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GUIDELINES ON LIMITS OF EXPOSURE TO ULTRAVIOLET RADIATION OF WAVELENGTHS BETWEEN 180 nm AND 400 nm (INCOHERENT OPTICAL RADIATION)

The International Non-Ionizing Radiation Committee of the International Radiation Protection Association

PREFACE

THE INTERNATIONAL Radiation Protection Association (IRPA) formed a working group on non-ionizing radiation (NIR) in 1974, which among other tasks, examined the question of protection against adverse health effects of exposure to ultraviolet radiation. At the 1977 IRPA Congress in Paris, this working group became the International Non-Ionizing Radiation Committee (IRPA/INIRC).

The IRPA/INIRC, in cooperation with the Environmental Health Division of the World Health Organization (WHO), has undertaken responsibility for the development of health criteria documents on non-ionizing radiation. These form part of the WHO Environmental Health Criteria Programme, which is funded by the United Nations Environment Programme (UNEP). The documents include an overview of the physical characteristics, measurement and instrumentation, sources and applications of the NIR, a thorough review of the available standards and their rationale, and evaluations of the health risks of human exposure to NIR. These criteria then become the scientific data base for the development of exposure limits and codes of practice.

A document entitled *Environmental Health Criteria* 14, *Ultraviolet Radiation* (UN79) was published in 1979. The document contains a review of the biological effects reported from exposure to ultraviolet radiation and serves as the scientific rationale for the development of these guidelines. The important publications which relate most directly to the guidelines (some of which have appeared since the EHC document was drafted) are referenced in the rationale (Appendix).

The purpose of these guidelines is to deal with the basic principles of protection against non-coherent ultraviolet radiation, so that they may serve as guidance to the various international and national bodies or individual experts who are responsible for the development of regulations, recommendations or codes of practice to protect the workers and the general public from the potentially adverse effects of ultraviolet radiation.

The Committee recognized that when standards on exposure limits are established, various value judgments are made. The validity of scientific reports has to be considered, and extrapolations from animal experiments to effects on humans have to be made. Cost versus benefit analyses are necessary, including economic impact of controls. The limits in these guidelines were based on the scientific data and no consideration was given to economic impact or other nonscientific priorities. However, from presently available knowledge, the limits should provide a healthy working or living environment from exposure to ultraviolet radiation (UVR) under all normal conditions.

The IRPA Associate Societies as well as a number of competent institutions and individual experts were consulted in the preparation of the guidelines and their cooperation is gratefully acknowledged.

During the preparation of this document, the composition of the IRPA/INIRC was as follows:

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These guidelines were approved by the IRPA Executive Council in May 1984.

INTRODUCTION

Ultraviolet radiation (UVR) occupies that portion of the electromagnetic spectrum from 100 to 400 nanometers (nm). In discussing UVR biological effects the International Commission on Illumination (CIE) has divided the UV spectrum into three bands. The band 315 to 380–400 nm is designated as UV-A, 280 to 315 nm as UV-B, and 100 to 280 nm as UV-C (CIE70). Wavelengths below 180 nm (vacuum UV) are of little practical biologic significance since they are readily absorbed in air. Ultraviolet radiation is used in a wide variety of medical and industrial processes and for cosmetic purposes. These include photocuring of inks and plastics (UV-A and UV-B), photoresist processes (all UV), solar simulation (all UV), cosmetic tanning (UV-A and UV-B), fade testing (UV-A and UV-B), dermatology (all UV), and dentistry (UV-A). Even though the principal operating wavelengths for most of these processes are in the UV-A, almost always some shorter wavelength (UV-B and UV-C) radiation and violet light are emitted as well. Many industrial applications employ arc sources for heat or light (e.g. welding) which also produce UVR as an unwanted admixture for which control measures may be necessary. While it is generally agreed that some low-level exposure to UVR benefits health (UN79), there are adverse effects which necessitate the development and use of exposure limits (EL) for UVR.

The most significant adverse health effects of exposure to UVR have been reported at wavelengths below 315 nm, known collectively as actinic ultraviolet. This guideline has been limited to wavelengths greater than 180 nm where UVR is transmitted through air. The most restrictive limits are for exposure to radiation having those wavelengths less than 315 nm.

PURPOSE AND SCOPE

The purpose of this document is to provide guidance on maximal limits of exposure to UVR in the spectral region between 180 nm and 400 nm and represent conditions under which it is expected that nearly all individuals may be repeatedly exposed without adverse effect (see paragraph on Special Considerations). These EL values for exposure of the eye or the skin may be used to evaluate potentially hazardous exposure from UVR; e.g. from arcs, gas and vapor discharges, fluorescent lamps, incandescent sources, and solar radiation. The limits do not apply to UV lasers. Most incoherent UV sources are broadband, although single emission lines can be produced from low-pressure gas discharges. These values should be used as guides in the control of exposure to both pulsed and continuous sources where the exposure duration is not less than 0.1 μs. These ELs are below levels which would be used for UV exposures of patients required as a part of medical treatment or for elective cosmetic purposes. These ELs are exceeded by noonday

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sunlight overhead at 0°–40° latitude within 5–10 minutes in the summertime. The ELs should be considered absolute limits for the eye, and "advisory" for the skin because of the wide range of susceptibility to skin injury depending on skin type. The ELs should be adequate to protect lightly pigmented individuals.

BASIC CONCEPTS

This document makes use of the spectral band designations of the CIE. Unless otherwise stated, UV-A is from 315 to 400 nm, UV-B is from 280 to 315 nm, and UV-C is from 100 to 280 nm (CIE70). It should be noted that some specialists follow this general scheme but take the dividing line between UV-A and UV-B at 320 nm. The UVR exposure should be quantified in terms of an irradiance E (W/m^2 or W/cm^2) for continuous exposure or in terms of a radiant exposure H (J/m^2 or J/cm^2) for time-limited (or pulsed) exposures of the eye and skin. The geometry of exposure to UVR is very important. For example, the eyes (and to a lesser extent the skin) are somewhat anatomically protected against UVR exposure from overhead sources (e.g. the sun overhead) (UN79). The limits should be applied to exposure directed perpendicular to those surfaces of the body facing the radiation source, measured with an instrument having cosine angular response (UN79). The irradiance and the radiant exposure should be averaged over the area of a circular measurement aperture not greater than 1 mm in diameter. These ELs should be used as guides in the control of exposure to UV sources and as such are intended as upper limits for non-therapeutic and nonelective exposure. The ELs should be considered as absolute limits for ocular exposure. The ELs were developed by considering lightly pigmented populations (i.e. white Caucasian) with greatest sensitivity and genetic predisposition. Exposure during sun bathing and tanning under artificial sources may well exceed these limits but exposed individuals should be advised that some health risk is incurred from such activity. Eye protection is always required during therapeutic exposures. Nevertheless, occasional exposures to conditioned skin may not result in adverse effects. The rationale for the UVR exposure limits is provided in the Appendix.

EXPOSURE LIMITS

The EL for both general and occupational exposure to UVR incident upon the skin or eye where irradiance values are known and the exposure duration is controlled are as follows:

For the near-ultraviolet UV-A spectral region (315 to 400 nm) the total irradiance incident upon the unprotected skin or eye should not exceed 1 mW/cm^2 (10 W/m^2) for periods greater than 10^3 seconds (approximately 16 minutes); and for exposure times less than 10^3 seconds the radiant exposure should not exceed 1.0 J/cm^2 (10 kJ/m^2).

For the actinic UV spectral region (UV-C and UV-B from 180 to 315 nm), the radiant exposure incident upon the unprotected skin or eye within an 8-hour period should not exceed the values given in Table 1. Values for the relative spectral effectiveness S_λ are given to 318 nm to aid in spectroradiometric measurements.

To determine the effective irradiance of a broadband source weighted against the peak of the spectral effectiveness curve (270 nm), the following weighting formula should be used:

$$E_{\text{eff}} = \sum E_\lambda \cdot S_\lambda \cdot \Delta_\lambda$$

where:

E_{eff} = effective irradiance in μW/cm^2 [μJ/(s·cm^2)] or W/m^2[J/(s·m^2)] normalized to a monochromatic source at 270 nm

E_λ = spectral irradiance from measurements in μW/(cm^2·nm) or W/(m^2·nm)

S_λ = relative spectral effectiveness (unitless)

Δ_λ = bandwidth in nanometers of the calculation or measurement intervals.

Permissible exposure time in seconds for exposure to actinic UVR incident upon the unprotected skin or eye may be computed by dividing 30 J/m^2 by the value of E_{eff} in W/m^2. The maximal exposure duration may also be determined using Table 2 which provides representative exposure durations corresponding to effective irradiances in W/m^2 or μW/cm^2.

SPECIAL CONSIDERATIONS

These EL values are intended to apply to UVR exposure of the working population, but with some precaution also apply to the general population. However, it should be recognized

Table 1. Ultraviolet radiation (UVR) exposure limits at representative wavelengths

Wavelength (nm)	EL (J/m^2)	EL (mJ/cm^2)	Relative spectral effectiveness S_λ
180†	1,000	100	0.03
190†	1,000	100	0.03
200	1,000	100	0.03
205	590	59	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.12
225	200	20	0.15
230	160	16	0.19
235	130	13	0.24
240	100	10	0.30
245	83	8.3	0.36
250	70	7.0	0.43
*254	60	6.0	0.50
255	58	5.8	0.52
260	46	4.6	0.65
265	37	3.7	0.81
270	30	3.0	1.0
275	31	3.1	0.96
280	34	3.4	0.88
285	39	3.9	0.77
290	47	4.7	0.64
295	56	5.6	0.54
297	65	6.5	0.46
300	100	10	0.30
303	250	25	0.19
305	500	50	0.060
308	1,200	120	0.026
310	2,000	200	0.015
313	5,000	500	0.006
315	10,000	1,000	0.003
316‡	—	—	0.002
317‡	—	—	0.0015
318‡	—	—	0.001

* Principal emission line of low-pressure quartz-mercury lamps.

† Tentative values given for use only when sources emit substantial amounts of UVR in this band.

‡ Values provided for guidance in spectroradiometer measurements.

that some rare, highly photosensitive individuals exist who may react adversely to exposure at these levels. These individuals are normally aware of their heightened sensitivity. Likewise, if individuals are concomitantly exposed to photosensitizing agents (see for example reference Fi74), a photosensitizing reaction can take place. It should be emphasized that many individuals who are exposed to photosensitizing agents (ingested or externally applied chemicals, e.g. in cosmetics, foods, drugs, industrial chemicals, etc.) probably will not be aware of their heightened sensitivity. Lightly pigmented individuals conditioned by previous UVR exposure (leading to tanning and hyperplasia) and heavily pigmented individuals can tolerate skin exposure in excess of the EL without erythemal effects. However, repeated tanning may increase the risk for those persons later developing signs of accelerated skin aging and even skin cancer. Such risks should be understood prior to the use of UVR for medical phototherapy or cosmetic exposures.

PROTECTIVE MEASURES

Protective measures will differ depending upon whether the UVR exposure occurs indoors or outdoors. The use of hats, eye protectors, facial shields, clothing, and sun-shading structures are practical protective measures. As with any indoor, industrial hazard, engineering control measures are preferable to protective clothing, goggles, and procedural safety measures. Glass envelopes for arc lamps will filter out most UV-B and UV-C. Where lengthy exposure to high power glass-envelope lamps, and quartz halogen lamps will occur at close proximity, additional glass filtration may be necessary. Light-tight cabinets and enclosures and UVR absorbing glass and plastic shielding are the key engineering control measures used to prevent

Table 2. Limiting UV exposure durations based on exposure limits

Duration of exposure per day	Effective irradiance E_{eff} (W/m^2)	Effective irradiance E_{eff} ($\mu W/cm^2$)
8 hours	0.001	0.1
4 hours	0.002	0.2
2 hours	0.004	0.4
1 hour	0.008	0.8
30 minutes	0.017	1.7
15 minutes	0.033	3.3
10 minutes	0.05	5
5 minutes	0.1	10
1 minute	0.5	50
30 seconds	1.0	100
10 seconds	3.0	300
1 second	30	3,000
0.5 second	60	6,000
0.1 second	300	30,000

human exposure to hazardous UVR produced in many industrial applications such as the fade testing of materials, solar simulation, photoresist applications, and photocuring. For arc welding, cabinets are not practical. Shields, curtains, baffles, and a suitable separation distance are used to protect individuals against the UVR emitted by open-arc processes such as arc welding, arc-cutting, and plasma spraying. Progress is being made in the development of dynamic-filter welding helmets, see-through curtains, and other new safety equipment. There is a need for operational rules to protect potentially exposed individuals. Operators should be trained to follow these general rules properly. Ventilation may be required exhausting ozone and other airborne contaminants produced by UV-C radiation.

MEASUREMENT

Although UVR radiometers exist, attempts to produce relatively inexpensive field safety survey meters which respond directly to UV-B and UV-C radiation (following the S_λ function) have not been fully successful. However, relatively expensive instruments exist which respond to UV-B and UV-C radiation according to the relative spectral effectiveness, S_λ. Spectroradiometric measurements of the source which can then be used with the S_λ weighting function to calculate E_{eff} are often necessary for measurements more accurate than with simple, direct-reading safety meters. Whichever measurement technique is applied, the geometry of measurement is important. All the preceding ELs for UVR apply to sources which are measured with an instrument having a cosine-response detector oriented perpendicular to the most directly exposed surfaces of the body when assessing skin exposure and along (or parallel to) the line(s) of sight of each exposed individual when assessing ocular exposure. The use of UV film badges makes it possible to integrate UV exposure on specific body sites which move with respect to the UVR source; however, the spectral response of such film badges still does not accurately follow S_λ.

CONCLUDING REMARKS

The increasing use of UVR in medicine, in the industrial work environment, for cosmetic use, and partly in consumer products necessitates that greater attention be paid to the potential hazards of this type of electromagnetic radiation. The present understanding of chronic effects and injury mechanisms of UVR is limited, and this problem awaits further research. The above guidelines will be subject to periodic review and amendment as appropriate.

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APPENDIX

RATIONALE FOR THE LIMITS OF EXPOSURE TO UVR

1. *Background*

A comprehensive review of UVR effects has been published by UNEP/WHO/IRPA (UN79) and the interested reader is referred to that document. The following discussion is a brief review of those physical and biological factors used to derive the UVR guidelines.

2. *General biological effects*

Life has evolved under the daily exposure to solar radiation. Although UVR is only about 5 percent of the sunlight that reaches the earth's surface, it plays a significant biological role since the energies of individual photons are the greatest for any of the photons in the solar spectrum. These shorter wavelength, higher energy photons have sufficient energy to initiate biological effects that may be injurious. The critical organs for UVR exposure are the eye and the skin since they may be readily exposed. In some dental applications, the interior of the mouth may also be exposed.

The thresholds for the observed bioeffects vary significantly with wavelength. Consequently, various "action spectra" have been developed to establish dose–response relationships. In photobiology, the term "action spectrum" refers to the relative spectral effectiveness of different wavelengths in eliciting a biological effect.

3. *Erythema*

Erythema (e.g., the reddening of the skin in sunburn) is the most commonly observed effect on skin after exposure to UVR. This effect was first quantitatively documented as a wavelength dependent effect in the late 1920s by Hausser and Vahle in Germany (Ha28). These and other quantitative studies since that time have confirmed that the erythemal threshold varies with anatomical site, wavelength, and time between exposure and assessment (Co31; Lu30; Ev65; Fr66; Be68; Wi72; Va69; Pa82; Ba82). In addition, the variation in published threshold values is due to differences in the clinical definition and estimate of minimal erythema and radiometric measurement techniques. Erythema is a photochemical response of the skin normally resulting from overexposure to wavelengths in the UV-C and UV-B regions (180–315 nm). Exposure to UV-A alone can produce erythema, but only at very high radiant exposures (>10 J/cm^2). The UV-A added prior to UV-B exposure may slightly intensify the erythemal response (Wi72). This synergistic effect of two spectral bands is known as photoaugmentation. The opposite effect where one previous exposure desensitizes the skin also occurs, and may be more pronounced for simultaneous exposure of UV-A and UV-B (Va69; Pau82). Hausser and Vahle first showed (as reported by Hausser) that erythema induced by the longer UV-B wavelengths (295–315 nm) is more severe and persists for a longer period than that for shorter wavelengths (Ha28). The increased severity and time course of the erythema may result from the deeper penetration of these wavelengths into the epidermis. In general it is accepted that UVR releases a number of diffusing mediators, which in turn carries the inflammatory effect into deeper skin layers. The assessment of a threshold for the maximum sensitivity of the skin to erythema varies from 250 nm to 297 nm depending upon the criteria of assessment and the period following the exposure. Action spectra for different grades of erythema are quite different. For the most severe grade of erythema this maximum sensitivity occurs between 290 and 300 nm. The minimal erythemal doses (MED) reported in more recent studies for untanned, lightly pigmented skin range from 6 to 30 mJ/cm^2 (Ev65; Fr66; Pa82). These MED data suggest that for this type of skin, the EL values are approximately 1.3 to 6.5 times less than the MED values. Skin pigmentation and "conditioning" (thickening of the stratum corneum and tanning) may result in an increase of the MED by at least one order of magnitude. Figure 1 shows the variation of the skin erythema action spectrum.

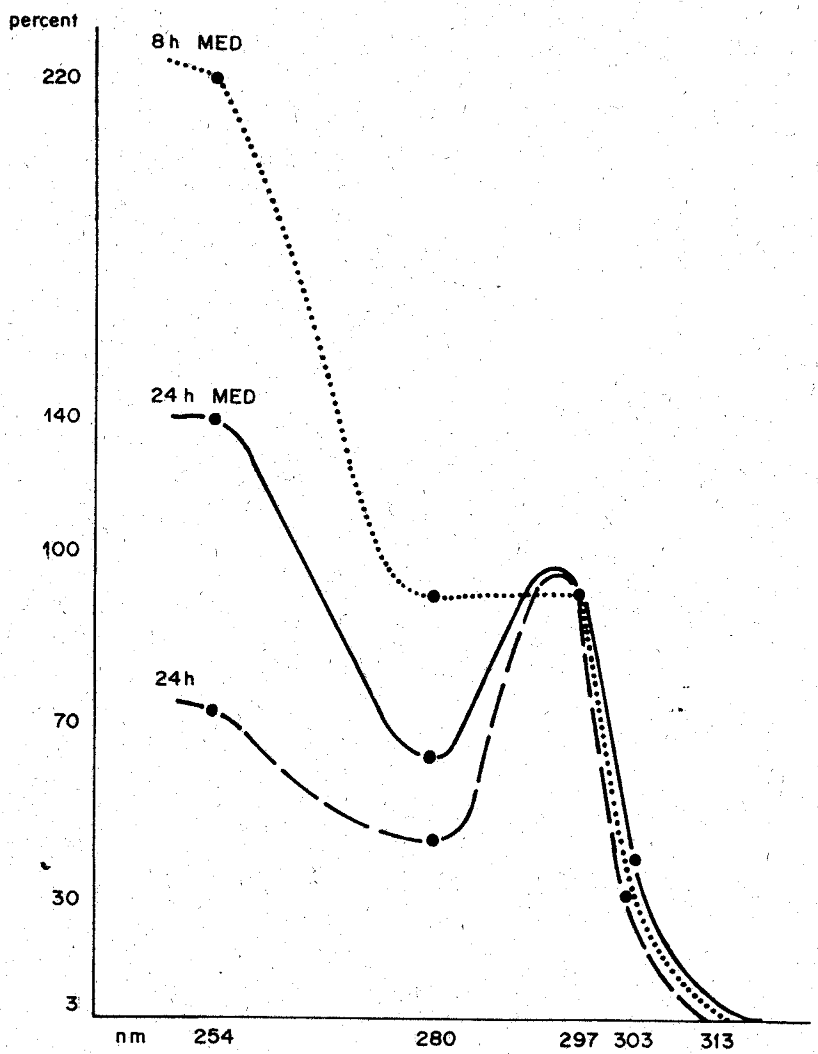

FIG. 1. Action spectrum of human skin. Averages of relative values for abdominal skin of five subjects. Note great similarity for wavelengths from 297–313 nm, and marked differences at shorter wavelengths for 8 hours (after irradiation) MED, 24 hours (after irradiation) MED, and a curve constructed by using values for moderate erythema.

4. *Delayed effects on the skin*

Chronic exposure to sunlight, especially the UV-B component, accelerates the skin aging process and increases the risk of developing skin cancer (Va84). The solar spectrum is greatly attenuated by the earth's ozone layer, limiting terrestrial UV to wavelengths greater than approximately 290 nm. The UV-B irradiance at ground level is a strong function of the sun's elevation angle in the sky. This is due to the change of UV attenuation with atmospheric path length (time of day and season). Several epidemiologic studies have shown that the incidence of skin cancer is strongly correlated with latitude, altitude, and cloud cover (Ch78; Cu74; Cu77; Ur74; Sw71; Go76). Exact quantitative dose-response relationships have not yet been established although fair-skinned individuals, especially of Celtic origin, are much more prone to develop skin cancer. Skin cancer is typically a disease of outdoor workers such as farmers and seamen (Ur74). Only a few quantitative studies have examined work populations chronically exposed to artificial sources of UV-B to determine whether there is an increased skin cancer risk in the occupational environment. Squamous cell carcinoma is the most common type. This is localized at exposed sites (e.g. hands and back of the neck). No studies of the incidences of melanoma have been reported for outdoor workers.

5. *Photokeratoconjunctivitis*

Actinic UVR (UV-B and UV-C) is strongly absorbed by the cornea and conjunctiva. Overexposure of these tissues causes photokeratoconjunctivitis, commonly referred to as welder's flash, arc-eye, etc. Pitts has characterized the course of ordinary clinical photokeratitis (Pi71; Pi74; Pi77). The latent period varies inversely with the severity of exposure ranging from 1/2 to 24 hours but usually occurs within 6–12 hours. Conjunctivitis tends to develop more slowly and may be accompanied by erythema of the facial skin surrounding the eyelids. The individual has the sensation of a foreign body or sand in the eyes and may experience photophobia, lacrimation, and blepharospasm to varying degrees. The acute symptoms last from 6 to 24 hours and discomfort usually disappears within 48 hours. Although exposure rarely results in permanent ocular injury, the individual is visually incapacitated during this 48-hour period. Threshold data for photokeratitis in humans have been established by Pitts and Tredici for 10 nm wavebands from 220 to 310 nm (Pi71). The guideline ELs between 200 nm and 305 nm are about 1.3 to 4.6 times less than the threshold for minimal change. The maximum sensitivity of the human eye was found to occur at 270 nm. The wavelength response (action spectrum) between 220 and 310 nm does not vary as greatly as in the case of erythema with the thresholds varying from 4–14 mJ/cm². Corneal injury from UV-A wavelengths requires levels exceeding 10 J/cm² (Pi77; Sh77; Zu77; Zu80; Ta69; Ha69).

6. *Cataract*

Wavelengths above 295 nm can be transmitted through the cornea and are absorbed by the lens. Pitts *et al.* (Pi77) have shown that both transient and permanent opacities of the lens (cataracts) can be produced in rabbits and monkeys by exposure to UVR having wavelengths in the 295–320 nm band. Thresholds for transient opacities ranged dramatically with wavelength, from 0.15 to 12.6 J/cm². Thresholds for permanent opacities were typically twice those for transient opacities (Pi77). Whether chronic exposure at lower levels will produce lenticular opacities has not been determined (Pir71; Hi77; Ku77; Ma72; Pi71; So64; Ha69; Tr25; Va25; Fi35).

7. *Retinal effects*

The cornea and crystalline lens normally sufficiently shield the retina from acute effects from UVR exposure. Normally, less than 1 percent of UV-A reaches the retina, shorter UV-B wavelengths being totally attenuated (Sl80; Pi77). Upon removal of the crystalline lens, Ham and colleagues (Ha82) demonstrated acute retinal injury at levels of the order of 5 J/cm² at the retina.

8. *Envelope action spectrum*

a. Clearly, the development of UVR exposure limits for workers and the general population must consider two risks. These are the risks of acute and chronic injury to both the eye and skin. The literature indicates that thresholds for injury vary significantly with wavelength for each effect. In the UV-B and UV-C regions, an action spectrum curve can be drawn which envelopes the threshold data for exposure doses (radiant exposures) in the range of reciprocity (Sc64; Zu80) for acute effects obtained from recent studies of minimal erythema and keratoconjunctivitis. Reciprocity means that irradiance E and exposure duration t have a reciprocal relation, and a constant product of E and t (i.e. exposure) results in a given effect. This EL curve does not differ significantly from the collective threshold data considering measurement errors and variations in individual response (Sl72; Sl80). Although the safety factor is minimal for minimally detectable keratitis it is believed to range from 1.5 to 2.0 for acute keratitis. The curve is also well below the acute UV-B cataractogenic thresholds (Pi77; Sl80). Repeated exposure of the eye to potentially hazardous levels of UV is not believed to increase the protective capability of the cornea as does skin tanning and thickening of the stratum corneum. Thus, this EL is more readily applicable to the eye and must be considered a limiting value for that organ (Sl72). Any accumulation of UV-B and UV-C exposures causing photokeratitis is limited to about 48 hours since the outer corneal epithelial layers are replaced in about 48 hours by the normal repair process of this tissue. Some slight additivity of UV-A exposures exists beyond 48 hours because of the deeper penetration of UV-A rays (Zu80). The additivity factors were considered in deriving the magnitude of the safety factor built into the EL. On the basis of acute effects, the safety factor for UV-A ELs is large, varying from about 7 at 320 nm to more than 100 at 390 nm.

b. Because of the wide variations in threshold values and exposure history (conditioning) among individuals, these guidelines should only be used as a starting point for evaluating skin hazards (De78; Ge78; Sl80; Ma79). The envelope guideline has some margin of safety to protect all but the most sensitive individuals. An exact value for this margin cannot be given, but for lightly pigmented persons, it varies from about 3 to 20 depending on the spectral composition of the radiation. Since there may be more than one erythemal mechanism and, therefore, more than one erythemal action spectrum, the effect of radiations of two widely differing wavelengths in the 180 nm to 315 nm range may not be simply additive. The EL should be used with caution in evaluating sources such as the sun and fluorescent lamps, having a rapidly increasing spectral irradiance in the 300–315 nm range. Large errors can arise because of the difficulty in making accurate spectral measurements of such sources in this region.

c. The EL may not provide adequate protection for photosensitive individuals or for normal individuals exposed concomitantly to chemical, pharmaceutical, or phyto-photosensitizers, and special precautions must be taken for such cases (Be70).

d. The EL should reduce the risk of occurrence of chronic skin effects by preventing acute effects and limiting life-long UV exposure. An action spectrum for UV skin carcinogenesis is not known for man, although the erythemal action spectrum has been used for global estimates of UV exposure. The Dutch Health Council (Ge78) proposed envelope limits similar to these ELs for acute daily exposure up to 10 years duration. For longer periods, to protect against chronic effects, another set of values which are about 15 percent of the acute set should be used. These should have the same action spectrum in the UV-B and UV-C. In many cases, occupational exposure to UV-B adds to an individual's nonoccupational exposure to solar UV-B.

e. In addition to the UV hazard, very intense UV-C sources may also produce hazardous concentrations of ozone and nitrogen oxides from the air and of phosgene gas in the presence of degreasers.

9. *UV-A radiation effects*

Limited data are available on which an EL for UV-A may be reasonably formulated. However, few industrial sources emit sufficient intensity in this spectral region to cause adverse biologic effects. Skin damage is principally thermal in nature requiring very high irradiances except in photosensitive individuals (Pa82). Photokeratitis and lenticular opacities have been produced in experimental animals with acute exposure at high radiant exposures (Pi77; Zu80; Zu77). There are no indications that the low levels of UV-A found in most indoor work environments present a hazard although it has been hypothesized as one causative agent for cataracts in the past (Sl80). Thus, the EL for UV-A should be below most conceivable thermal or photochemical injury mechanisms.

In recent years there has been a rapidly growing population of aphakic individuals who have had one or both crystalline lenses removed following cataract. Many of these aphakics have received artificial intraocular lenses of glass or plastic. (Such individuals are frequently referred to as pseudophakics). Aside from a few with implants designed to absorb UV-A, these persons would not be adequately protected against retinal injury from UV-A exposure at the EL (Ha82). Such persons should be fitted with UV-A protective lenses if working with sources of UV-A radiation.