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Application and Measurement Of Ultraviolet Radiation

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Commercially available ultraviolet lamps are mostly mercury vapor lamps, either low-pressure or high-pressure. Low-pressure lamps are used extensively to destroy bacteria. High-pressure lamps are used more for lighting. The power, properties and effectiveness of each type are discussed with precautions for safe use. Methods of measuring the intensity of ultraviolet radiation are reviewed, but there is no simple, inexpensive meter available.

ULTRAVIOLET lamps are extensively used in hospitals, biological laboratories, schools, homes, and industry. Most of the commercially available ultraviolet lamps contain mercury vapor. The passage of current through the vapor results in excitation of the mercury atoms to various energy states. In making transitions from one state to another, the atoms emit radiation of definite wavelengths. The relative intensity of radiation in different spectral regions depends in part upon the pressure of the mercury vapor, the amount and type of other gases, and the electrical conditions in the discharge. These lamps vary in size, wattage, and the emitted spectrum. Many of the lamps have been designed for specific applications, for example, for photochemical reactions, for suntanning and vitamin D production, for bactericidal effect or for ozone production. An understanding by the industrial hygienist of the types of radiation emitted by various ultraviolet generators, their biological effects and methods of measurement would be useful in the proper application and supervision of these lamps.

Low-Pressure Mercury Vapor Lamps

At very low mercury vapor pressures (*e.g.*, 10 microns) most of the emitted radiation is the result of a transition from the excited state at 4.88 electron volts (ev) to the ground state. This is known as resonance radiation. In a low-pressure mercury vapor discharge over 85% of the radiation is emitted at 2537Å, Table I. The amount of 1849Å radiation produced is dependent upon the transmission of the lamp envelope. Most bactericidal lamps are made of glasses that transmit less than 2.0% of the generated 1849Å radiation. The so-called “cold quartz” lamps emit 50% to 90% of the 1849Å radiation depending upon the quality of the quartz.

Two types of low-pressure mercury lamps are manufactured, the hot cathode and the cold cathode type. In the former, a localized hot spot is produced by ion bombardment to supply the necessary electrons for the discharge. The lamps operate at low voltage, at high current, and with a low cathode drop. The electron emission from the cold cathode is supplied by an ion bombardment of a large metal surface. These lamps require high voltage, operate at

TABLE I
Relative Intensities of Wavelengths Emitted by Low-Pressure Mercury Discharge Lamp

Wave Length (angstroms)	Relative Energy
1849	5.0 (approximate)
1942	nil
2054	nil
2260	nil
2537	100.0
2652	0.14
2753	0.05
2893	0.07
2967	0.37
3022	0.17
3126-3132	1.43
3650-3663	1.30
3906-4077	1.60
4339-4358	3.40
5461	2.25
5770-5791	0.60

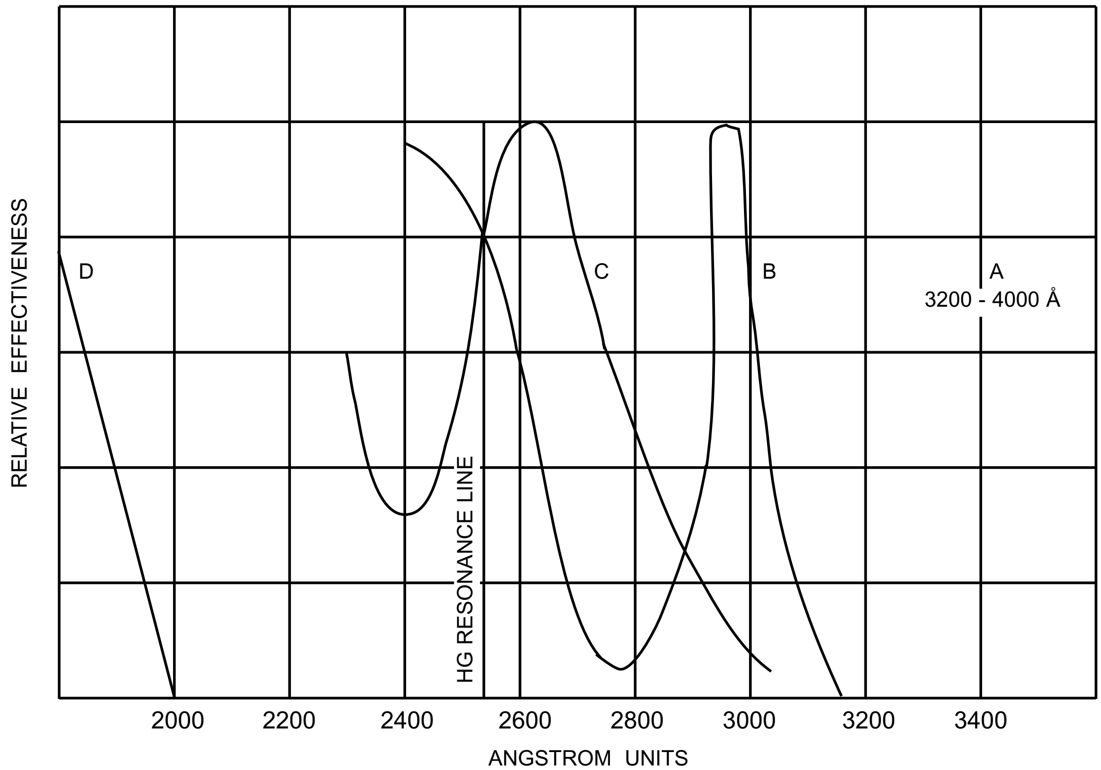

FIGURE 1. The relative effectiveness of various bands of radiation for: (A) "black-light" excitation, (B) erythemal response, (C) bactericidal effect, and (D) ozone generation.

low current, and have a high cathode drop. The spectrum from the two types of lamps is the same.

Applications of Low-pressure Mercury Lamps

Low-pressure mercury discharge lamps are used extensively to destroy air-borne and surface bacteria, viruses, yeasts and molds. Since about 90% of the ultraviolet energy from these lamps is radiated at the 2537Å line, which is near the peak of the maximum bactericidal activity, at 2650Å, Figure 1, these lamps are nearly ideal generators for this purpose. The amount of 2537Å energy necessary to destroy various bacteria, yeasts, and mold is shown in Table II. There are many sizes of these bactericidal lamps, Table III. The application generally dictates the type of lamps to be used.

Ultraviolet cold cathode lamps have been used in operating rooms for more than 25 years. Hart[1] placed the lamps on the ceiling to irradiate the entire operating area. The intensity of 2537Å radiation measured at the operating site was 20 to 24 microwatts/cm^2 while the intensity at the periphery of the room was 10 microwatts/cm^2 or more. Hart and Nicks[2] reported that post-operative infections could be reduced by 85% by this method.

Recently Hart and Nicks described the use of reflected ultraviolet radiation in the operating room. Ultraviolet lamps in aluminum reflectors were hung from the ceiling at a seven-foot level with all of the radiation directed toward the ceiling which was painted with aluminum paint. About 60% of the radiation is reflected from the ceiling, giving an even distribution of bactericidal energy throughout the entire room. Hart and others have for some time used portable high intensity ultraviolet units to disinfect the air and furnishings in rooms immediately after discharging a patient and before introducing a new patient into a room.

Indirect radiation has been used in many operating rooms, wards, schoolrooms, and offices. High intensity lamps enclosed in special fixtures are placed on the walls of the room about seven feet from the floor. The air in the upper portion of the room is exposed to an average intensity of 50 microwatts/cm^2 of 2537Å radiation. Based on the

TABLE II

Incident Energies at 2537A Radiation Necessary to Inhibit Colony Formation in 90% of the Organisms and for Complete Destruction

		Energy (Microwatt-sec/cm^2)	
Organism		**90%**	**100%**
Bacillus anthracia		4520	8700
S. enteritidis		4000	7600
B. Metatherium sp. (veg.)		1300	2500
B. megatherium sp. (spores)		2730	5200
B. paratyphosus		3200	6100
B. subtilis		5800	11000
B. subtilis spores		11600	22000
Corynebacterium diphtheriae		3370	6500
Eberthella typosa		2140	4100
Escherichilia coli		3000	6600
Micrococcus candidus		6050	12300
Micrococcus sphaeroides		10000	15400
Neisseria catarrhalis		4400	8500
Phtomonas tumeficiens		4400	8500
Proteus vulgaris		3000	6600
Pseudomonas aeruginosa		5500	10500
Pseudomonas fluorescens		3500	6600
S. typhimurium		8000	15200
Sarcina lutea		19700	26400
Seratia marcescens		2420	6160
Dysentery bacilli		2200	4200
Shigella paradysenteriae		1680	3400
Spirillum rubrum		4400	6160
Staphylococcus albus		1840	5720
Staphylococcus aureus		2600	6600
Streptococcus hemolyticus		2160	5500
Streptococcus lactis		6150	8800
Streptococcus viridians		2000	3800
Yeast			
Saccharomyces ellipsoideus		6000	13200
Saccharomyces sp.		8000	17600
Saccharomyces cerevisiae		6000	13200
Brewers' yeast		3300	6600
Bakers' yeast		3900	8800
Common yeast cake		6000	13200
Mold Spores	**Color**		
Penicillium roqueforti	Green	13000	26400
Penicillium expansum	Olive	13000	22000
Penicillium digitatum	Olive	44000	88000
Aspergillus glaucus	Bluish green	44000	88000
Aspergillus flavus	Yellowish green	60000	99000
Aspergillus niger	Black	132000	330000
Rhisopus nigricans	Black	111000	220000
Mucor racemosus A	White gray	17000	35200
Mucor racemosus B	White gray	17000	35200
Oöspora lactis	White	5000	11000

work of Wells[3] it has been shown that many of the organisms in the air enter the high intensity zone near the ceiling. Under optimum conditions, only about one-half of the air-borne organisms in the room are destroyed. Many of the modern hospitals have low ceilings so that only a small portion of the air would be exposed and the efficiency of killing the air-borne organisms by this method would be low. Riley and O'Grade[4] have been able to control the spread of *Mycobacterium Tuberculosis* organisms in one wing of a hospital by the use of indirect radiation plus curtains of direct radiation above the doors. McLeon[5] has shown that the incidence of Asian flu could be reduced among hospital patients by the use of indirect radiation. The decrease in the incidence of respiratory diseases of school children in irradiated rooms has been reported to be in the range of 15 to 50%.[3,4]

Bactericidal lamps are extensively used in industry. In some applications direct radiation of the entire work area has been found to be necessary to destroy the air-borne mold and bacteria. In other applications, the ultraviolet lamps are enclosed in hoods or ducts to protect the prod-

TABLE III
Bactericidal Ultraviolet Lamps

Desig.	Mfgr.	Rated Input (Watts)	Rated Life (Hours)	Total 253.7 mμ Ultraviolet output (Watts) at 100 hrs.	Intensity at 1 Meter 253.7 mμ U.V. microwatts/ sq. em at 106 hrs.	Arc Current (amps)	Useful Arc Length (inches)
G4T4	1,3	4	5000	0.5	7	0.08	6.0
G8T5	1,3,4	8	5000	1.3-1.5	14-17	.155-.160	8.5
G15T8	1,3,4	15	7500	3.6-3.7	38	0.30	14.0
G25T8	1	25	7500	5.0		.600	14.0
G30T8	1,3,4	30	7500	8.3-9.9	85	.340-.355	32.0
793	4	3.5	4000	.13	1.3	0.04	3.0
794	4	3.5	4000	.1	1.2	0.35	.375
794H	4	3.5	4000	.1	1.2	0.35	.375
OZ4S11	1	3.5	4000	.1	1.2	0.35	.375
G4-S11	3	3.5	4000	.1	1.2	0.35	.375
782H10	4	12	17500	2.0	20	0.060	10.0
		20	12000	2.8	28	0.090	10.0
782L20	4	14	17500	3.9	35	0.050	20.0
		17	17500	5.2	46	0.050	30.0
782L30	4	29	12000	8.3	73	0.090	30.0
782H30		17	17500	5.2	46	0.050	30.0
		29	12000	8.3	73	0.090	30.0
782VH29	4	17	17500	5.7	50	0.050	29.0
		29	12000	9.1	80	0.090	29.0
93A-1 (2851)	2	8	17500	1.9	21	0.030	11.5
84A-1 (2852)	2	14	17500	4.1	46	0.030	24.75
83A-1	2	22	17500	3.1	35	0.120	10.75
94A-1	2	32	17500	7.2	80	0.120	24.75
86A-45	2	8	17500	1.4	16	0.120	4.50
87A-45	2	22	17500	4.3	47	0.120	10.50
88A-45	2	32	17500	10.4	113	0.120	24.50
G10T5-1/2H	4	16	7500	5.3	55	0.400	10.00
G36T6	1,4	23-27	7500	8.7-11.4	90-100	0.200	29.25
		30-34	7500	10.6-13.1 (5)	110-115 (5)	0.300	29.25
G36T6H	4	36-39	7500	11.6-13.8 (5)	120 (5)	0.420	29.25
G37T6-VH	4	39	7500	15.2	132	0.420	30.25
G64T6	1	65	7500	18.0		0.425	64.00

1. General Electric; 2. Hanovia; 3. Sylvania; 4. Westinghouse; 5. In still air at 80^{o}F, output increased in cool or moving air.

uct from air-borne contamination or to disinfect the surface of the material. As an example, high intensity radiation is used in the tenderization and preservation of meat. The surface of most of the meat in such a room is exposed to 2537Å radiation to retard mold and bacterial growth. Those portions of the meat not exposed to direct radiation are protected from microbial growth by ozone. Special bactericidal lamps have been designed to emit a controlled amount of 1849Å radiation. This radiation dissociates oxygen in the air to produce ozone.

$$O_2 \xrightarrow{1849Å} 2\ O$$
$$2\ O_2 + 2\ O \longrightarrow 2\ O_3$$

Ozone is bactericidal at concentrations of 0.04 ppm providing the relative humidity is 60% to 90%. The number of lamps in such an installation is controlled so that the amount of ozone is well below 0.1 ppm.[6]

Pharmaceutical houses and biological laboratories use bactericidal lamps in a number of ways. In certain critical areas, the entire room is irradiated to prevent contamination of the product. Direct radiation is used to prevent the spread of pathogenic organisms from the laboratory to the office areas.[7] In other applications high intensity lamps are installed in work-hoods or over conveyors to protect the product from contamination.

Still another method is the irradiation of air in air-conditioning ducts. High intensity bactericidal lamps can readily destroy 90% to 99% of the air-borne pathogenic organisms passing by the lamps.[8] The amount of radiation necessary to destroy air-borne organisms in ducts is determined by the flow of air (cubic feet/minute), the length and width of the duct and the temperature of the air. Data in Figure 2 were obtained from actual tests in ducts using *E. coli* organisms. The chart is presented in a manner that simplifies the method of calculating the number of lamps necessary for various size installations. Correction for ultraviolet output of the lamp at various temperatures and air velocity is given in Figure

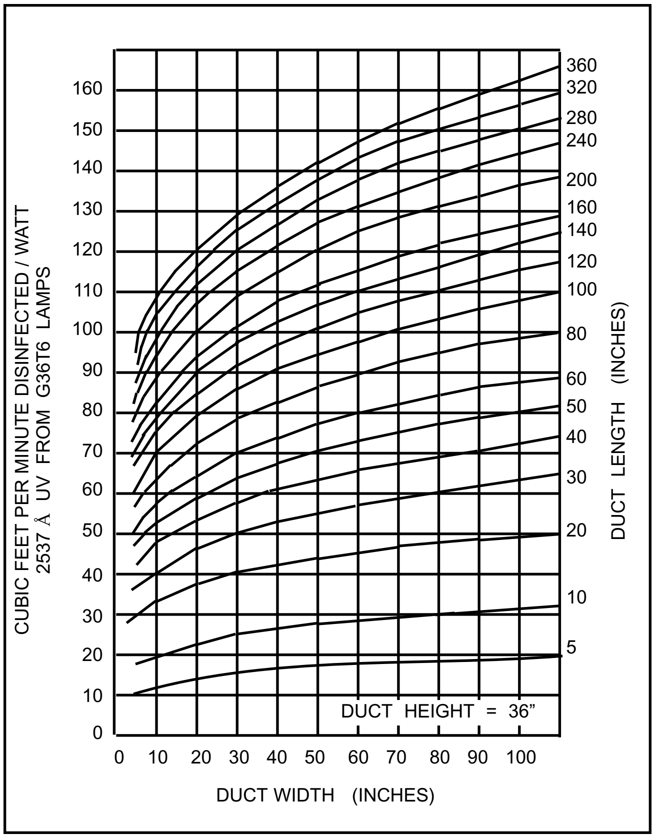

Figure 2. Quantity of air that can be disinfected by one watt of 2537Å radiation to 10% survival value assuming organisms have vulnerability similar to *E. coli*.

3. Tests have shown that to obtain smaller survival values, it is necessary to multiply the number of lamps for 90% disinfection by the following factors:

95 % kill 1.5
98 % kill 2.5
99 % kill 3.3

Most liquids, except water, are opaque to 2537Å radiation. Approximately 50% of the radiation is absorbed in 5 cm of water containing iron salts or organic matter. Nearly 85 cm of distilled water is required to absorb 50% of the bactericidal radiation. Under most conditions over 100 gal/hr of water can be made potable per watt of 2537Å radiation. Bactericidal radiation, 2537Å, does not impart a residual germicidal effect to water. However, if a lamp such as the G37T6 VH is used, most of the 1849Å radiation generated will be absorbed by the water resulting in the formation of hydrogen peroxide. Walker and Pryer[9] have shown that such irradiated water can destroy water-borne organisms.

Sugar syrup is used in the preparation of soft drinks, candies, ice cream, canned and baked products. Mold growth that sometimes develops on the surface of the sugar syrup is controlled by bactericidal lamps. Recently it was shown that yeast and thermophylic organisms can be destroyed by recirculating the sugar syrup through an ultraviolet water sertilizer.[10]

Precautions in the Use of Bactericidal Radiation

Bactericidal radiation will produce an erythema, Figure 1. Nearly twice the amount of 2537Å radiation is necessary to evoke an erythema on normal skin as is required for 2967Å, the radiation most active in the "suntan" region. However, the results are not the same. Even large doses of 2537Å radiation will not produce blistering or tanning of the skin. Nearly all of this short radiation is absorbed by the corneum with only a small amount of radiation penetrating to the Malpighian layer. Rusch, *et al.*[11] stated that no skin tumors can be produced by 2537Å radiation no matter how large the dose.

The protective clothing for the operating team or pharmaceutical personnel consists of long-sleeved gowns to protect the arms while a small cape sewed to the cap protects the back of the neck and the sides

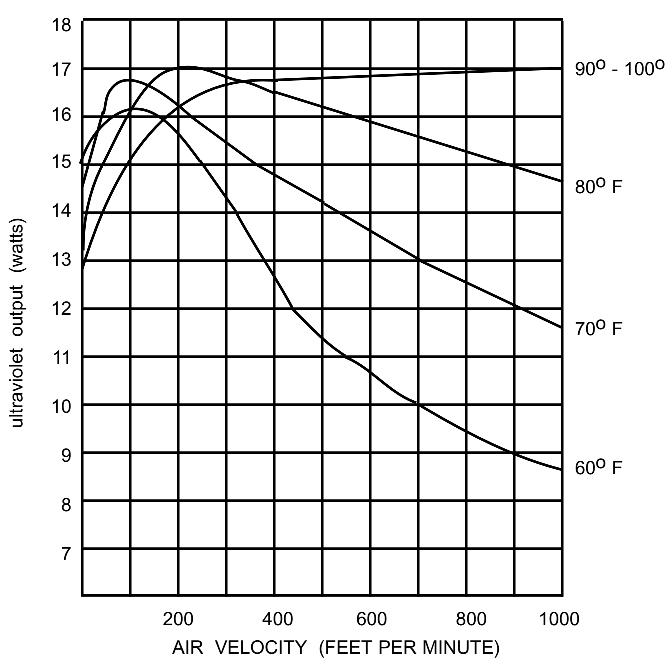

FIGURE 3. Correction factors for G36T6 Sterilamp Tube at 420 ma when employed in air ducts at various temperatures and rates of air flow.

of the face. Ordinary gowns absorb about 99% of the radiation. The eyes must be protected by an eyeshade. However, if an individual is working in the room for any length of time, he must wear glasses or a face shield because many materials reflect 2537Å radiation, Table IV. Regular types of glass or plastic face shields completely absorb 2537Å radiation.

The amount of 2537Å energy necessary to produce a threshold keratitis is only about one-tenth of that necessary to produce a minimal perceptible erythema.[12] All of the radiation is absorbed by the cornea and conjunctiva and does not penetrate to the lens. No permanent damage to the eye from this type of radiation has been reported. Hudnell[13] has used many times the threshold dose of 2537Å radiation in the treatment of corneal infections with success and without permanent damage to the cornea or other portions of the eye.

In the application of indirect bactericidal radiation for disinfection of air in school rooms, office, hospital wards, or laboratories, the American Medical Association[14] specified 0.5 microwatts/cm^2 as the maximum permissible ultraviolet intensity for 7-hour per day exposure and 0.1 microwatts/cm^2 for continuous exposure. This amount of energy would be far below the limit necessary to produce a perceptible erythema on an untanned normal skin.

TABLE IV
Reflectance of 2537Å Radiation From Various Surfaces

Material	% Reflectance*
Aluminum, etched	88
Aluminum foil	73
Chromium	45
Nickel	38
Stainless Steel	20-30
Silver	22
Tin-plated steel	28
White wall plaster	40-60
White paper	25
White cotton	30
White oil paints	5-10
White porcelain enamel	5
Glass	4
Water paints	10-30

*Values obtained at normal incidence. The percentage reflectance increases rapidly at angles greater than 75%.

TABLE V
Relative Spectral Energy Distribution of a Quartz High-Pressure Mercury Vapor Discharge Lamp

Wave Length (angstroms)	Relative Energy
6234	4.9
5700	88.5
5400	63.0
4960-4358	57.2
4045-3906	48.5
3660	100.0
3351	11.1
3130	68.7
3025	34.3
2967	14.2
2925-2893-2803	12.8
2752-2700	8.0
2652	24.0
2571	9.7
2537	25.6
2482-2400-2360-2300	24.0
1942-1849	6.2

High-Pressure Mercury Vapor Lamps

There are many types of high-pressure mercury lamps. Some operate at a fraction of an atmosphere of mercury vapor pressure, while others may operate at over a hundred atmospheres pressure. At the lower pressures, the characteristic mercury lines predominate. At higher pressures, the lines broaden and a continuous background radiation appears. In typical quartz lamps the amount of energy below 3800Å is approximately 30% to 50% greater than the visible energy radiated, depending upon the mercury pressure, Table V.

Application of High-pressure Mercury Lamps

The majority of the high-pressure mercury lamps manufactured are used for lighting applications. The mercury arcs are enclosed in a glass envelope that absorbs all radiation below 3100Å.

High-pressure mercury arcs enclosed in special filter glasses to transmit ultraviolet radiation between 3200Å and 4000Å are generally called "black-light" lamps. These lamps are useful in photochemical reactions, in identification of minerals, for observation of fluorescence of various substances and for identification and treatment of certain skin diseases.

High-pressure mercury arcs enclosed in an enve-

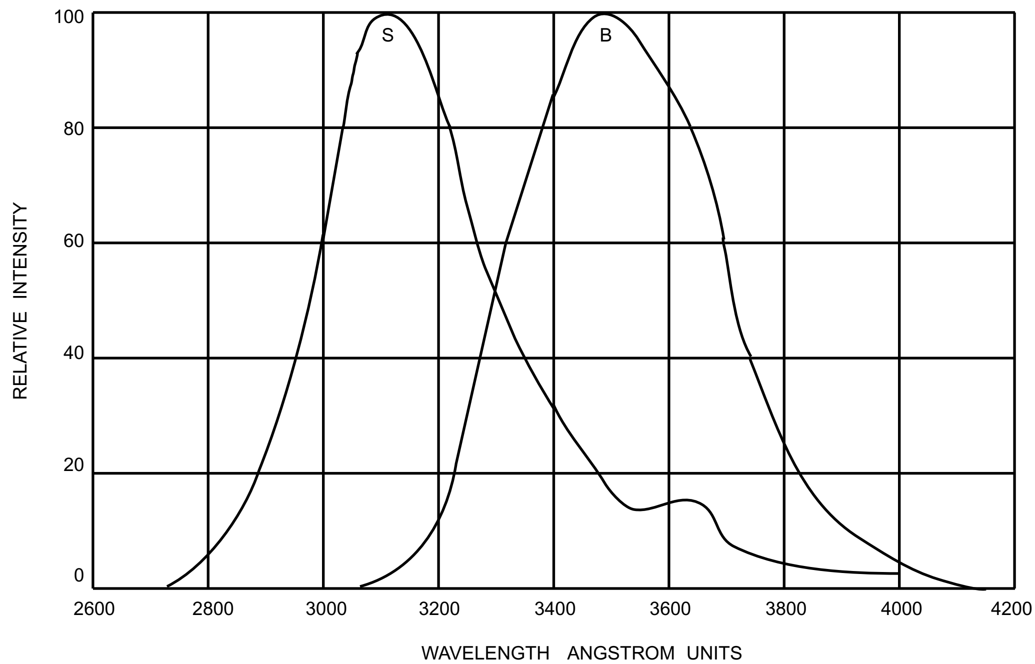

FIGURE 4. Spectral emission of fluorescent sunlamp (S) and "black-light" (B) ultraviolet lamps.

lope that absorbs all of the radiation below 2800Å are used as sunlamps for the production of tan and vitamin D in the skin. Nearly all of the therapeutic lamps are quartz envelope mercury vapor arcs having a spectrum as shown in Table V.

Fluorescent-Type Ultraviolet Generators

Two fluorescent-type ultraviolet lamps are used in medicine and industry, Figure 4. The fluorescent sunlamp is a low-pressure mercury vapor lamp with a special ultraviolet transmitting glass envelope. The glass is coated internally with a calcium zinc phosphate: T1 phosphor that has its emission between 2800Å to 3700Å with its peak at 3220Å. Such lamps have been extensively used in solaria. The fluorescent-type "black-light" lamp is a low-pressure mercury lamp in regular lime glass coated internally with a barium silicate: Pb phosphor that has its emission between 3200Å and 4000Å with its peak at 3500Å. Some of these lamps are made with special blue filter glass to remove visible radiation.

Precautions in the Use of High-pressure Mercury Lamps

Quartz mercury arcs such as used in therapeutic sunlamps or special photochemical reactions emit a large amount of both bactericidal and "suntan" ultraviolet radiation. The radiation between 2000Å and 2800Å would cause an erythema or conjunctivitis similar to the low-pressure mercury lamp. Large amounts of radiation between 2800Å and 3200Å can produce severe burns of the skin or eyes similar to an over-exposure to sunlight. Approximately 20,000 microwatt-seconds/cm^2 of radiation at 2967Å will produce a minimum perceptible erythema on an untanned normal skin. Ordinary window glass and safety glass will completely absorb the erythemal radiation. While nearly all plastics in the thickness generally employed in face shields will absorb the bactericidal radiation, some plastics transmit a sufficient amount of the erythemal radiation to cause conjunctivitis.

The large mercury arcs used in lighting are generally enclosed in glass receptacles and absorb all radiation below 3200Å. The large 400W and 1000W mercury arc lamps often used for lighting inside large factories could cause an erythema if the workmen were within one to two feet of a new lamp. The outer bulbs of these lamps solarize rather rapidly so that the amount of erythemal energy at normal working areas is nil.

Radiation between 3200Å and 4000Å does not cause injury to the eyes or skin. The sun is very rich in this band of radiation. Pathak, *et al.*[15] have shown that very large doses of radiation in this region produce pigmentation of the skin.

Measurement of Ultraviolet Radiation

Proper application of ultraviolet lamps in hospitals and industry requires knowledge of the intensity and ultraviolet output of the lamps. Over a period of years many methods of measurement have been suggested.[16] For example, various types of photoelectric cells, photoconductive cells, photo-voltaic cells, and photochemical reaction detectors have been used. Generally special filters and phosphors are employed to isolate that portion of the ultraviolet spectrum of interest to the investigator.

The intensity and total ultraviolet output of the bactericidal lamps in Table III were obtained by comparison with a standard lamp obtained from the Bureau of Standards. A convenient method of comparing lamps is with a 775 phototube, Figure 5, and a SM200 meter or an electrometer. Since about 90% of the ultraviolet energy from a bactericidal lamp is at 2537Å such a phototube is nearly ideal for measuring this radiation. The 767 phototube can be calibrated to measure "suntan" radiation while the 773 tube can be used to measure "black-light." The 789 phototube is conveniently used to compare the amount of radiation below 2000Å from different sources and thus to estimate the relative amount of ozone that would be generated by various lamps.

All bactericidal lamps become less efficient in the generation of ultraviolet radiation with use. This rate of deterioration is determined by the conditions of burning and type of glass envelope. Generally the lamps are replaced when the ultraviolet output has been reduced to about 70% of the 100-hour value. A field instrument called the SM600 ultraviolet meter has been developed to estimate the ultraviolet intensity of the lamp in an installation. This is a small light meter modified by means of a filter and phosphor to measure 2537Å radiation from bactericidal lamps. Each meter is calibrated for use with most types of bactericidal lamps. Measurements made with such a meter will give the approximate intensity of the base lamp at a distance of one meter. The actual intensity at any distance is determined by the type of reflector housing. A parabolic reflector would increase the base lamp intensity at a given distance by a factor of five. Simple inexpensive meters to measure the intensity of ultraviolet radiation for research and practical applications are not readily available.

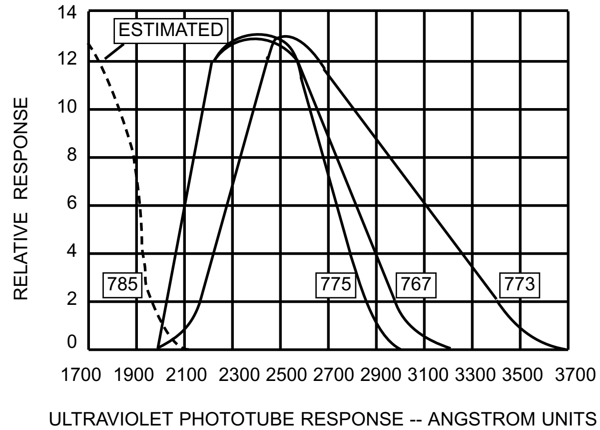

FIGURE 5. Response of various phototubes.

References

1. HART, DERYL: Bactericidal Ultraviolet Radiation in the Operating Room - Twenty-Nine-Year Study for Control of Infections. *J. Amer. Med. Assoc. 172*: 1019 (1960).
2. HART, DERYL, and JEAN NICKS: Ultraviolet Radiation in the Operating Room. *AMA Arch. Surg. 82*: 449 (1961).
3. WELLS, W. F.: *Air-borne Contagion and Air Hygiene.* The Harvard University Press, Cambridge, Mass. (1955).
4. RILEY, R. L.: *Air-borne Infection Transmission and Control*. The Macmillan Co., New York (1961).
5. MCLEAN, R. L.: The Effect of Ultraviolet Radiation upon the Transmission of Epidemic Influenza in Long-Term Hospital Patients. *Amer. Rev. Resp. Dis. 83*: 36 (Feb. Part 2) (1961).
6. NAGY, R.: Application of Ozone from Sterilamp in Control of Mold, Bacteria, and Odors. *Advances in Chemistry Series* No. 21, pp. 57-65, The American Chemical Society (1959).
7. PHILLIPS, G. B. and EVERETT HANEL, JR.: *Use of Ultraviolet Radiation in Microbiological Laboratories* PB147 043, Library of Congress, Photoduplication Services. Publication Board Project, Washington 25, D. C. (Nov. 1960).
8. NAGY, R., G. MOUROMSEFF, and F. H. RIXTON: Disinfecting Air with Sterilizing Lamps. *Heating, Piping, and Air Cond. 26*: 82 (1954).
9. WALKER, W.F., and R. W. PRYER: Bactericidal Action of Water Treated by Ultraviolet Rays. *Amer. J. Public Health, 11*: 703 (1921).
10. PACIFIC ULTRAVIOLET CO., Los Angeles, Calif.: Private communication.
11. RUSCH, H. P., B. E. KLINE, and C. A. BAUMANN: Carcinogenesis by Ultraviolet Rays with Reference to Wavelength and Energy. *Arch. Path. 31*: 135 (1941).
12. ROOKS, R.: Bactericidal Lamp Conjunctivitis. *J. Iowa Med. Soc. 35*: 141 (1945).
13. HUDNELL, A. B., and E.W. CHICK: Corneal Ultraviolet Phototherapy. *Arch. Ophthalmology 18*: 40 (1962).
14. AMERICAN MEDICAL ASSOCIATION, COUNCIL ON PHYSICAL MEDICINE: Acceptance of Ultraviolet Lamps for Disinfecting Purposes. *J. Amer. Med. Assoc. 137*: 1600 (1948).
15. PATHAK, M. A., F. J. RILEY, T. B. FITZPATRICK, and W. L. CURWEN: Melanin Formation in Human Skin Induced by Long-Wave Ultraviolet and Visible Light. *Nature 193*: 149 (1962).
16. NAGY, R.: Measurement of Ultraviolet Radiation, in *Encyclopedia of Instrumentation for Industrial Hygiene*, pp. 1115-1122, University of Michigan, Ann Arbor, Mich. (1956).