VIII APPENDIX I

MEASUREMENT OF ULTRAVIOLET ENERGY

The ultraviolet portion of the electromagnetic spectrum has been basically divided into several bands. While these bands were arbitrarily determined by physicists and are not directly related to the biological action spectrum of ultraviolet radiation, they are important for two primary reasons: (1) The development of artificial sources of ultraviolet energy to accomplish specific tasks, and (2) the availability of measuring devices to cover these specific areas of the ultraviolet spectrum.

The band between 320 to 280 nm is referred to as the erythemal region with 295 to 298 nm being the wavelengths of maximal effect. This area is also the one which has been identified as having a carcinogenic effect upon the skin.

Slightly overlapping these wavelengths is a germicidal band between 280 and 220 nm with a maximum germicidal effective wavelength at 265 nm with some erythemal effect noted between 250 and 260 nm.

The last band is between 220 and 170 nm and is only partially covered by the recommended environmental limit suggested in this criteria document. This is generally known as the ozone region and includes wavelengths that result in the most effective production of atomic oxygen. The absorption coefficient of ultraviolet by oxygen for wavelengths below 200 nm becomes very large; and therefore, emissions in this region have little biological significance except as related to the production of ozone.

There are several major classes of instruments for the detection of ultraviolet energy: physical, chemical, and biological. Concerning this recommended standard, only the physical methods of measurement are considered. These depend upon photosensitive elements to convert electromagnetic emissions into electrical energy.

The simplest of detection or measurement devices is the barrier layer, a photovoltaic cell which is normally insensitive at lower levels of ultraviolet energy and is sensitive to a limited or a narrow band of ultraviolet energy.

Some instruments which have been considered more reliable and sensitive for routine industrial hygiene use have relied upon vacuum phototubes and where extremely low levels of energy were to be measured have utilized photomultiplier tubes to develop the sensitivity required. Most commercially available ultraviolet measuring devices, with the exception of the thermopile, are wavelength selective. Special filters or phosphors are required to isolate the portion of the ultraviolet spectrum where specific emissions occur with any given exposure or industrial process. This results in two basic types of measurement that are necessary in determining potential exposure to hazardous levels of ultraviolet energy. In many industrial operations, such as in welding, the ultraviolet emissions are across the entire band of ultraviolet energy and into other portions of the spectrum as well. These types of exposures require measuring devices that will integrate the intensity of the ultraviolet energy over the frequency range covered by the standard. Secondly, exposures from artificial sources that give specific emissions in limited wavelengths may require filters that can measure only in those specific wavelengths.

As a consequence of the variety of conditions of measurement required to assess the hazard from ultraviolet energy and the limited availability of ultraviolet measuring devices, care must be taken in the selection of the available instrumentation or in the calculation of the energy output of the specific source being considered.

In order to avoid errors of major magnitude in assessing ultraviolet energy, the following must be given serious consideration:

1. The spectral output of the specific source being evaluated and the spectral response of the phosphor or phototube that is being utilized in measurement of ultraviolet energy. The selection of a meter or phototube should be one that is sensitive in the range most nearly covering that part of the spectrum under consideration. Response curves of various phototubes are shown in Figure X-9.

2. Solarization and aging of lenses, tube envelopes, or cells. This can be accomplished only by calibration against a source of known wavelengths and intensity.

3. Water vapor in the atmosphere may cause absorption of ultraviolet energy as well as affecting the electronic circuitry.

4. The directionality of the meters. This is specifically true with the use of phototubes.

5. The reflection of ultraviolet from nearby surfaces or from high intensity visible light can affect most of the phototubes and

cells that are presently used for measurement of ultraviolet energy. These factors are of particular importance when measuring an intense wide-band source of ultraviolet energy.

There are several sources of commercial measuring devices available. These devices are primarily designed to measure output from specific sources. They are not in frequency ranges that can be satisfactorily utilized for purposes of evaluating exposures from wide-band sources. An attempt to use these measuring devices with specific phototubes or phosphors can be extremely hazardous and give erroneous results when attempts are made to utilize them for wide-band ultraviolet energy.

Most of the devices are marketed as being sensitive at a specific wavelength. However, it should be pointed out that the ultraviolet response may be much wider than the one wavelength indicated; and the relative spectral response of each filter or phototube must be known to reasonably assess the exposure to ultraviolet energy. Examples of spectral response of several phototubes and filters are included in Figures X-9, X-10 and X-11.

An ultraviolet device to measure broad-band ultraviolet energy is not presently available. However, it is possible to construct through a series of filters and phototubes a reasonable assessment of the levels of ultraviolet energy to which a worker may be exposed.

Narrow-band interference filters are commercially available for 254 nm, 280 nm, 297 nm, and 313 nm. When the emitted ultraviolet radiation is known to be at one of these wavelengths, single interference filters can be used for evaluating the hazard. Filters with peak spectral response (see Table X-10) corresponding to that of the emitted radiation should be used. Care should be taken so that visible light does not affect the measurement.

IX. APPENDIX II

DEFINITIONS AND CONVERSION FACTORS

Action Spectrum -	An action spectrum is a range of wavelengths in which biological effectiveness can be defined.
Biological Effectiveness -	The biological effectiveness is a measure of the effectiveness of radiation at different wavelengths (within a defined range or action spectrum) in carrying out a specific reproducible photobiological process.
Irradiance -	The unit of radiant power per unit area ($Watt/cm^2$) is the irradiance.
MED -	Minimal erythema dose.
Radiant Exposure (Dose) -	The unit of radiant energy per unit area ($joules/cm^2$) is the radiant exposure.
Relative Biological Effectiveness -	The relative biological effectiveness is an

experimentally determined ratio of an absorbed dose of radiation to an absorbed dose of a reference radiation required to produce an identical biological effect in a particular organism or tissue.

CONVERSION FACTORS

Radiant Energy Units

	erg	joule	W sec	μW sec
erg=	1	10^{-7}	10^{-7}	0.1
joule=	10^{7}	1	1	10^{6}
W sec=	10^{7}	1	1	10^{6}
μW sec=	10	10^{-6}	10^{-6}	1

Radiant Exposure (exposure dose) Units

	erg/cm^2	$joule/cm^2$	$W\ sec/cm^2$	$\mu W\ sec/cm^2$
erg/cm^2=	1	10^{-7}	10^{-7}	0.1
$joule/cm^2$=	10^{7}	1	1	10^{6}
$W\ sec/cm^2$=	10^{7}	1	1	10^{6}
$\mu W\ sec/cm^2$=	10	10^{-6}	10^{-6}	1

Irradiance (exposure dose rate) Units

	$erg/cm^2 \cdot sec$	$joule/cm^2 \cdot sec$	W/cm^2	$\mu W/cm^2$
$erg/cm^2 \cdot sec$=	1	10^{-7}	10^{-7}	0.1
$joule/cm^2 \cdot sec$=	10^{7}	1	1	10^{6}
W/cm^2=	10^{7}	1	1	10^{6}
$\mu W/cm^2$=	10	10^{-6}	10^{-6}	1

TABLE X-1

Occupations Potentially Associated with Ultraviolet Radiation Exposures

Aircraft workers	Iron workers
Barbers	Lifeguards
Bath attendants	Lithographers
Brick masons	Metal casting inspectors
Burners, metal	Miners, open pit
Cattlemen	Nurses
Construction workers	Oil field workers
Cutters, metal	Pipeline workers
Drug makers	Plasma torch operators
Electricians	Railroad track workers
Farmers	Ranchers
Fishermen	Road workers
Food irradiators	Seamen
Foundry workers	Skimmers, glass
Furnace workers	Steel mill workers
Gardeners	Stockmen
Gas mantle makers	Stokers
Glass blowers	Tobacco irradiators
Glass furnace workers	Vitamin D preparation makers
Hairdressers	Welders
Herders	

From Reference[1]

TABLE X-2

Number of Workers Exposed to Ultraviolet Radiation
(Estimate from Chicago Metropolitan Survey
Extrapolated to U.S. Population)

Manufacturing Standard Industrial Classifications 19-39	211,000
Transportation & Communication Standard Industrial Classifications 40-49	49,000
Wholesale, Miscellaneous Retail, Service Stations Standard Industrial Classifications 50,59,55	17,000
Services Standard Industrial Classifications 70-89	41,000
Total	320,000*

Sources: Welding (Arc)
Air Purifiers
Sanitizers

*Not equal to sum across Standard Industrial Classification because of rounding.

TABLE X-3

Summary of Minimum Erythema Dose (MED) Values in Humans

Investigators	Wavelength nm	MED $\mu W\ sec/cm^2 \times 10^4$	MED mJ/cm^2
Luckiesh, Holladay, and Taylor, 1930[28]	297	4.3	43
Coblentz, Stair, and Hogue, 1932[44]	297	1.9-6.4	19-64
Olson, Sayre, and Everett, 1966[103]	300	2.42	24.2
Freeman, Owens et al., 1966[33]	300	1.4	14
Berger, Urbach, and Davies, 1968[34]	297	1.14	11.4
Cripps and Ramsay, 1970[145]	300	1.16	11.6

TABLE X-4

Ultra-Violet Transmissivity of Fabrics*

Material	Transmissivity, %
Batiste, white (Muslin)	50
Cotton voile	37-43
Kapron	31
Crepe de Chine (l. grey)	32.5
Kapron and Nylon	26.6
Nylon	25-27
Silk stockings	25
Cotton stockings	18
Stockinet	14-16.5
Linen, white, coarse	12
Rayon stockings	10.5
Satin, beige	10
Linen cambric	8-9.5
Rayon (linen type)	3.8-5.3
Wool stockinet	1.4-2.8
Flannelette	0.3
Poplin	0

*Data based on Morikofer,[146] Pfeiderer[147] and Voznesenskaia[148]

TABLE X-5

TRANSMISSION OF NOVIOL GLASSES

Wavelength in Angstroms	CG 338 Yellow Noviol C	CG 038 Lt Yellow Noviol A	CG 306 Noviol O 2 mm
	Fraction Transmitted		
3400			
3600			0
3800			0.120
4000			0.473
4200		0	0.635
4400	0	0.55	0.745
4600	0.38	0.702	0.795
5000	0.765	0.787	0.835
6000		0.825	0.880

Koller[141]

TABLE X-6

Reflectance of 253.7 nm Radiation From Various Surfaces (Summer[149])

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 X-7

REFLECTION OF WHITE PIGMENTS AND OTHER MATERIALS*

	2537 Å in Percent	2967 Å in Percent	3650 Å in Percent	Visible Light in Percent
Pressed zinc oxide	2.5	2.5	4	88
Barytes	65	70	77	86
Titanium oxide	6	6	31	94
Pressed magnesium oxide	77	86	87	93-95
Smoked magnesium oxide	93	93	94	95-97
Pressed calcium carbonate	78	83	86	96
White wall plaster	46	65	76	90
S.W. white Decotint paint	33	41	58	79
Kalsomine white water paint	12	20	40	70
Albastine white water paint	10	14	45	78
White porcelain enamel	4.7	5.4	63	80
Flat black Egyptian lacquer	5	5	5	5
Five samples of wallpaper	18-31	21-40	33-50	55-75

*M. Luckiesh: Applications of Germicidal, Erythemal and Infrared Energy. New York, D. Van Nostrand Co., 1946, p. 383.

TABLE X-8

ULTRAVIOLET REFLECTANCE OF DRY WHITE PIGMENTS*

Pigment	Ultraviolet Reflectance Factor in Per Cent
Lead-free zinc oxide	3
35% leaded zinc oxide	4
Zinc Sulfide	6
Titanox B	6
Lead titanate	6
Titanium dioxide	7
Titanox C	7
Lithopone	8
Antimony oxide	17
Zirconium oxide (commercial)	41
Diatomaceous silica (Celite 110)	45
Basic sulfate white lead	48
China clay	54
Aluminum oxide	55
Basic carbonate white lead (Dutch process)	62
Aluminum hydroxide	67
Zirconium oxide, C.P.	78
Magnesium carbonate (commercial)	81

*D. F. Wilcock and W. Soller: Ind. Eng. Chem. 32: 1446, 1940

Note: Lead-based pigments must not be applied where their use might result in ingestion; lead-based pigments will be limited in paints for the home by Food and Drug Administration regulations.

TABLE X-9

REFLECTANCE OF PAINTS WITH WHITE PIGMENT SUSPENDED IN SILICONE*

Pigment	Reflectance at 3000 Å	Reflectance at 4000 Å
Zinc sulfide†	5%	58%
Antimony oxide†	8%	70%
Calcium carbonate†	22%	33%
China clay†	5%	27%
Basic white lead carbonate†	15%	65%
Leafing aluminum flake	63%	66%

*From W.A.D.D. Technical Report 60-703, Part III F.M. Noonan, A.L. Alexander, J.E. Cowling, U.S.N.R.L.
†30% pigment volume.

Note: Lead-based pigments must not be applied where their use might result in ingestion; lead-based pigments will be limited in paints for the home by Food and Drug Administration regulations.

TABLE X-10

Properties of Typical Ultraviolet
Interference Filters

Peak Spectral Response	Half Power Bandwidth
254 nm ± 1.5 nm	15 ± 2.5 nm
280 nm ± 1.0 nm	10 ± 2.5 nm
297 nm ± 1.0 nm	10 ± 2.5 nm
313 nm ± 0.8 nm	8 ± 2.0 nm

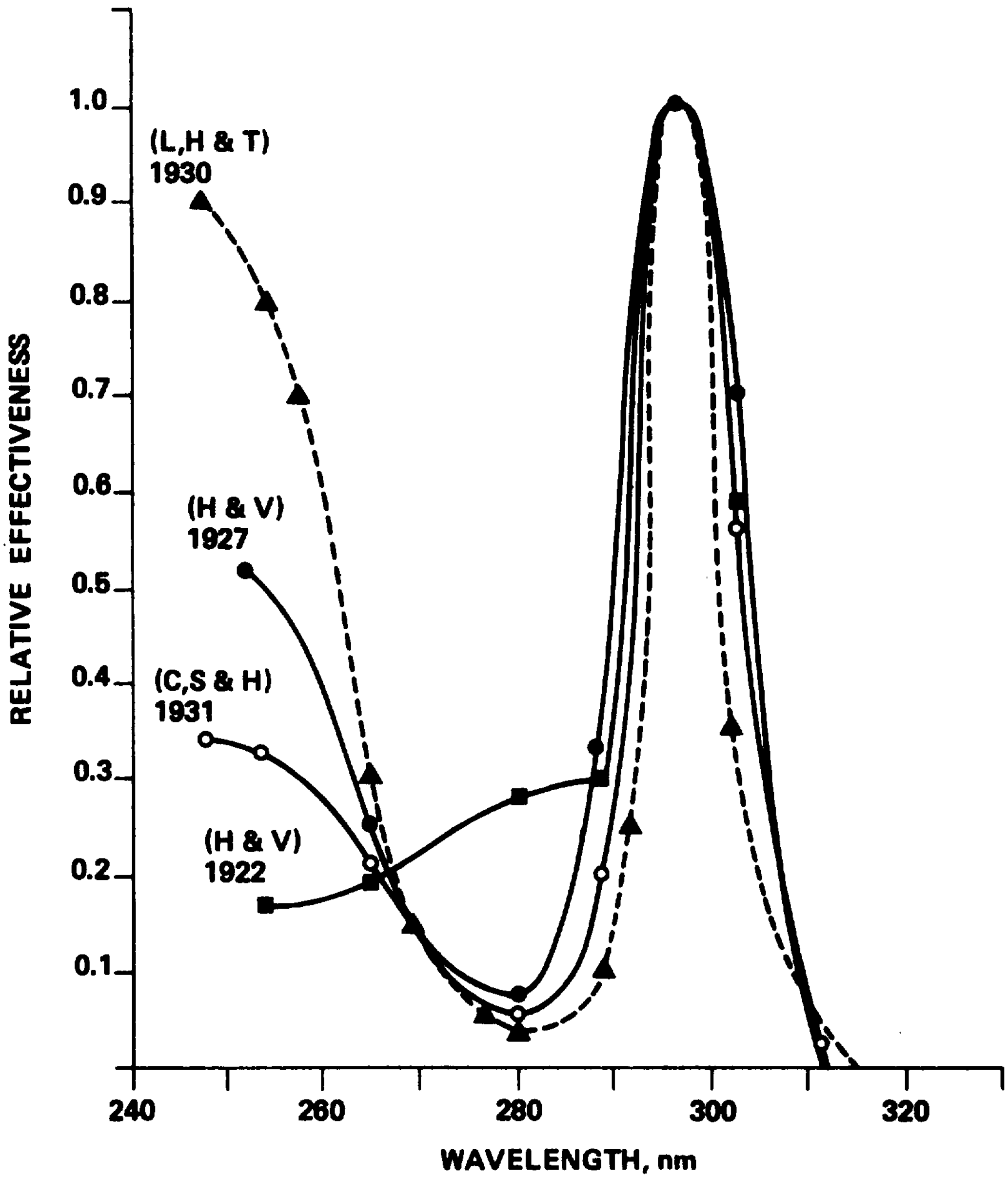

Figure X-1. Erythema action spectra (previous observers). From Everett, Olson, and Sayer.[32]

Luckiesh, Holladay, and Taylor[28] (L, H, & T)
Hausser and Vahle[26] (H & V)
Coblentz, Stair, and Hogue[29] (C, S, & H)

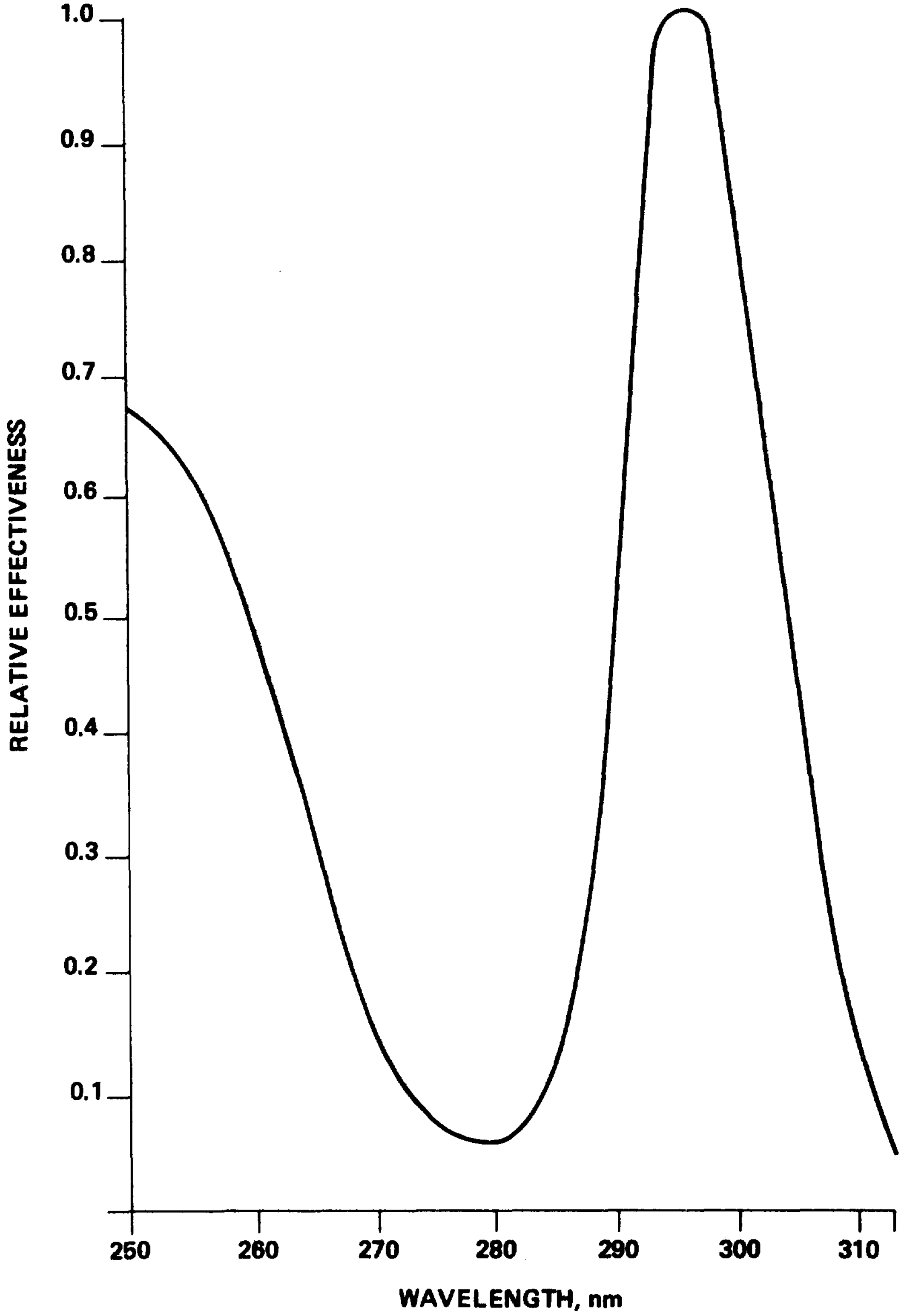

Figure X-2. "Standard" curve for erythemal effectiveness.

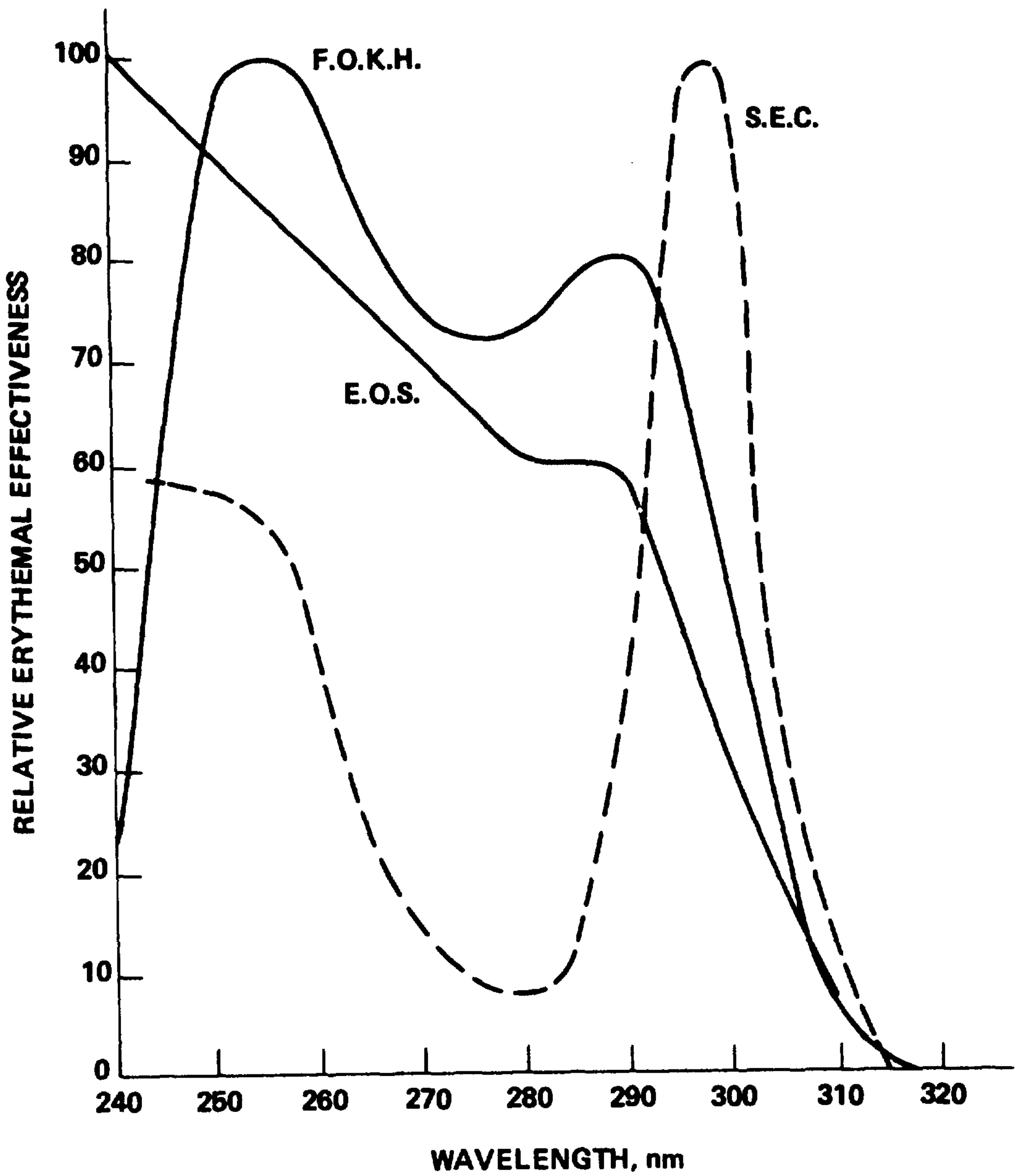

Figure X-3. Comparison of Standard Erythemal Curve (S.E.C.) with relative erythemal effectiveness curves of Everett, Olson, and Sayre (E.O.S.) and Freeman, Ownes, Knox, and Hudson (F.O.K.H.). From Matelsky.[119]

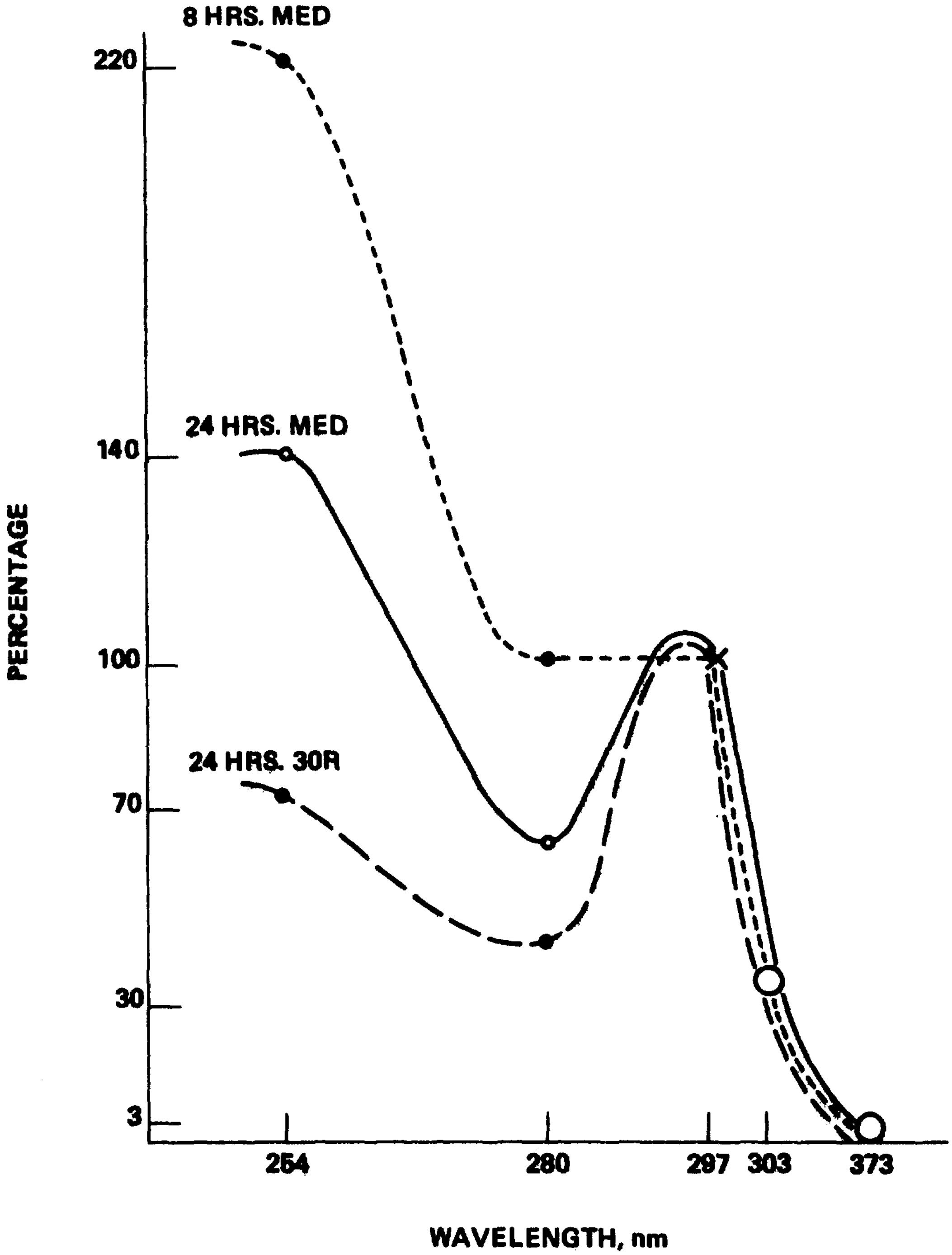

Figure X-4. "Action Spectrum" of Human Skin. Averages of values for five subjects, abdominal skin, second exit slit. Note great similarity for wavelengths from 297 to 313 nm. and marked differences for 8hr. MED, 24 hr. MED and a curve constructed by using values for moderate erythema (Kodak Color Balancing Filter 30 R). From Berger, Urbach, and Davies.[34]

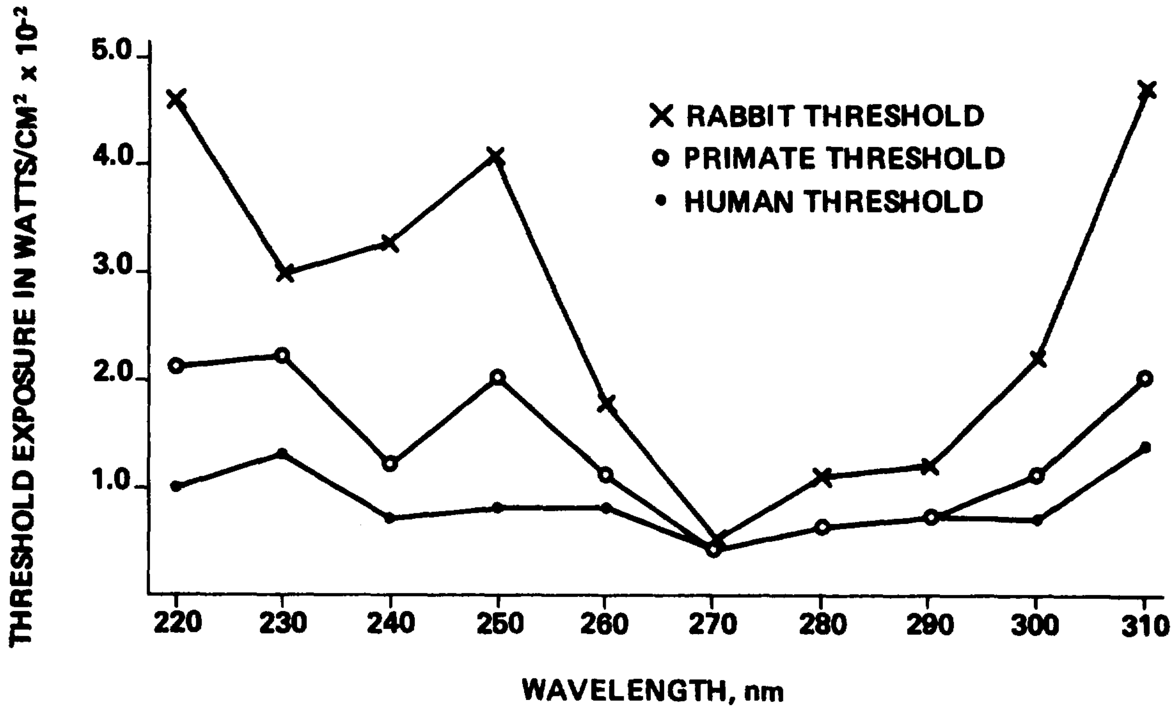

Figure X-5. Comparison of the ultraviolet action spectrum for the rabbit, primate, and human. From Pitts and Gibbons.[9]

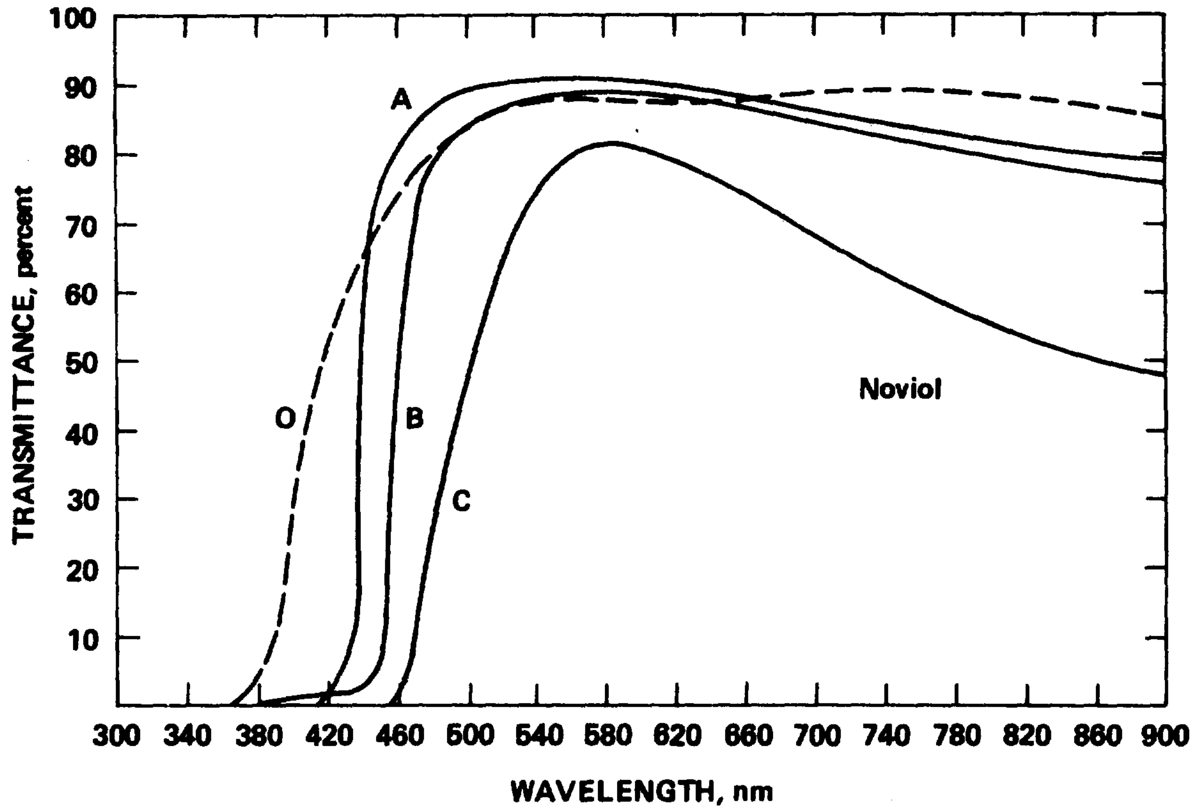

Figure X-6. Spectral transmittance of Noviol glass. Noviol O, thickness 2.63 mm. Noviol A, thickness 1.90 mm. Noviol B, thickness 2.89 mm. Noviol C, thickness, 3.05 mm. From reference 140.

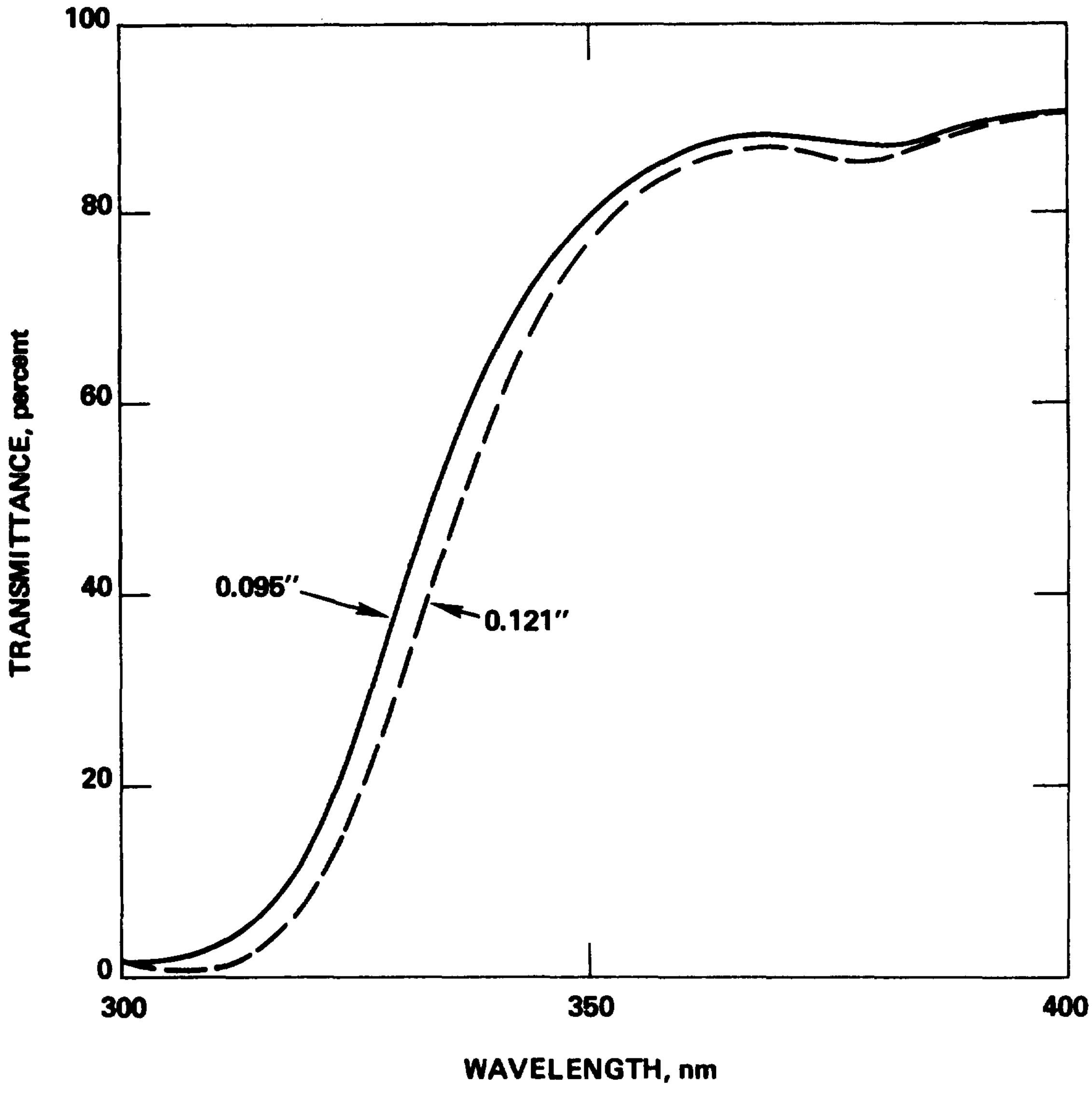

Figure X-7. Transmission for two thicknesses of window glass. From Koller.[141]

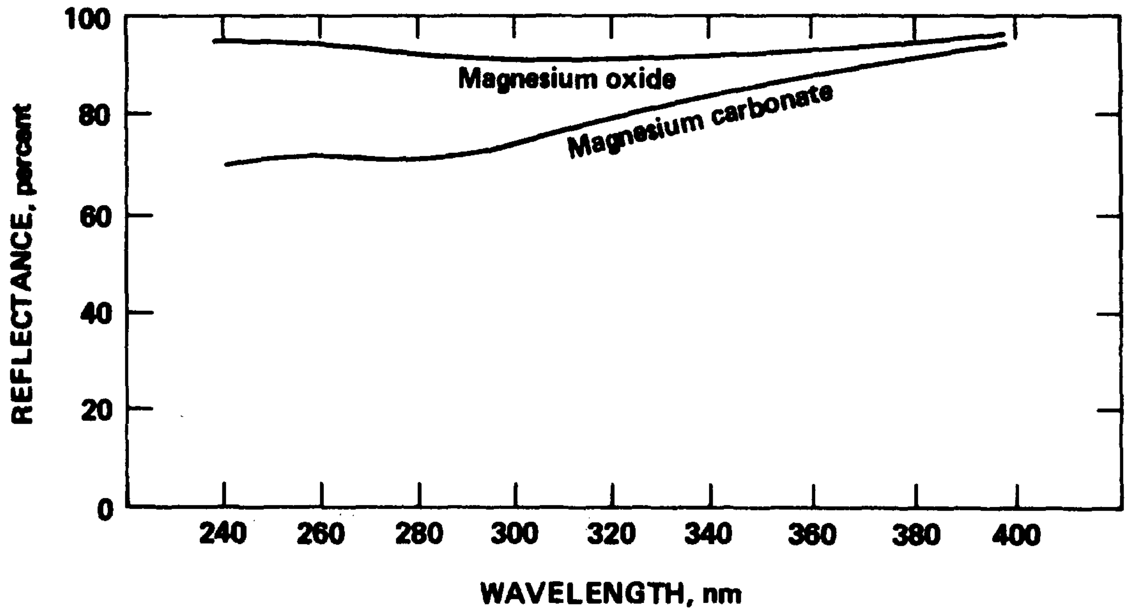

Figure X-8. Reflection from magnesium oxide and magnesium carbonate. From Benford F, Schwartz S, and Lloyd G, J Opt Soc Am 38: 964, 1948.

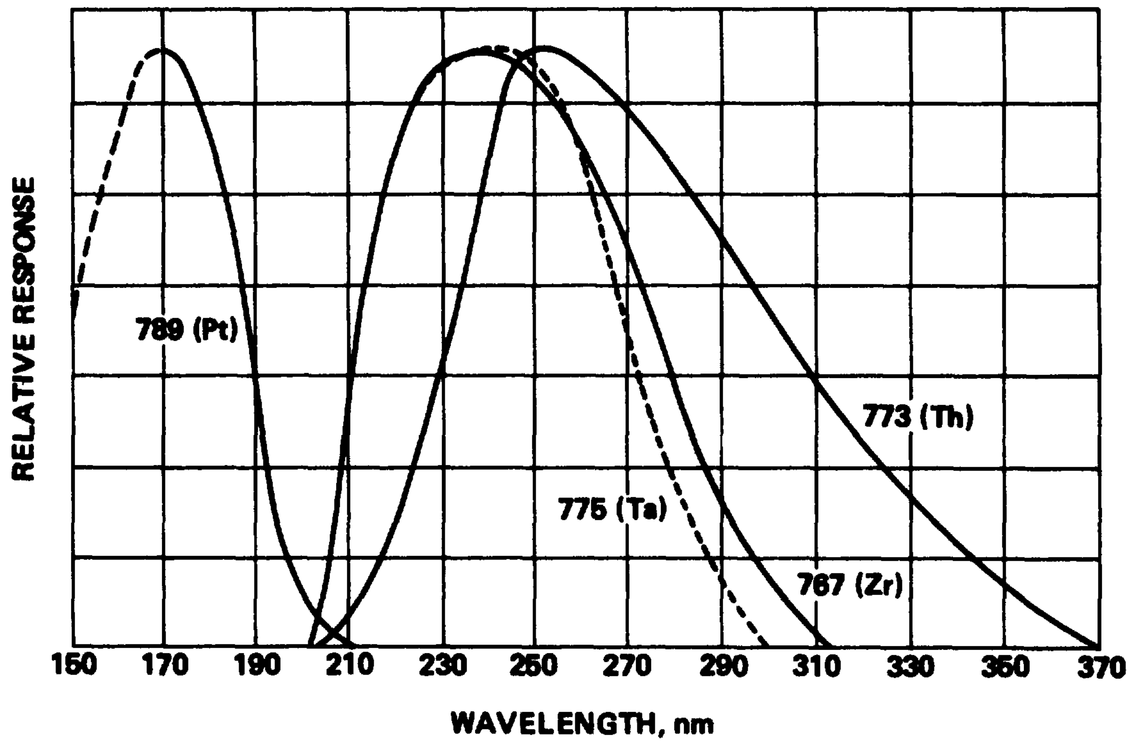

Figure X-9. Response of various phototubes. From Fanney JH, Powell CH: Field measurement of ultraviolet, infrared, and microwave energies, Am Ind Hyg Assoc J 28: 335-42, 1967.

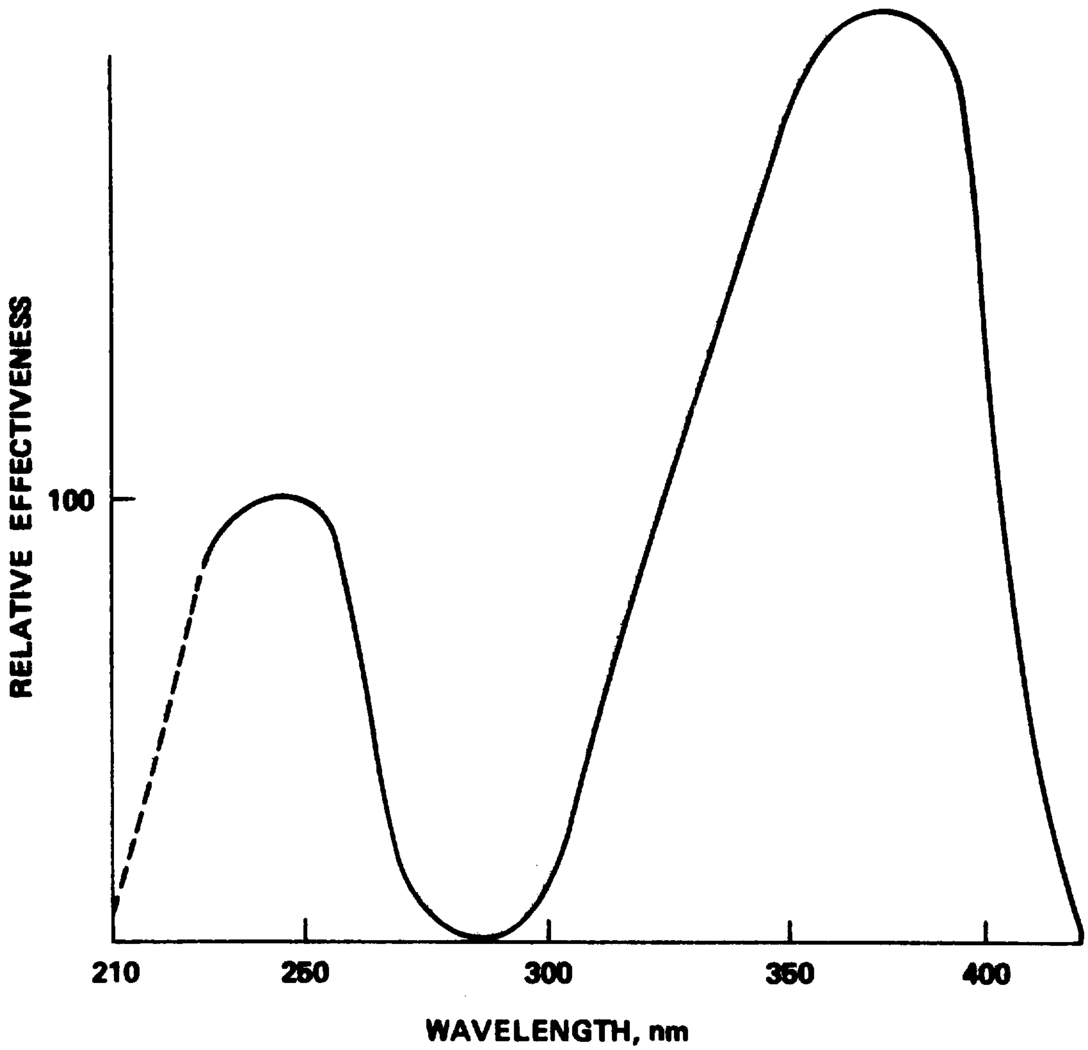

Figure X-10. Relative spectral response of a short-wavelength filter for ultraviolet meter. From Powell, Goldman, and Key.[14]

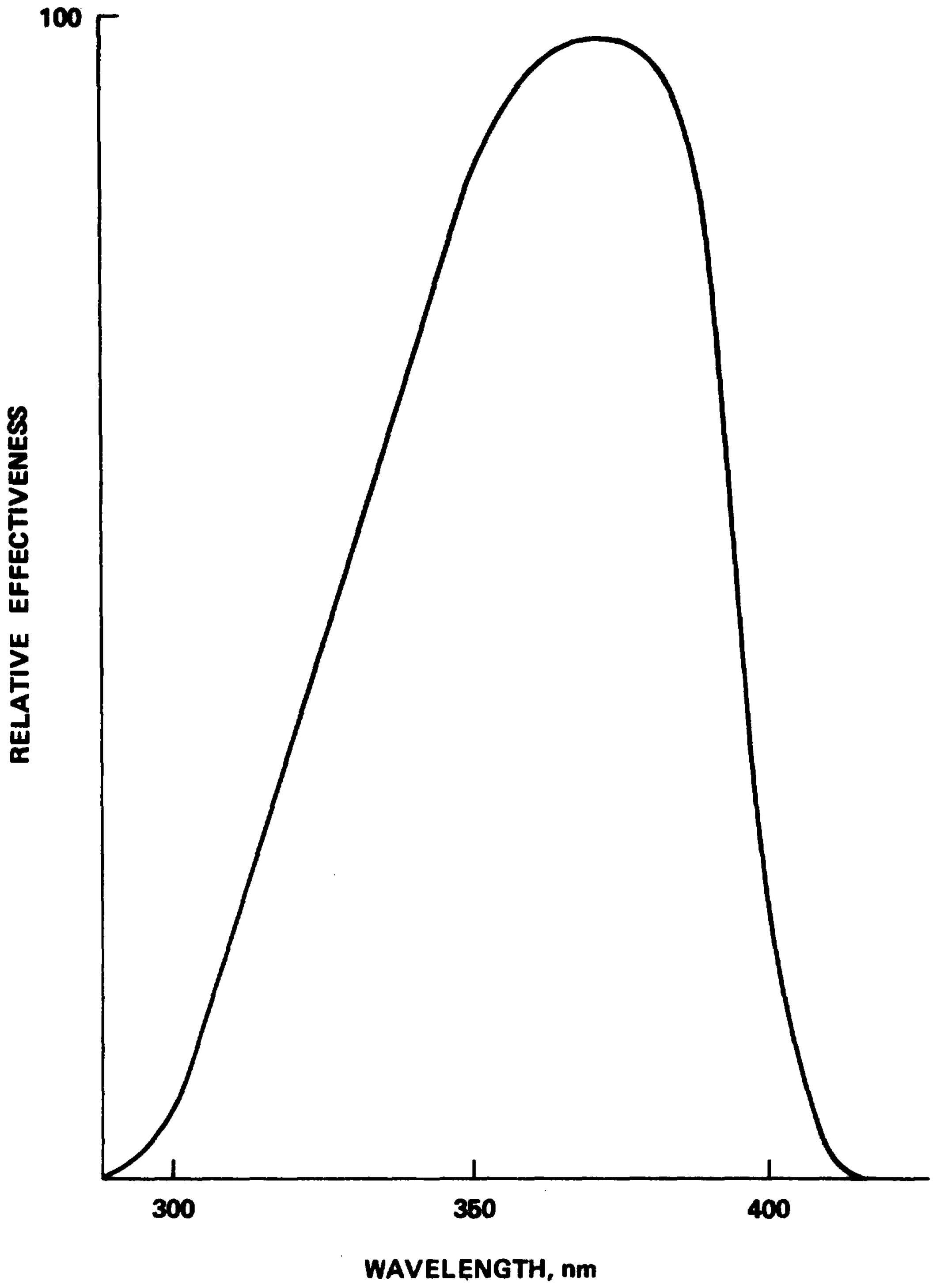

Figure X-11. Relative spectral response of a long-wavelength filter for ultraviolet. From Powell, Goldman, and Key.[14]

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