only) as determined during this evaluation. The UVHM relative spectral response was not determined for the slow setting because of the variation that occurred in the location of the response peak. The UVHM fast setting response adhered well to the normalized curve. Although

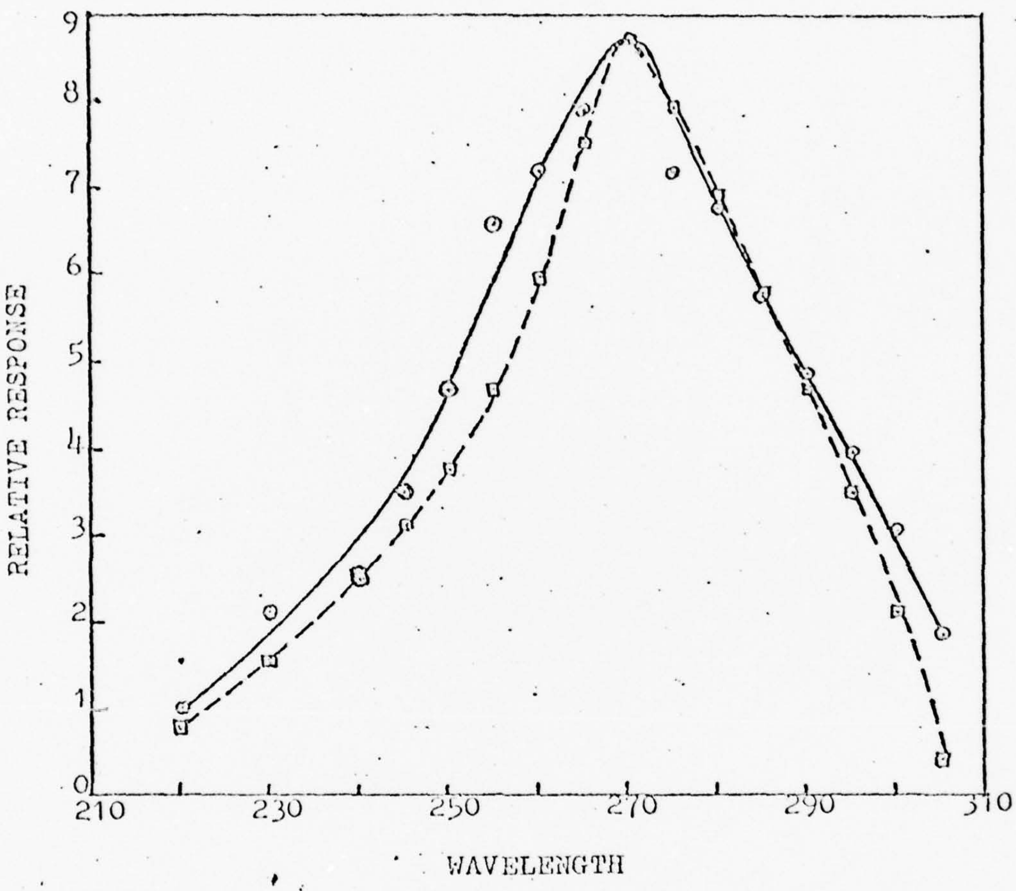

FIGURE 10 RELATIVE RESPONSE CURVE OF THE UVHM (fast response curve)

NBS PHOTODIODE RESPONSE (NORMALIZED) -- ⊡

UVHM RESPONSE -- ⊙

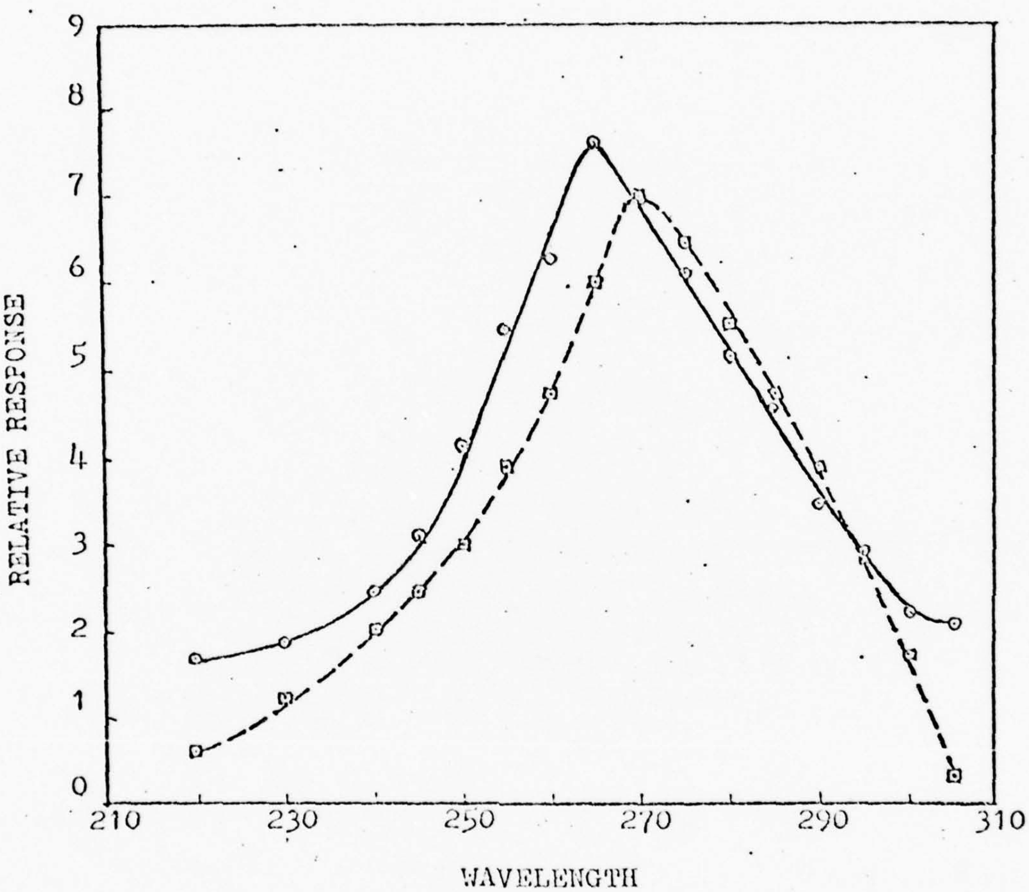

FIGURE 11 RELATIVE RESPONSE CURVE OF THE UVHM (slow response setting)

NBS PHOTODIODE RESPONSE (NORMALIZED) -- ⊡

UVHM RESPONSE -- ⊙

TABLE 4

RELATIVE SPECTRAL RESPONSE OF UVHM
(FAST RESPONSE SETTING ONLY)

WAVELENGTH (NANOMETER)	MEASURED RESPONSE (% OF MAXIMUM)
220	11.6
230	24.3
240	29.5
245	40.2
250	53.8
255	75.7
260	82.9
265	90.9
270	100.0
275	82.7
280	78.2
285	66.5
290	56.1
295	45.7
300	35.3
305	21.4

the slow setting response did not adhere as well, this may be due to the monochromator speed instead of instrument design.

d. UVHM Calibration Factor

The calibration of the UVHM was conducted using an Optronics Laboratories 30 Watt 40 Spectral Irradiance Deuterium (D_2) Lamp (Serial No. UV-205) connected to an Optronics Lab Model 45 D_2 Lamp Precision Current Source set at 550 milliamps. The D_2 lamp, traceable to the NBS, was positioned at a distance of 30 cm, the calibration distance of this lamp, from the UVHM. Five readings were taken with the monitor being moved and returned to the same 30 cm position after each reading. The average maximum reading was 2.91 $\mu W/cm^2$ with the range being 2.87 $\mu W/cm^2$ to 2.96 $\mu W/cm^2$. Using the spectral irradiances from the D_2 lamp and the following formula from Appendix 1:

$$I_{eff} = \Sigma I_\lambda \Delta\lambda S_\lambda \qquad \text{Eq. 4}$$

the total effective irradiance between 220 and 305 nm was calculated to be 4.45 $\mu W/cm^2$. The average irradiance reading obtained was only 65% of this calculated value. Therefore, the indicated maximum monitor value must be increased by a factor of 1.53 to yield a reliable value.

e. Maximum UVHM Response

During the testing of the UVHM, the maximum irradiance reading was obtained by keeping the center of the UVHM's optical window at the same distance from a standard source while pivoting the meter 14° to the left. Figure 12 shows the UVHM position for the maximum response. The maximum response occurred at 14° for all three distances checked. When the UVHM was moved from 14° to a position directly facing the source, the reading was reduced by about one-half.

This 14° deviation indicates that a portion of the optical system is off center. This deviation may have always been inherent in the UVHM from date of manufacture or may have occurred during a check of the UVHM's internal components. When using the UVHM in its present condition, the optical window should be held about 14° toward the left of the ultraviolet source to be monitored. A logical solution would be to correct the deviation problem by determining if the optical assembly or if only one of its internal components needs to be repositioned. As an interim measure, an arrow drawn on a piece of masking tape has been placed on the top of the UVHM to guide the operator in obtaining the maximum reading.

f. Sensitivity Response

The sensitivity response was defined as the relative spectral response of the different UVHM's sensitivity scales to the same ultraviolet source. Of the six scales, three are inoperative. Only the three lower scales (3×10^{-7}, 3×10^{-6} and 3×10^{-5} Watts/cm^2) are usable. The relative spectral response was checked using the same

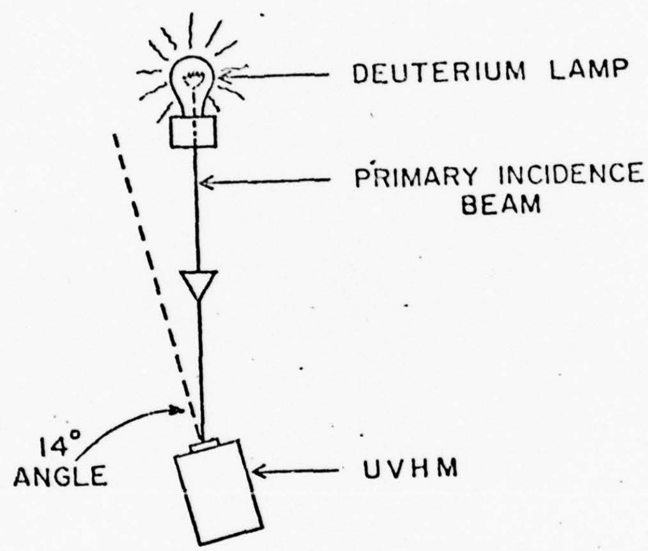

Figure 12. Maximum UVHM response determination setup.

equipment referred to in section c. The results of checking the three scales showed a uniformity of response with the peak of the spectral response occurring at 270 nm.

A different check of the sensitivity response was performed using a 1000 Watt Tungsten-Halogen Spectral Irradiance Lamp (ozone free). The lamp was cooled using a small fan. The UVHM was positioned about two meters from the lamp and a reading taken, e.g. 2.75×10^{-7} W/cm^2. The scale selector switch was changed to the next higher scale and the UVHM was again read, e.g. 0.21×10^{-6} W/cm^2. This changing of scales produced an 18% difference in readings with the 10^{-7} scale reading being the higher figure. This greater sensitivity on the 10^{-7} W/cm^2 scale was to be expected. The 18% variation between the two scales indicated that the sensitivity provided uniform linear responses on all scales.

g. Filtration Addition

With the UVHM's indicator readout meter only providing a 0 to 3 readout and the 10^{-5} W/cm^2 scale setting being the highest operable scale, the use of optical neutral density filters of varying shades, e.g. 0.5 or 1, could be used to compensate for these limitations. Using the 1000 Watt Tungsten-Halogen lamp mentioned earlier, the UVHM's response was evaluated with and without an optical neutral density filter of one. The optical filter of one was intended to reduce the irradiance value by a factor of ten. The results showed that the filtration did produce approximately a factor of 10 decrease (reduction of 97% noted). For example, one reading without filtration was 2.25×10^{-6} W/cm^2 while the reading with filtration was 0.3×10^{-6} W/cm^2. Instead of achieving the expected 2.02 unit reduction, a 1.95 unit reduction was obtained. This factor of 10 reduction showed that neutral density filters could be used with satisfactory results being obtained.

h. Inverse Square Law Adherence

One of the basic relationships that generally hold for electromagnetic energy is the inverse square law (ISL). A reasonable test of instrumentation that measures electromagnetic energy would be how well the instrument followed this relationship. The ISL states that the propogation of energy through space is inversely proportional to the square of the distance it must travel.

Ultraviolet energy theoretically follows the ISL. The UVHM was evaluated to determine if it would respond according to this relationship. The Optronics UV-40 Spectral Irradiance Lamp mentioned earlier was used with the UVHM being positioned at three different distances (30 cm, 60 cm, and 90 cm) from the source. The placement of the UVHM at these locations followed a randomized pattern established by using the random number selector program on a Texas Instrument SR-51A Pocket Calculator. Three readings were taken at each location with the average reading being: 1) 30 cm = 1.44×10^{-6} W/cm^2, 2) 60 cm = 0.5×10^{-6} W/cm^2

and 3) 90 cm = 0.25×10^{-6} W/cm^2. Using the average 30 cm reading as the reference, the ISL predicted that the 60 cm reading should have been 0.36×10^{-6} W/cm^2 and the 90 cm reading should have been0.16 x 10^{-6} W/cm^2. The average 60 cm reading was 38.9% higher than expected and the average 90 cm reading was 56.3% higher than expected. If the average 60 cm reading was used as the reference in predicting the expected ISL reading at 90 cm, then the observed 90 cm reading was only 13.6% higher than the predicted reading.

One possible explanation for the difference between the calculated ISL value (30 cm reference) and the values obtained could be due to directionality problems with the ultraviolet source. After completion of the UVHM evaluation testing, it was discovered that the spectral irradiance lamp used had an extremely critical directionality requirement. This requirement was that the primary ultraviolet energy beam from the lamp be almost perfectly normal to the measurement device. If the lamp's primary beam was a degree or two off the normal, there would be a definite drop in the irradiance levels measured. If the 30 cm readings were not perfectly normal, then this could account for the deviations noted. Further testing with a source that is not so directional should be conducted to determine if the UVHM responds according to the ISL at 30 cm.

The UVHM can be used to estimate irradiance levels at various distances from an ultraviolet source using the ISL.

Until further testing, the measurement should be made at a distance of 60 cm or greater from the source.

i. Angle of Acceptance

Figure 13 depicts the setup for the angle of acceptance check. The check was made to determine the response of the UVHM to ultraviolet energy at various angles from the normal to the UVHM's optical window. Another term that could be applied to the angle of acceptance is field of view. Measurement of two or more nearby ultraviolet point sources could be made to obtain the total irradiance at the measurement location if the sources are within the field of view of the UVHM. By knowing the angle of acceptance, the UVHM operator would be able to determine if one or more measurements would be required to obtain the total irradiance at a given location.

In the check, the monitor was positioned at 103.3 cm from an Optronics Lab UV-40 Lamp. The lamp was mounted so that it could be moved along a track normal to the primary beam of the lamp. The lamp was moved either left or right from the center of the UVHM's optical window. The lamp's primary beam was maintained normal to the track. The results indicated that the total angle of acceptance was 18° for a 50% or greater response.

The maximum response of the UVHM occurred when the source was moved to the right of the optical window. The maximum reading occurred at an angle of only 8° to the right

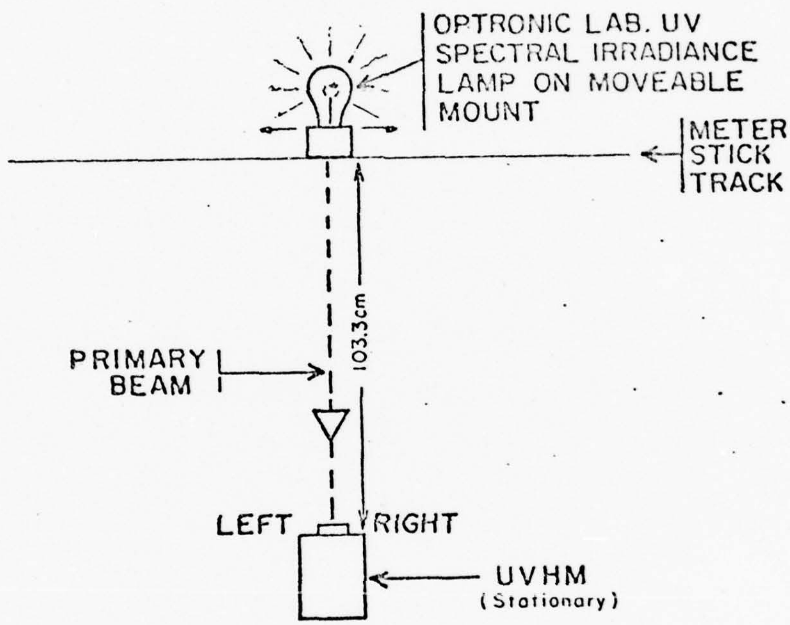

Figure 13. Angle of acceptance measurement setup.

of center. This did not coincide with the 14^{o} deviation determined earlier. The difference possibly being accounted for by different experimental setups. In the 8^{o} deviation, the source was moved. In the 14^{o} deviation, the instrument was rotated. Both the 8^{o} and 14^{o} deviations indicate that a problem exists with the UVHM's optical system. This problem causes the angle of acceptance to be definitely limited. As the lamp was moved further to the right of the maximum response, the UVHM's response plummeted. As the lamp was moved to the left of the maximum response, the UVHM's response showed a more gradual decline. This unsymmetrical acceptance by the UVHM indicated that the housing was blocking some of the incident energy.

j. Minimum Aperture Beam Size

The minimum size of beam that would be required to yield a full response was examined. Using an Oriel Corp. Variable Aperture Guide affixed to the UVHM's optical window, ultraviolet energy from a 30 Watt D_2 Lamp was beamed at the monitor from a distance of 47 cm. The aperture settings were varied and the results were plotted (Figure 14). The results indicated that for a full response of the UVHM, a primary beam diameter of at least 1.3 cm must be presented to the center of the optical window.

k. Response Reliability as a Function of Operating Time

The operating time of the UVHM was noted to be

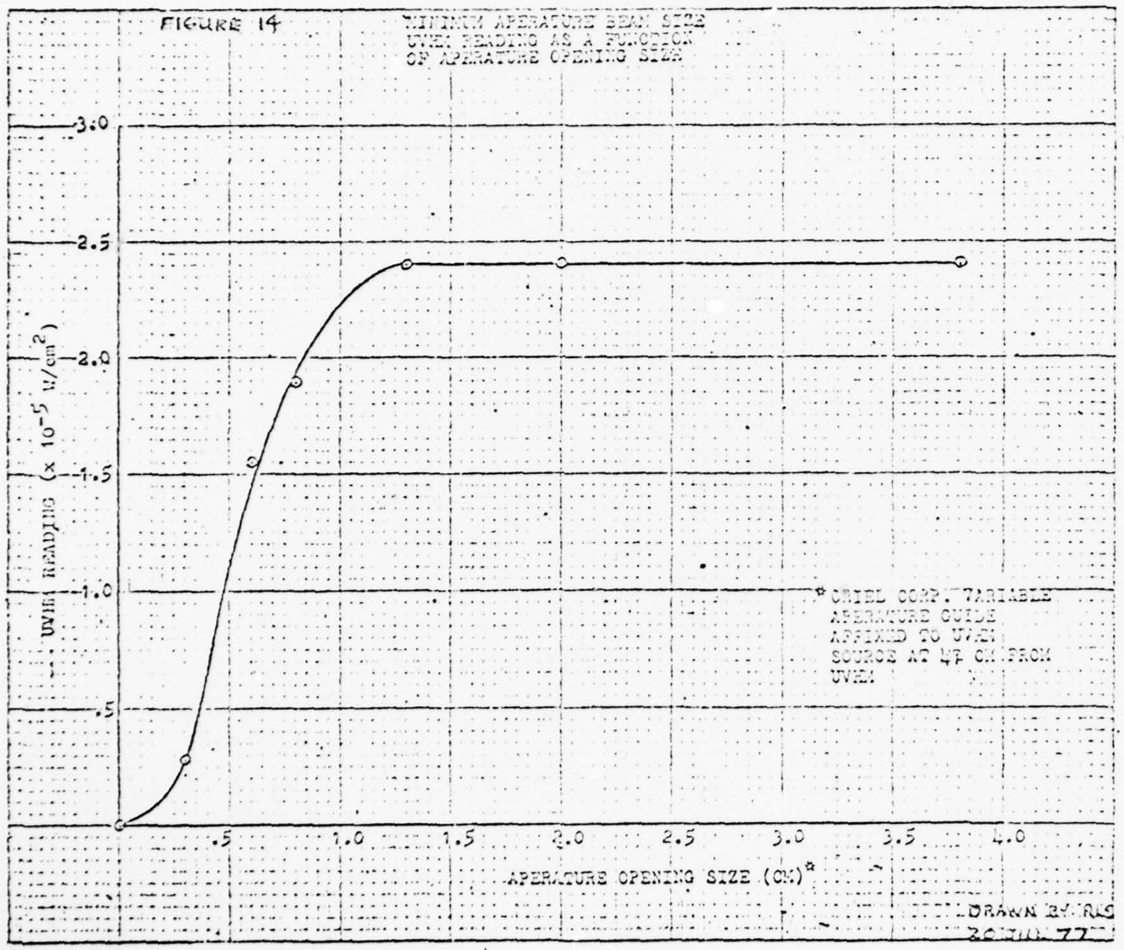
FIGURE 14
MINIMUM APERATURE BEAM SIZE
UVEM READING AS A FUNCTION
OF APERATURE OPENING SIZE
3.0
2.5
2.0
1.5
1.0
.5
UVEM READING (x 10^-5 W/cm^2)
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
APERATURE OPENING SIZE (CM)*
* ORIEL CORP. VARIABLE
APERATURE GUIDE
AFFIXED TO UVEM
SOURCE AT 47 CM FROM
UVEM
DRAWN BY RLS

only about 1-1/2 to 2 hours continuous before a drop in response would occur. The response of the monitor decreased about 20% as the batteries neared their charge point. According to previously published literature,(31) the operating time of the UVHM was stated to be 20 hours; however, they did not state if the operating time was continuous or intermittent. Also, the literature did not indicate if any reduction in UVHM response would occur as the charge condition of the batteries deteriorated. Considering these findings, the rechargeable batteries are possibly nearing the end of their useful life and could be replaced. The replacement could allow the UVHM to be more reliable over several hours of continuous use. Prior to conducting a field survey, the batteries should be fully charged. As the survey progresses, the battery condition should be periodically checked.

C. Physical Characteristics

a. Portability

The UVHM is portable because of its legal weight (3 Kg), small size (23 cm by 11.5 cm by 16.5 cm), and its ability to operate from its own rechargeable batteries. This unit can easily be carried with one hand. The internal charger circuit does not enable recharging of the batteries from a 60 Hz power line while operating the UVHM from the same power line. In fact, the response produced when operating from the charging line was always lower than the response produced when operating with the batteries fully charged.

b. Readout

The form of the UVHM readout is an important physical characteristic. The readout meter ranges from 0 to 3 units full scale. The meter is located on the upper portion of the opposite side from the optical window (optical input). To read the meter, the operator must face the ultraviolet source with his/her eyes directly in line with the source. This poses the possibility of the operator accidently being overexposed. If the meter was on top of the UVHM, the operator would not have to worry about this possible overexposure. The readout is linear and in units of W/cm^2 and so no reference has to be made to a calibration chart or curve. Since the meter has only three units full scale, when a source has an irradiance greater than three, either a neutral density filter or the next higher sensitivity scale has to be used. If a linear response meter from 0 to 10 full scale deflection would have been installed, the need for filtration or the switching of sensitivity scales to measure an ultraviolet source, could possibly be eliminated.

c. Output Plug Adapter

The UVHM has an output plug adapter which allows connection of the UVHM to a data recorder. This feature is highly desireable for it allows a permanent record to be kept for future reference. Once the recorders response is properly calibrated to the UVHM's response, the UVHM could be left for a period of time in the general area of an ultraviolet source and the irradiance levels measured with minimum exposure to the UVHM operator.

d. Ease of Operation

It is essential that the UVHM be easy to operate in the field by an operator without special knowledge or training, and that the controls provided minimize operator bias. Even though the UVHM is a prototype, it is very easy to operate. The controls are easily accessible and clearly labeled but are located on the opposite side from the optical input. This again poses a risk of an accidental overexposure to the operator's eyes while making a hazard survey. If the controls were on the top of the UVHM along with the readout meter, the chance of an accidental overexposure would be minimized.

e. Zero Adjustment

The UVHM does not have an external zero adjust so that when the optical window is blocked and no ultraviolet energy is being optically measured, the UVHM cannot be adjusted to obtain the zero reading. Since there is no external zero adjust knob, then the operator must block the optical window to prevent stray ultraviolet energy from entering, obtain the reading, and use that reading as the basis for further readings.

f. Optical Window Maintenance

To prevent dirt and dust from entering the optical assembly, the outer end of the mounting barrel was terminated with a recessed, ultraviolet grade quartz window. The window allowed the ultraviolet energy to be transmitted through it with a minimum loss of energy.[31] This window should not be touched with fingers or cleaned with coated tissues. Residue deposited could decrease the amount of ultraviolet energy transmitted to the sensor. The windows delicacy definitely creates a problem in its cleaning. Special cleaning techniques need to be developed to prevent loss of energy transmission due to either a dirty window or to the damage from improper cleaning. On future ultraviolet measuring instruments, an optical window which can be readily cleaned and still allow the maximum ultraviolet transmission should be developed.

D. Recommended Use Techniques

Using the results of the evaluation of the UVHM, the following are recommended methods of using the UVHM in its present condition.

a. For most survey work, the UVHM should be set at the fast response position to minimize the time necessary to obtain maximum irradiance readings.

b. The batteries should be fully charged prior to use. After about 1 hour of continuous use, the battery condition should be checked. If the meter indicates that the batteries are near the recharge point, no futher readings should be made.

c. Before making measurements, the optical window should be blocked with some material opaque to ultraviolet and the zero irradiance meter indication noted on all operating scales. These zero readings should then be subtracted from the measurement readings to obtain the actual response of the UVHM.

d. The survey should be performed using the highest sensitivity scale setting and then lowered as indicated by the meter response. The sensitivity scale which gives the maximum deflection without pegging the readout meter should be used.

e. When using the UVHM during a survey, the optical window should be pointed toward the left (operators left) of the ultraviolet source until the maximum reading is obtained.

f. After the measurements have been made, the irradiance reading should be multiplied by the calibration factor of 1.53 to obtain the corrected irradiance levels.

E. Summary

The UVHM is a prototype instrument that was built under a contract for NIOSH. Its designed purpose was to provide an easy to use instrument to measure broad-band ultraviolet energy according to the NIOSH and the ACGIH recommended ultraviolet exposure standard. The various performance and physical parameters of the UVHM found in this study are summarized in Table 5. Knowledge of the UVHM operating parameters is essential if one is to perform a proper ultraviolet energy hazard evaluation.

In addition to knowing the operating parameters of the detector, one must also know when and where to use the detector. This author has developed a guide to use in performing a UV hazard evaluation. This is shown in Appendix 4. With this guide, and the knowledge of the UVHM operating parameters, one should be able to perform a quick but accurate hazard evaluation. As far as this author knows, this is the first time an ultraviolet worksheet has been developed.

TABLE 5

SUMMARY OF UVHM CHARACTERISTICS

Angle of Acceptance	18^{o} total
Calibration Factor	1.53 times UVHM reading
Continuous Battery Operating Time	1 to 2 hours
Inverse Square Law Relationship	Predicted value within 13-14% of UVHM value
Maximum UVHM Response	UVHM facing 14^{o} to left of UV source
Minimum Beam Diameter for Full UVHM Response	1.3 cm
Relative Spectral Response	Peak at 270 nm (Fast Response Setting)
Response Time for 100% Value	
Fast Setting	1.8 ± 0.2 seconds
Slow Setting	30 ± 2.0 seconds
Sensitivity Range (Full Scale)	3×10^{-7} to 3×10^{-5} W/cm^2
Warm-up Time	1 Minute
Data Output Jack for Connection to Recorder	Available and Functional
Ease of Operation	Extremely Easy
Portability	Easily Carried
Size	23 cm X 11.5 cm X 16.5 cm
Weight	3 Kgm
Zero Adjust Control	None

The results showed that the filtration did produce

VI. Survey of an Industrial Process

As a final evaluation of the UVHM operation parameters and characteristics, an industrial survey was conducted of a welding process at a valve manufacturer. The survey was conducted to determine the UVHM capability of providing reliable data that could be used in determining the potential ultraviolet hazard to the welders and to the nearby workers.

A. Survey Conditions

On 7 July 1977, a survey was conducted in the welding department of the valve manufacturer for ultraviolet energy using the UVHM. Two different arc welding units were surveyed in one section of the welding area: a Westinghouse D.C. Arc Welder and a Miller Arc Welder. A third arc welding process was surveyed in a different location from the first two welding units. All the welders wore long sleeve shirts with the sleeves buttoned and had on welding face shields. Welding screens/curtains were located around all the welding units to reduce exposures to adjacent personnel. There was no local mechanical exhaust ventilation provided to these surveyed units. At each of the units surveyed, the welder was the only person in the enclosed area. The welders maintained a 30 to 46 cm distance from their face shield to the welding arc. The workers actual exposure to the arc welding process varied depending upon the size of the items to be welded. The

taken at each location with the average reading being:
1) 30 cm = 1.44 x 10^{-6} W/cm^2, 2) 60 cm = 0.5 x 10^{-6} W/cm^2

welders stated that their total actual welding time ranged from 3 to 5 hours per day depending upon the sizes of the pieces to be welded and the production requirements for the pieces. On the day of the survey, the room temperature in the welding area was estimated to be higher than 85^{o} F, dry bulb.

B. Survey Results

The completed ultraviolet hazard worksheet used for the survey is in Appendix 5. The three units surveyed yielded the following arc irradiance data with the calibration factor having already been applied:

1. Westinghouse Argon Gas Arc Welder operated at 210 amperes and welding stellite on steel; the corrected reading at the survey distance of 254 cm was 1.7 x 10^{-5} W/cm^2.

2. Miller Arc Welder operated at 300 amperes and welding stellite on steel, the corrected reading at the survey distance of 188 cm was 4.4 x 10^{-5} W/cm^2.

3. Arc welder welding 7018 mild steel on steel, the corrected reading at the survey distance of 190 cm was 1.5 x 10^{-7} W/cm^2.

Applying the inverse square law, the welders estimated potential exposure at 30 cm was:

1. Westinghouse Arc Welder: 1.2 x 10^{-3} W/cm^2
2. Miller Arc Welder: 1.6 x 10^{-3} W/cm^2
3. 7018 Mild Steel Arc Welder: 6.0 x 10^{-6} W/cm^2

various distances from an ultraviolet source using the ISL.

C. Comparison of Results with NIOSH Criteria Document

Listed in Table I-2 of the NIOSH Criteria Document are the maximum permissible exposure times for selected values of effective irradiance levels. The table utilized an inverse relationship between exposure duration and effective irradiance. The maximum permissible time at any given effective irradiance can be calculated from the following equation:

$$T_2 = \left(\frac{I_{eff_1}}{I_{eff_2}}\right) (T_1) \qquad \text{Eq. 5}$$

where T_1 = Maximum permissible exposure time at I_{eff_1} (from Table I-2)[7]

I_{eff_1} = Effective irradiance at T_1

I_{eff_2} = Effective irradiance at T_2

T_2 = Maximum permissible exposure time allowable at I_{eff_2}

Using Eq. 5, the maximum permissible exposure time without adequate protection calculated to be:

1. Westinghouse Arc Welder operator: 2.5 seconds
2. Miller Arc Welder operator: 1.9 seconds
3. Welder operator using 7018 Mild Steel: 8.3 minutes.

source was moved to the right of the optical window. The
maximum reading occurred at an angle of only 8^o to the right

As can be seen, there was not a reasonable allowable time the welders could work without wearing proper eye and skin protection.

D. Discussion of Results

The results of the survey indicated that the welders definitely needed to use proper eye and skin protection. The welding curtains that were around all the welding units definitely were needed to provide adequate protection for personnel in surrounding areas.

The readings taken were probably understating the actual ultraviolet energy irradiance levels because the fumes generated during the welding process were not being removed by a ventilation system. These fumes were absorbing some of the ultraviolet energy produced which would yield the lower irradiance levels.

A limiting factor in the exposure pattern of the welders on the day of the survey was the high temperatures in the area. This high temperature coupled with the heat generated by the welding process seemed to limit the time that a welder would weld continuously to about 5 to 10 minutes. After this time, the welder would cease and take about a 5 to 10 minute break in a cooler environment.

E. Discussion of UVHM Handling and Use

The UVHM, being portable, was easy to handle during the survey. The location of the readout meter created the problem of a potential ultraviolet energy exposure to the operators eyes as the operator obtained the irradiance readings. To avoid this potential exposure, the UVHM was held high enough to block the source from the operators eyes while allowing the operator to read the meter. The UVHM was held at an angle with the front of the UVHM lower than the back so that the welding puddle was in full view of the optical window.

Having solved the problem of the potential exposure to the operators eyes, another problem developed. With the UVHM being held with both hands above shoulder height, the adjustment of the sensitivity selector became difficult. This problem was corrected by lowering the UVHM, making the adjustment while not looking at the welding arc, and raising the UVHM to obtain the reading as stated before. With the UVHM held high, the siting of the optical window toward the welding arc to obtain the maximum response was a little tricky but not impossible.

The UVHM has a mounting on the underneath of its casing that would enable it to be mounted on a tripod. If a tripod would have been available, the operator problems noted earlier may have been avoided. Another possible solution to the problems would have been to use a data recorder connected to the UVHM. This would have allowed minimal operator exposure while obtaining a permanent record of the data.

K. Response Reliability as a

Time

The operating time of the UVHM was noted to be

VII. Conclusion

Within the last decade, emphasis has been put on recommending standards that would attempt to control mans occupational exposure to ultraviolet energy. The standards proposed by NIOSH and the ACGIH were similar and were based on the effects of ultraviolet energy upon the skin and the eyes.

With the publishing of the recommended standard, a need for ultraviolet hazard evaluation instrumentation was created. NIOSH awarded a contract to CBS Laboratories to develop a prototype ultraviolet hazard monitor with permanent delivery being made in April 1973.

A study of the performance and physical characteristics of the UVHM was made to determine if this monitor would accomplish its designed objective. This objective being the instrument would measure the ultraviolet energy while yielding a value which would be biologically meaningful in relation to the NIOSH standard.

The UVHM basically incorporated the desired characteristics to make an assessment of the biological significance of the incident ultraviolet energy upon occupationally exposed workers. However, there were a few undesirable physical characteristics. These were the location of the controls, the problem with the cleaning of the optical window and a lack of a zero adjust control. One major performance problem was uncovered during this evaluation. This problem was that the entire optical system, or one of its lenses was askew. The skewed optics system required the UVHM to be positioned not directly facing the ultraviolet source. Recommendations were made to correct the optical system. If other such ultraviolet monitors were to be built, recommendations were made for certain physical characteristic changes.

After a laboratory evaluation of the characteristics was completed, survey procedures were developed for use with the UVHM. Along with these procedures, a survey worksheet was developed to aid in accomplishing a hazard evaluation of an ultraviolet energy source. This ultraviolet energy survey worksheet appears to be the first of its kind to aid in performing a hazard evaluation.

Finally, a hazard survey of an industrial welding process was accomplished to verify the laboratory evaluation findings. The UVHM responses indicated that the welders definitely needed adequate protective equipment and that the welding curtains around the welding processes were needed to protect workers in adjacent areas and passersby.

The UVHM, being a prototype monitor, responded as satisfactorily as could have been expected. Its response was basically as required by the NIOSH design guidelines. By knowing the limitations of the UVHM, the monitor was useful in determining the hazard to individuals occupationally exposed to ultraviolet energy. If an ultraviolet hazard monitor designed along the lines of UVHM would become commercially available, at a reasonable cost, a very important milestone would have been achieved in helping to control occupationally related ultraviolet energy exposures.

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APPENDIX I

CRITERIA FOR A RECOMMENDED STANDARD

OCCUPATIONAL EXPOSURE

TO

ULTRAVIOLET RADIATION

I. RECOMMENDATIONS FOR AN ULTRAVIOLET RADIATION STANDARD

The National Institute of Occupational Safety and Health (NIOSH) recommends that occupational exposure to ultraviolet energy in the workplace be controlled by compliance with the following sections. Ultraviolet radiation (ultraviolet energy) is defined as that portion of the electromagnetic spectrum described by wavelengths from 200 to 400 nm. Adherence to the recommended standards will, it is believed, prevent occupational injury from ultraviolet radiation, that is, will prevent adverse acute and chronic cutaneous and ocular changes precipitated or aggravated by occupational exposure to ultraviolet radiation.

Sufficient technology exists to prevent adverse effects on workers, but technology to measure ultraviolet energy for compliance with the recommended standard is not now adequate, so work practices are recommended for control of exposure in cases where sufficient measurement or emission data are not available.

These criteria and the recommended standard will be reviewed and revised when relevant information warrants.

SECTION I - EXPOSURE STANDARDS

(a) For the ultraviolet spectral region of 315 to 400 nm, total irradiance incident on unprotected skin or eyes, based on either measurement data or on output data, shall not exceed 1.0 mW/cm^2 for periods greater than 1000 seconds, and for exposure times of 1000 seconds or less the total radiant energy shall not exceed 1000 mW sec/cm^2 (1.0 J/cm^2).

(b) For the ultraviolet spectral region of 200 to 315 nm, total irradiance incident on unprotected skin or eyes, based on either measurement data or on output data, shall not exceed levels described below.

(1) If the ultraviolet energy is from a narrow-band or monochromatic source, permissible dose levels for a daily 8-hour period can be read directly from Figure I-1, or, for selected wavelengths, from Table I-1.

(2) If the ultraviolet energy is from a broad-band source, the effective irradiance (I_{eff}) relative to a 270 nm monochromatic source shall be calculated from the formula below. From I_{eff}, the permissible exposure time in seconds for unprotected skin or eyes shall be computed by dividing 0.003 J/cm^2, the permissible dose of 270 nm radiation, by I_{eff} in W/cm^2.

$$I_{eff} = \Sigma\, I_\lambda S_\lambda \Delta_\lambda$$

I_{eff} = effective irradiance relative to a monochromatic source at 270 nm.

I_λ = spectral irradiance in W/cm^2/nm

S = relative spectral effectiveness (unitless); see Table I-1 for values of S_λ at different wavelengths.

Δ_λ = bandwidth in nm.

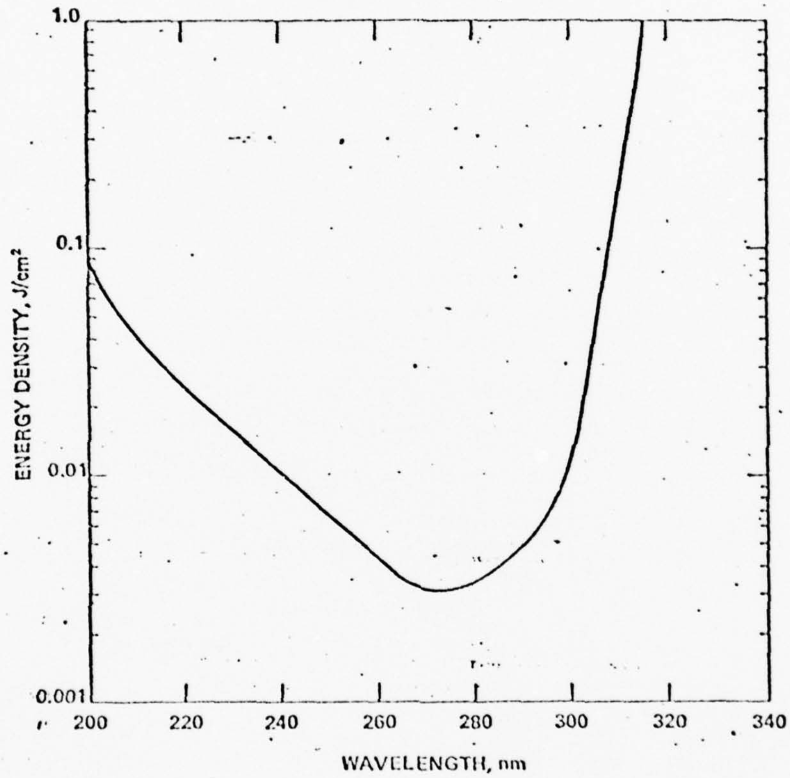

Figure I-1. Recommended Ultraviolet Radiation Exposure Standard
This figure was adapted from a figure developed and published by the American Conference of Governmental Industrial Hygienists in "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1972".

Table I-1

Total Permissible 8-Hour Doses and Relative Spectral Effectiveness of Some Selected Monochromatic Wavelengths

Wavelength (nm)	Permissible 8-Hour dose (mJ/cm^2)	Relative spectral effectiveness ($S\lambda$)
200	100.0	0.03
210	40.0	0.075
220	25.0	0.12
230	16.0	0.19
240	10.0	0.30
250	7.0	0.43
254	6.0	0.50
260	4.6	0.65
270	3.0	1.00
280	3.4	0.88
290	4.7	0.64
300	10.0	0.30
305	50.0	0.06
310	200.0	0.015
315	1000.0	0.003

This table was adapted from a table developed and published by the American Conference of Governmental Industrial Hygienists in "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1972."

Table I-2 lists permissible exposure times corresponding to selected values of I_{eff} in $\mu W/cm^2$.

If radiation intensity from a point source is knows at some distance from the worker, for example, from measurement at another point or from output data at a known distance from the ultraviolet source, attenuation of radiation decreases with the square of the distance it must travel. For example, an object 3 feet away from a radiation source receives 1/9 the energy of an object 1 foot away. This assumption is conservative in some instances, since ultraviolet radiation, especially at very low wavelengths, may be absorbed by some components of the atmosphere. Where information on atmospheric absorption of ultraviolet radiation is known, further correction may be applied. The calculation of intensity of radiation at any given point by use of the inverse square formula explained above does not take into consideration reflected energy.

The recommended standard is not proposed for application as a standard to lasers. It should be recognized that significant non-occupational exposure to ultraviolet radiation can occur from exposure to sunlight, particularly during the summer months.

Table I-2

Maximum Permissible Exposure Times
for Selected Values of I_{eff}

Duration of Exposure per day	Effective irradiance, I_{eff} ($\mu W/cm^2$
8 hrs.	0.1
4 hrs.	0.2
2 hrs.	0.4
1 hr..	0.8
30 min.	1.7
15 min.	3.3
10 min.	5.0
5 min.	10.0
1 min.	50.0
30 sec.	100.0

This table was adapted from a table developed and published by the American Conference of Governmental Hygienists in "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1972."

APPENDIX 2

DERIVATION OF EQUATION 3

The NBS calibrated photodiode was furnished with measurements of its Quantum Efficiency (Q.E.). The Q.E. was defined as the ratio of the number of electrons emitted to the number of incident quanta. The photodiode current was measured as a function of wavelength. From the current, the power of the incident radiant energy was derived as follows:

$$C = f\lambda \qquad \text{Eq. 1}$$

$$E = hf \qquad \text{Eq. 2}$$

By solving for f in Eq. 1 and substituting that value in Eq. 2, the following equation results:

$$E = h\frac{C}{\lambda} = \frac{\text{energy}}{\text{quantum}} \qquad \text{Eq. A}$$

The incident power (I.P.) would be: the number of quanta per second times the energy per quantum. The number of electrons emitted per second would be the number of incident quanta per second times the Q.E., or

$$\text{Q.E.} \times \frac{\text{No. Quanta}}{\text{second}} = \frac{\text{No. of electrons}}{\text{second}} = \frac{\text{current}}{\frac{\text{charge}}{\text{electron}}}$$

Therefore,

$$\text{I.P.} = \frac{\text{Quanta}}{\text{second}} \times \frac{\text{energy}}{\text{Quantum}} \qquad \text{Eq. B}$$

$$I.P. = \frac{\text{No. of electrons/second}}{Q.E.} \times \frac{hC}{\lambda} \qquad \text{Eq. C}$$

$$I.P. = \left(\frac{I}{Q_m}\right)\left(\frac{1}{Q.E.}\right)\left(\frac{hC}{\lambda}\right) \qquad \text{Eq. D}$$

where

I = current in amperes

h = Planck's Constant = 6.626×10^{-27} erg-seconds

$Q_m = 1.602 \times 10^{-19}$ coulomb

$C = 3 \times 10^{10}$ cm/second

Using the above values and simplifying:

$$I.P. = 1.24 \frac{I}{(\lambda)(Q.E.)} \qquad \text{Eq. 3}$$

APPENDIX 3

RELATIVE SPECTRAL RESPONSE DATA

WAVELENGTH(nm)	UVHM (FAST RESPONSE)	NORMALIZED PHOTODIODE	UVHM (SLOW RESPONSE)	NORMALIZED PHOTODIODE
220	1.00	0.77	1.70	0.62
230	2.10	1.52	1.89	1.23
240	2.55	2.52	2.45	2.03
245	3.48	3.11	3.10	2.48
250	4.65	3.74	4.14	2.99
255	6.55	4.63	5.47	3.69
260	7.17	5.93	6.28	4.74
265	7.86	7.47	7.62	6.01
270	8.65	8.65	7.00	7.00
275	7.15	7.91	6.14	6.44
280	6.76	6.89	5.19	5.50
285	5.75	5.79	4.56	4.73
290	4.85	4.67	3.44	3.85
295	3.95	3.46	2.90	2.83
300	3.05	2.11	2.20	1.73
305	1.85	0.41	2.10	0.34

All the data for the UVHM and the photodiode were in relative power units.

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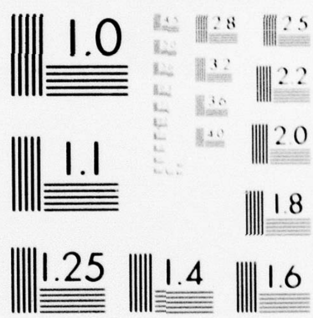


MICROCOPY RESOLUTION TEST CHART

APPENDIX 4

RECOMMENDED ULTRAVIOLET HAZARD SURVEY PROCEDURES

The following procedures were formulated to aid a surveyor in accomplishing a hazard evaluation of an ultraviolet energy source using a biologically weighted ultraviolet hazard monitor.

A. Prior to actual survey:

1. Using a NBS traceable calibration standard, calibrate the monitor and determine the calibration factor for the monitor.

2. Charge the batteries allowing sufficient time to obtain a full charge.

3. Insure availability of all necessary survey items, e.g., worksheets, extra paper, tape measure, pens, etc.

4. Check condition of suitable safety/protective equipment, e.g., coveralls and welding goggles/shields.

B. During the survey:

1. Turn on the monitor and allow sufficient warm-up time.

2. Check the zero reading by covering the optical window and either zero the monitor or record the zero reading value for future irradiance level corrections.

3. Wear suitable protective equipment.

4. Obtain irradiance readings at locations routinely occupied.

5. If using the UVHM with the optical system problem, position the UVHM at such an angle from the ultraviolet source as to obtain the maximum irradiance reading.

6. Periodically check the battery charge condition.

7. Complete the worksheet as thoroughly as possible so that a determination of the biological hazard of the ultraviolet source could be made.

8. After all irradiance levels have been taken, apply the calibration factor to obtain the corrected irradiance levels to be used in making the hazard evaluation.

APPENDIX 5

UV HAZARD EVALUATION

SURVEY WORKSHEET

COMPANY: ____________________ DATE: 7 July 1977

CITY: Cincinnati STATE: Ohio ZIP: 45214

DEPT.: Welding SECTION: ____________

PERSONNEL CONTACTED:

NAME:	POSITION:	PHONE:
Mr. Russ Clayton	Engineer	

DESCRIPTION OF OPERATIONS: The company manufacturers various types of valves for different industries, e.g., the chemical process industry.

DESCRIPTION OF AREA SURVEYED: Welding of different valve parts; two different locations where welding performed; high ceilings throughout.

DESCRIPTION OF SOURCE(S) OF ULTRAVIOLET ENERGY:

	SOURCE 1:	SOURCE 2:
POWER RATING:		
SPECTRAL RANGE:	Broadband	Broadband
MANUFACTURER:	Westinghouse	Miller
TIME IN OPERATION:	3 to 5 hrs/day	3 to 5 hrs/day
OTHER INFORMATION:		

WORKER EXPOSURE:

NO. WORKERS EXPOSED: one/unit DISTANCE TO SOURCE:

30 - 46 cm EXPOSURE TIME: 3 to 5 hours/day

NO. PERSONNEL IN ADJACENT AREAS: varies

DISTANCE FROM SOURCE: ____

POTENTIAL EXPOSURE TIME: 8 hours/day

WORKER PROTECTIVE EQUIPMENT:

EYE PROTECTION WORN: YES X NO ___ TYPE: Face shields with filters PROTECTIVE CREAMS USED: YES ___ NO X COVERALLS WORN: YES ___ NO X

OTHER PROTECTIVE EQUIPMENT: Long sleeve shirts worn by welders; welding screens around welding units

WARNING SIGNS POSTED: YES ___ NO X

INDIRECT ENVIRONMENTAL PROBLEM POTENTIALS:

GASES USED: Argon

SOLVENTS USED (TYPE AND QUANTITY): None

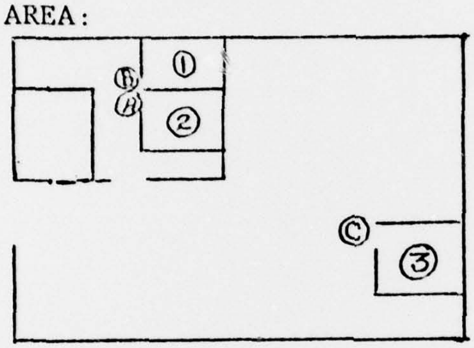
NOISE: Not checked

LIGHTING: Appeared adequate

FIRE/SAFETY PROBLEMS: ____

VENTILATION USED: General room; no mechanical local exhaust system.

SKETCH OF AREA:



1 - Miller Arc Welder

2 - Westinghouse Arc Welder

3 - 7018 Mildsteel Welder

SURVEY DATA:

LOCATION:	TIME:	READING: (W/cm^2)	COMMENTS:

See addendum for welding surveys

SURVEY EQUIPMENT: MANUFACTURER: CBS Laboratories

MODEL: UVALERT SERIAL NO:

CALIBRATION DATE: May 1977

SURVEYOR: RONALD L. SCHILLER

NAME (PRINT) SIGNATURE DATE

ADDENDUM FOR WELDING SURVEYS:

LOCATION:	TIME:	ELECTRODE TYPE:	AMPERES:	READING: (W/cm^2)
A (254 cm)	0910	Stellite	210	1.1×10^{-5}
B (188 cm)	0920	Stellite	300	2.9×10^{-5}
C (190 cm)	0927	7018 Mild Steel		1.0×10^{-7}

COMMENTS:

The welding area was quite warm; estimated dry bulb temperature higher than 85° F. Workers shorts were wet with perspiration. Welding process quite warm.