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Field Measurement of Ultraviolet, Infrared, and Microwave Energies

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⊗ The industrial hygienist has for some time been aware of the possible hazards which exist from the energies in the non-ionizing portion of the electromagnetic spectrum. Potential sources of these radiations and instrumentation available for field measurement are reviewed. The instruments by categorical types, their advantages, disadvantages, and specificity for various portions of the spectrum, as well as the interpretation of their responses are discussed. Field survey techniques for specific sources and/or energies are also presented. The needs are stated for continuing research on instrumentation with recommendations related to spectral response and reliability.

THE FAMILIAR REGIONS of the electromagnetic spectrum are radio, infrared, visible light, ultraviolet, x-rays and gamma rays. Although these various emissions have different properties, they are similar in nature, being energy propagated as an electromagnetic wave. The velocity of propagation is the same for all—approximately 184,000 miles per second. They differ only in wavelength and the amount of energy.

The wavelengths of known emissions range from approximately 150 kilometers (1,000 cycles per second) for long radio waves to 10^{-11} centimeters (3×10^{15} megacycles per second) for x-rays produced by a betatron generator. This paper will deal only with those portions of the spectrum referred to as microwave, infrared, and ultraviolet. The subjects of ionizing energy and illumination are beyond the scope of this paper.

The names which have been given to the various bands of electromagnetic spectrum refer primarily to the methods of generation and detection, rather than to a particular wavelength. For example, oscillation in an electrical circuit generates waves detectable by a radio receiver, whereas an incandescent body emits infrared waves which in turn can

be detected by a heat sensing instrument such as a bolometer.

There is no sharp division between the various types of emissions; however, through custom the spectrum has been divided into bands, the boundaries of which are purely arbitrary and ill defined. In this paper the following band widths are delineated: x-rays and gamma rays, 0.001Å to 50.0Å; ultraviolet, 50Å to 4000Å; visible light, 4000Å to 7500Å; infrared, 7500Å to 3×10^{10} Å; and microwaves, 3×10^7 Å to 3×10^{10} Å. Since the wavelengths expressed in Angstroms ($1 \text{Å} = 10^{-8} \text{cm}$) cover such a wide range, it is customary to use different units such as millimicrons and microns ($10^4 \text{Å} = 1 \mu = 10^{-4} \text{cm}$) for ultraviolet and infrared respectively and centimeters or meters for microwaves. (See Figure 1.)

Microwaves

The term microwave is generally considered to apply to those energies emitted from portions of the electromagnetic spectrum ranging from 10 to 100,000 megacycles (MC), or wavelengths from 0.3 to 3000 cm. This wide range of frequencies includes such uses as television channels (54 to 890 MC),

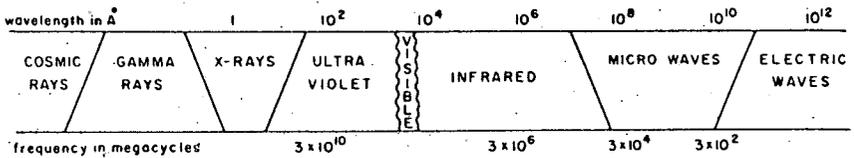


FIGURE 1. Electromagnetic spectrum.

FM broadcast bands (88 to 108 MC), and commercial and military radar which operate at distinct frequencies normally within the X (9000 to 9500 MC), S (2600 to 3200 MC) and L (1100 to 1400 MC) bands of radar. Sources of microwave energy are also utilized for the laminating of various material, and to produce heat in such medical applications as diathermy (27.12 and 40.68 MC) and microthermy (2450 MC). (See Figure 2.)

The amount of microwave energy absorbed in the body and transformed into some form of energy, usually heat, is dependent upon a number of factors, one of which is the frequency of the electromagnetic wave. At longer wavelengths (lower frequencies) the energy will penetrate the tissue to a greater depth than at shorter wavelengths.

The electromagnetic energy is thought to produce three primary responses. These are: (1) thermal effect; (2) the electrical and magnetic field effect; and (3) specific biologic effect.

The thermal effect is produced by the conversion of electrical energy of the electromagnetic wave into heat. This is the primary effect of concern; however, when the intensity of the electromagnetic energy generated is increased, not only is the amount of heat produced increased, but also there is the possibility that another biologic effect may occur. This is the electrical field effect. It is postulated that this electrical and, to a lesser degree, magnetic field effect is associated only incidentally with frequency. The field effect is considered to cause an enforced distribution of the electrical charge in the molecules of the tissues. This possible reorganization of the molecules would seem particularly possible in those having loose chemical bonds.¹ In addition, specific biologic effects have been reported, such as a

change in electrophoretic patterns, an increase in antiferretic activity, and the production of cataracts in the eyes of experimental animals.²

Field Measurement of Power Density

Early methods of field measurement included the explosion of photoflash bulbs by S band emissions at power densities which were calculated to be less than 2 milliwatts per square centimeter (mw/cm^2), and the ignition of steel wool at intensities approximately 10 to 15 mw/cm^2 . Small neon lamps are still utilized as a method of locating the primary lobe of the microwave field.

High power density measurements (greater than one watt) are normally obtained by using calorimetry to change the microwave energy into heat and then determining the relationship of the heat produced to the power density. Medium (1 w to 10 w) and low (less than 10 mw) power density measurements are usually made with a bolometer, which is a temperature resistive element for the determination of the amount of heat produced by absorption of the radio frequency power. In instruments of this type, the bolometer may be one arm of a Wheatstone bridge which in the absence of microwave energy is balanced by bias power. Bolometers are normally sensitive to change in the environmental temperature, and this sensitivity is usually the limiting factor for measuring minimum power levels with any degree of accuracy. The upper limit of measurable power densities can be extended by the use of attenuators.

In measuring the medium and low power densities, which include the range of most interest in industrial health, two basic types of bolometers are normally used as power density meters. These are:

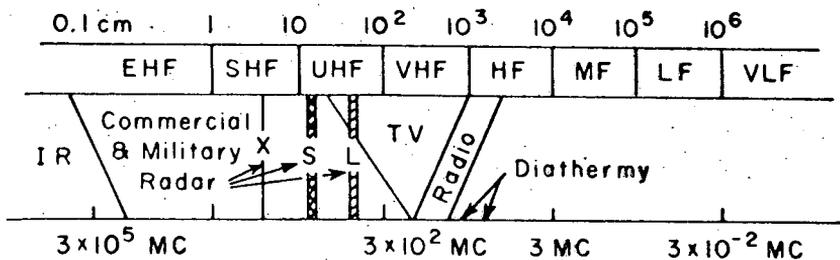


FIGURE 2. Microwave spectrum.

1. Barretters, which are made of a fine platinum wire with a positive temperature coefficient of resistance, the resistance of which can be impedance matched at the end of a transmission line. These detectors are usually delicate and burn out quickly in fields of excessive power densities.
2. Thermistors, which consist of a small bead of semiconducting material fused between two fine parallel wires. The primary resistance of a thermistor is in the bead, which has a negative temperature coefficient of resistance. The thermistor is usually mounted at the termination of the transmission line. These devices are usually more sensitive, and less delicate than barretters. In addition they are less susceptible to damage by high power density levels and, as a result, they are usually superior components for field instruments.

Thermistors or barretters are used with a calibrated antenna or feed horn to measure the radio frequency energy. The choice of antenna depends upon the frequency of the microwave energy to be measured. These antennae or probes are normally designed for a fixed narrow range of frequencies, but some may be tuned or adjusted for pick up of a very narrow selective band over a variable wider range of frequencies.

Instruments are available with antennae covering the frequency range of 200 to 10,000 MC, although some probes extend beyond this range. In some cases the antennae will have slightly overlapping ranges, to assure complete coverage of the desired frequencies.

Where there is the possibility of multi-frequency exposure, however, such as may be found at radar installations, the range of any one antenna will be so narrow as to preclude the possibility of measuring multiple power densities at one time. This may also be true if harmonics of the basic frequency were generated. In addition the antennae are highly directional and the absolute gain of the receiving probes may be changed drastically by the positioning of the antennae in relation to the field.

Most industrial health organizations will not have a microwave source of the appropriate frequency and intensity for calibration of power density meters, and this normally will necessitate return of the densitometer to the manufacturer for periodic calibration.

Most commercially available instruments are designed for an accuracy of ± 1 dB. At certain discrete frequencies however, the accuracy of some meters in the range of (0.1 mw/cm² to 2 w/cm²) has not been as good as expected. Thus, the antenna response varied from 1/3 to 4 times the calibrated field intensity. Drastic changes in environmental temperatures and/or air movement may affect the balance of the Wheatstone bridge requiring the instrument to be adjusted for these variations. Cable extensions to the antenna are available for commercial power density meters and usually it is not necessary to employ a correction factor. In fields of high microwave intensity there is a possibility that the field strength could affect measurement and it is assumed that these effects would not be linear.

The effectiveness of shielding power den-

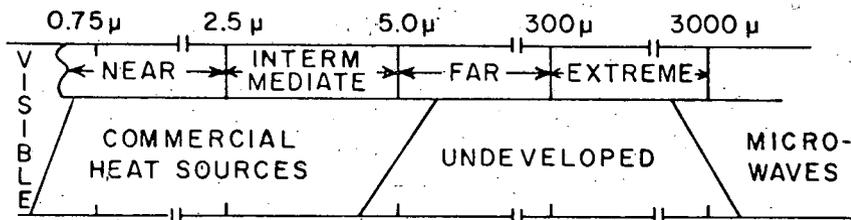


FIGURE 3. Infrared spectrum.

sity meters and their components in high intensity fields should be investigated. The development of a field source for use in the calibration of the power density meters by the industrial hygienist is of primary importance and until such a source is available the validity of microwave field measurement will be questionable.

Instrumentation must be developed that is not directionally dependent, is not affected by reasonable climatic changes, and is sensitive in all frequency ranges. A simple and reliable method for field calibration must also be developed and research must be continued to establish more definite parameters for a maximal safe exposure limit.^{3,4,5}

Infrared

As previously indicated, the infrared region falls between the visible red light (0.75μ) and the long wavelength (3000μ) of microwave generation. The infrared spectrum is usually divided into three bands: (1) near (0.75μ to 2.5μ), (2) intermediate (2.5μ to 5.0μ), and (3) far (5.0μ to $3,000\mu$). This division is arbitrarily based on instrumental methods or appropriate molecular motion.

Any object above 0°K is a potential emitter of infrared energy; however, the usual sources are hot or incandescent bodies which produce a continuous broad spectrum of infrared.

Exposures to infrared can occur in almost all industries. They need not be from an incandescent body, but could be from any surface which is hotter than the surrounding atmosphere. For example, heat absorbent glass exposed to solar radiation in turn re-emits infrared at a longer wavelength. The

more common industrial exposures are found in hot metal operations, glass making, photo-engraving, paint and enamel drying, and welding operations. The number of potential sources is increasing every day with our advancing technology (Figure 3).

Water vapor and carbon dioxide in the atmosphere strongly attenuates infrared energy between the wavelengths 4μ to 8μ and 14μ to 600μ . In the spectral region of 4.8μ to 5μ , where most commercial infrared sources operate, there are only irregular shaped peaks of absorption due to the atmosphere.^{6,7}

From the standpoint of biological effects the quantum energy in the infrared spectrum is sufficient to induce an increase in molecular and intramolecular motion which is recognized as heat. This energy penetrates tissue to a depth of about 3 mm at 1.2μ ; however, this penetration decreases rapidly with increase of wavelength because of moisture on the skin.⁸ The correlation of the depth of penetration of infrared energy with ocular effects is still a subject under considerable discussion. Since the eye media absorption characteristics are very similar to that of water, it would seem to indicate that the eyes have a greater absorption factor than skin.⁹ This consideration and inability of the eyes to dissipate heat and the focusing nature of the lens make the eye the organ of major concern.

Field Measurement of Infrared

Detectors for infrared operate on two basic mechanisms—photo-electric and thermal. A third possibility, resonant detectors which could be tuned to infrared frequen-

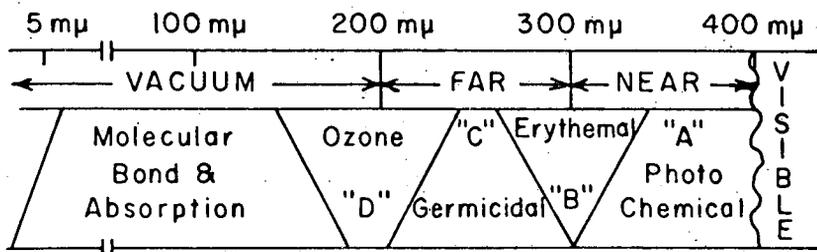


FIGURE 4. Ultraviolet spectrum.

ci's, has not advanced beyond experimental possibilities.

The photoelectric or quantum detectors which convert a given quantity of energy, above a minimum level, into a proportionate signal or reaction are useful in the near and intermediate bands. Specially sensitized photographic emulsions, photoemissive or photoconductive cells, and Geiger tubes are examples of quantum detectors. The response of such devices varies considerably with frequency and is limited to a maximum wavelength of about 5μ . The ability of such instruments to detect the visible portions of the spectrum may cause erroneous results.

In a large portion of the infrared spectrum the usable detectors are generally thermal or heat engines. These devices convert the energy into heat and use the thermal energy to operate a device that produces a signal proportional to the radiant energy received. Their response is the same to all kinds of radiation energy provided the emissions are converted into heat in the detector. Examples of thermal detectors are thermopiles and thermocouples, which produce an emf when heated; bolometers, whose electrical resistance changes upon heating; and pneumatic radiometers (Golay cells) in which mechanical motion is produced by increased pressure of a gas sealed in a diaphragm. Thermal detectors have a lower limit of sensitivity of the order of 10^{-10} watts when operating at ambient air temperatures and are completely insensitive to frequency changes.^{10,11}

Unfortunately, there are no commercially available field instruments which are specifically designed to quantitate infrared with

respect to frequency or specific frequency bands in the areas of concern to the industrial hygienist. Some investigators have been able to develop "ball park" figures by using black body readings, angular exposure and emissivity; however, these are applicable only to specific sources.

There is a definite need today for a critical evaluation of the criteria for maximum permissible levels and possible research into infrared absorption with respect to wavelength, affected organ, exposure time and dose. The development of instruments which would provide both the spectrum and quantity of infrared energy may have to be developed before sufficient information is available to establish more definite criteria.

Ultraviolet

As with the two previously discussed regions of the electromagnetic spectrum, ultraviolet energy has been arbitrarily divided by physicists into three bands—the near, 400 $m\mu$ to 300 $m\mu$, the far 300 $m\mu$ to 200 $m\mu$, and the extreme or vacuum 200 $m\mu$ to 5 meters.¹² However, from an occupational health viewpoint, the bands based on action spectrum are more convenient. "Black light" or the "A" band (Figure 4) is nearest to and slightly overlaps the visible portion of the spectrum with emission between 400 $m\mu$ and 300 $m\mu$. Most of the solar ultraviolet radiation reaching the earth's surface falls within this band.¹³ These wavelengths generally are not considered to be biologically active except in the production of rapid skin pigmentation and photo-reactions. The next band ("B"), between 320 $m\mu$ and 280 $m\mu$, is referred to as the erythema region with 295 $m\mu$ to 298 $m\mu$

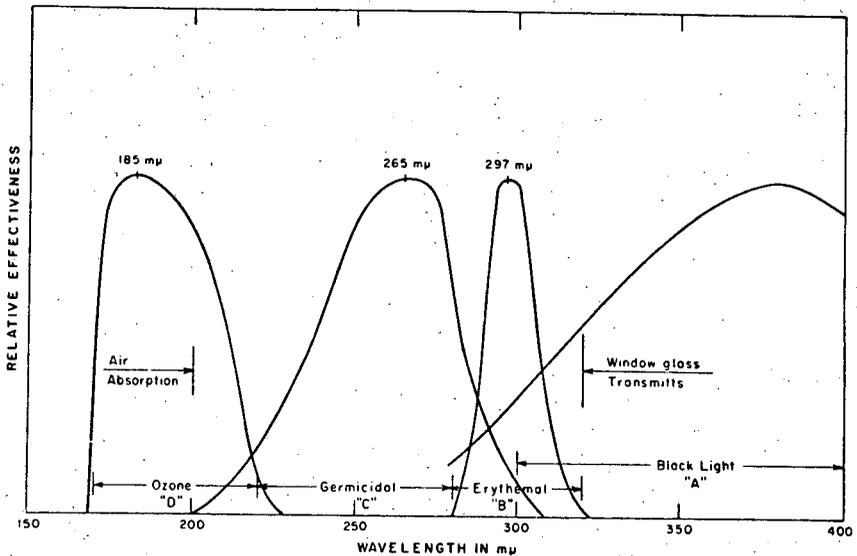


FIGURE 5. Ultraviolet action spectrum.

being the wavelength of maximal effect.^{14,15} Slightly overlapping these wavelengths is the germicidal band ("C"), between 280 $m\mu$ and 220 $m\mu$.¹⁶ The maximum germicidal effectiveness wavelength is 265 $m\mu$, with some erythemat effect noted between 250 $m\mu$ and 260 $m\mu$.¹⁷ The next band ("D"), between 220 $m\mu$ and 170 $m\mu$, is generally referred to as the ozone region. This is the most efficient wavelength range for the production of atomic oxygen which in turn combines with oxygen in the air to produce ozone.¹⁸ The absorption coefficient of ultraviolet by oxygen in the air, for wavelengths below 200 $m\mu$, becomes very large, therefore emissions in this region have little biological significance except as it relates to the production of toxic ozone. (See Figure 5.)

The sources of ultraviolet are of two classes—natural and artificial—there being only one natural source of any importance, the sun, which has a lower limit around 290 $m\mu$. There are a number of artificial sources of ultraviolet which can occur in a wide variety of forms and utilization. A few of the more common applications are: illumination; phosphorescent dial illumination; ad-

vertising; crime detection; laboratory and industrial chemical synthesis and analysis; product or process inspection; photoengraving; food, water, and air sterilization (this is the germicidal effect); vitamin production; medical diagnosis; and therapeutic treatment. Any radiating black body at a temperature of 1000°C or greater will give most of its electromagnetic emissions in the ultraviolet wavelengths.

New sources are being developed with surprising rapidity such as: coherent energy, fluorescent panels, and industrial and commercial illumination sources.

Some of the industrial processes in which ultraviolet is a by-product are: welding, particularly inert gas metal-arc welding; plasma torch operations; electronic tubes with sponge metal cathodes; photoelectric scanning; glass blowing; and hot metal operations.

The absorption by air of ultraviolet of wavelengths greater than 200 $m\mu$ is insignificant for distances up to several hundred meters. Below 200 $m\mu$ the absorption becomes very large, chiefly because of the presence of oxygen. The presence of foreign

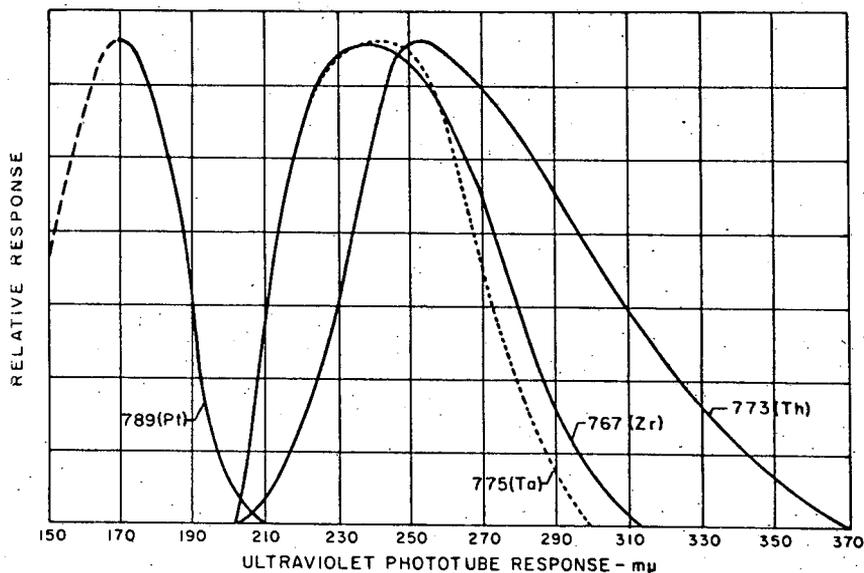


FIGURE 6. Response of various phototubes.

agents in the air, such as lint, oil droplets and organic vapors greatly reduces the transmission of ultraviolet.^{19,20}

Many substances which are good reflectors for visible energy are very poor reflectors of ultraviolet. Most metals are good reflectors of ultraviolet over a large portion of the spectrum provided that the surfaces are clean and free of heavy surface films such as oxides and tarnish. In general, the reflection coefficient for a given material increases with increasing wavelength.

Ultraviolet Measurement

There are available three major classes of detecting instruments for ultraviolet energy—physical, chemical, and biological. Only the physical detectors will be discussed since the other classes have only historic or research interest. Most of the physical meters depend upon photosensitive elements to convert electromagnetic emissions into electrical energy for readout display.

The thermopile is the primary standard for the evaluation of ultraviolet energy since it has a flat response to all wavelengths. Special precautions, filters and other elaborate

devices are required in the use of this apparatus.¹⁹ Therefore, its use is limited to the laboratory.

The simplest of detection and measurement devices is the barrier layer or photovoltaic cell, which is insensitive at low levels and which has a limited spectral response. The more reliable and sensitive instruments for routine use are the vacuum phototube type. Where extremely low levels of ultraviolet energy are involved, the photomultiplier tube types are utilized.

All the ultraviolet measuring devices except the thermopile are wavelength selective. Generally, special filters and phosphors are required to isolate that portion of the ultraviolet spectrum of interest to the investigator. The type of ultraviolet meter for any particular measurement is dependent upon the wavelength of energy to be measured, the intensity and nature of the source, and the accuracy of measurement required. In addition, it is necessary that the phototube or cell be calibrated for the specific frequencies of emission.

Detailed information as to the spectral response and operational limitations of com-

mercial ultraviolet meters is available in the literature.^{20,21,22} Unfortunately, there is no standard unit or source of ultraviolet emissions; however, it is a general practice to compare the output of similar spectral generators by measuring the energy in microwatts per square centimeter for one second at one meter from the source. In order to avoid gross errors in a field survey, the following items should be considered:

1. Spectral response of the phosphors and phototubes used in commercial instruments. The meter or phototube selected should be one which has its sensitivity range most nearly covering that part of the ultraviolet spectrum to be measured or generated. Typical response curves of phototubes are indicated in Figure 6.
2. Solarization and aging of lenses, tube envelopes and cells. This can only be determined by calibration with a source of known wavelengths and intensities.
3. Water vapor in the atmosphere will absorb the ultraviolet and adversely affect the electronic circuits of instruments.
4. Directionality of meters.
5. Reflection of ultraviolet from nearby sources or high intensity visible light can affect the meters. These factors can completely nullify the value of any survey.

There is a definite need for re-evaluation of the limited field instrumentation available for measuring ultraviolet. Consideration should be given to the development of devices which either would have a flat frequency response with a spectral as well as quantum readout, or would follow the contour lines of the maximum peak effects of erythral, conjunctival, keratitic, and carcinogenic effect. The available criteria on maximum permissible levels, which have been satisfactory for

our crude instrumentation, would definitely require re-analysis with more sophisticated detection devices. It is very likely that these values will have to be modified if and when better instruments are available.

References

1. BOYSEN, J. E.: Microwave Radiation, *Proceedings of Sanitary and Industrial Hygiene Engineering Symposium*, A.S.T.I.A. No. AD-287799, 65 (Oct. 1961).
2. BACH, S. A.: Biological Sensitivity to Radio Frequency and Microwave Energy, *Federation Proceedings*, 24 Supplement No. 14, No. 1, Part III S-22 (Jan.-Feb. 1965).
3. U. S. AIR FORCE: The Threshold Limit Value for Toxic Chemicals and Certain Electromagnetic Radiation, AFP 161-2-1 USAF Surgeon General, Washington, D.C. (April 1964).
4. U. S. AIR FORCE: Health Hazards Information on Microwave Radiation, AFP 160-6-13 USAF Surgeon General, Washington, D.C. (May 1958).
5. WEISS, M. M., and W. W. MUMFORD: Microwave Radiation Hazards, *Health Physics* 5: 160 (June 1961).
6. HOWARD, J. N.: The Transmission of the Atmosphere in the Infrared, *Proc. IRE* 47: 1451 (1959).
7. GENSBAK ELECTRIC CO.: *Data and Applications, Industrial Infrared Lamps*, Lamp Division, Application Engineering Dept., General Electric Co., LS-128 Cleveland, Ohio (Dec. 1951).
8. HARDY, J. L., and C. MUSCHONHEIM: Radiation of Heat from the Human Body, *J. Chi. Invest.* 3: 1 (1936).
9. FRIEDMAN, J.: Penetration of Corneal Opacities by Infrared, *Med. Electronics, ME* 7: 182 (July 1960).
10. DEWASNE, R., and E. M. WORMSER: Infrared Physics and Technology, *Proc. IRE*, 47 (9): 1503 (1959).
11. SMITH, R. A., F. E. JONES, and R. P. CHASNEY: *The Detection and Measurement of Infrared Radiation*, Swets & Zeitlinger, Amsterdam (1957).
12. KOLLER, LEWIS R.: *Ultraviolet Radiation*, John Wiley and Sons, Inc., New York (1932).
13. BLUM, H. F.: Photobiological Research with Particular Reference to Skin, *J.A.M.A.* 173: 1353 (July 1960).
14. ROVKS, R.: Bactericidal Lamp Conjunctivities, *J.A.M.A.* 35: 141 (1945).
15. HOLLANDER, A. (Editor): *Radiation Biology*, McGraw-Hill, New York (1955).
16. AMA COUNCIL ON PHYSICAL THERAPY: Acceptance of Ultraviolet Lamps for Disinfecting Purposes, *J.A.M.A.* 122: 503 (June 1943).
17. LUCKESH, M., and A. H. TAYLOR: Production of Erythema and Tan by Ultraviolet Energy, *J.A.M.A.* 112: 2511 (June 1939).
18. KOLLER, L. R.: Production and Decomposition of Ozone by Low-Pressure Mercury-Vapor Lamp, *J. Applied Phys.* 16: 816 (1945).
19. COLENTZ, W.-W., and R.-STAIR: A Standard Source of Ultraviolet Radiation for Calibrating Photoelectric Dosage Intensity Meters, *J. Research, NBS* 16: 83 (1936).
20. NAGY, R.: Measurement of Ultraviolet Radiation in *Encyclopedia of Instrumentation for Industrial Hygiene*, Publication Distribution Service, Univ. of Michigan (1956).
21. NAGY, R.: Application and Measurement of Ultraviolet Radiation, *Amer. I.N.A.J.* 274 (May-June 1943).
22. TAYLOR, A. H., and H. HAYNES: New Meters for Germicidal Energy, *General Electric Review*, 30: 27 (Oct. 1947).

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