

## V. DEVELOPMENT OF STANDARDS

### Basis for Previous Standards

The production of erythema has been the most commonly used endpoint in the evaluation of the biological activity of ultraviolet. Early investigators<sup>26-29</sup> produced a series of erythema action spectra (Figure X-1). These workers all based their curves on the production of moderate erythema, contending that the threshold for minimal erythema was too difficult to determine and too variable among individuals.<sup>8,34</sup> Coblenz and Stair<sup>29,30</sup> proposed a "standard" erythema action curve which was the average of the curves previously developed. This curve has been widely used and accepted as the "true" erythema action curve (Figure X-2).

In 1948 the Council on Physical Medicine of the American Medical Association<sup>104</sup> recommended an ultraviolet exposure guide. The following criteria were recommended for safe exposure to radiant energy from germicidal lamps, which produce an almost monochromatic emission in the 253.7 nm line: "The total intensity of ultraviolet radiation ... incident on the occupant for seven hours or less should not exceed five-tenths microwatt per square centimeter ( $0.5 \mu\text{W}/\text{cm}^2$ ) and for continuous exposure (twenty-four hours a day) should not exceed 0.10 microwatt per square centimeter of wavelength 2,537 A." (253.7 nm). The criteria were based on that dose which would not produce erythema. According to the "standard" curve of Coblenz and Stair, moderate erythema occurs at a dose of  $20 \text{ mJ}/\text{cm}^2$  at the most effective wavelength of 296.7 nm. The 253.7 nm line, however, is only 50% effective, and the dose at this shorter wavelength ultraviolet necessary to produce moderate erythema is  $30 \text{ mJ}/\text{cm}^2$ . The 7-hour and 24-hour doses

recommended by the AMA Council are  $12 \text{ mJ/cm}^2$  and  $8.6 \text{ mJ/cm}^2$ , respectively. Both of these values are substantially below the "standard" action spectrum to protect against erythema.

Recognizing that many factors affect individual responses, Matelsky<sup>119</sup> suggested, based on the "standard" erythema action curve, the following threshold doses weighted on the basis of their action spectra:

(1) Minimum erythematous dose for previously non-exposed skin:  
 $20$  to  $25 \text{ mJ/cm}^2$  of erythemally-weighted ultraviolet.

(2) Minimum erythematous dose for previously exposed skin:  
 $25$  to  $35 \text{ mJ/cm}^2$  of erythemally-weighted ultraviolet.

(3) Minimum keratitic dose:  $1.5 \text{ mJ/cm}^2$  of keratitically-weighted ultraviolet.

The American Conference of Governmental Industrial Hygienists<sup>120</sup> has proposed Threshold Limit Values, for 320 to 400 nm, of  $1.0 \text{ J/cm}^2$  for periods greater than, and  $1.0 \text{ mW/m}^2$  for periods less than, 1000 seconds. For the actinic spectral region of 200 to 315 nm, the Conference proposed limits described by a curve (see Figure I-1) in which the maximum permissible doses range upward at both longer and shorter wavelengths from  $3.0 \text{ mJ/cm}^2$  at 270 nm.

#### Basis for Recommended Standard

The environmental exposure standard recommended in this document is the same as that proposed by the American Conference of Governmental Industrial Hygienists.<sup>120</sup> The ACGIH has not published the documentation or reasoning behind their proposed standard. The NIOSH rationale for recommending the same environmental exposure standard is as follows:

The results of the early investigators were quite consistent in the 280 to 315 nm range, but were somewhat divergent in the lower wavelengths

studied (Figure X-1). Part of this divergence could be due to difference in body location tested and time after exposure at which erythema was determined. As pointed out by Berger, Urbach and Davies<sup>34</sup> for 254 nm, the erythema produced by the shorter wavelengths is relatively transient compared to that produced by wavelengths of 280 to 315 nm, so that time after irradiation is a major factor contributing to the degree of erythema observed.

Other workers<sup>121-124</sup> between 1946 and 1964 reported quantitative data on energy requirements for erythema production. In each case cited, in contrast to expectations from the "standard" erythema curve, less energy was required to produce erythema at shorter wavelengths of 250 to 260 nm than at longer wavelengths. Nevertheless, it was not until recently that the "standard" erythema action spectrum was seriously challenged. An erythema action curve published in 1965 by Everett, Olson, and Sayer<sup>32</sup> was continuous, requiring larger amounts of energy for production of effects as longer wavelengths were employed. In 1966, Freeman et al.<sup>33</sup> developed an erythema action spectrum which was intermediate between the "standard" and the Everett, Olson, and Sayer curve (Figure X-3).

Two basic differences in experimental technique apparently are responsible for the differences in action spectra. Data for the "standard" erythema action curve were based on moderate erythema determined at various times (usually 24 hours) after exposure. The data of Everett and of Freeman and their collaborators were based on minimal perceptible erythema, determined 8 hours after ultraviolet radiation was applied. Berger, Urbach, and Davies demonstrated (Figure X-4) that by varying these two factors, one can produce erythema action spectra resembling either the "standard" or the Everett et al. action spectra.

There has been little uniformity in the choice of body sites irradiated by the different investigators. Olson, Sayre, and Everett<sup>103</sup> have shown the trunk to be more sensitive than either the head or the extremities, and the abdomen (used by them to develop their action spectrum<sup>32</sup>) the most sensitive of three trunk locations tested. After exposing abdominal skin to ultraviolet radiation at nine wavelengths between 250 and 310 nm, they reported that, while erythema response was well developed for all wavelengths after 8 hours, the response had substantially decreased at the shorter wavelengths after 24 hours. Furthermore, the energy requirements for minimal perceptible erythema at 254 and 280 nm were lowest at 8 hours after irradiation and nearly twice as much at 24 hours. The energy requirements for minimal perceptible erythema at 297 nm, however, decreased about 5% between 8 and 24 hours. Thus, it is apparent that the recent erythema action spectra, indicative of minimal perceptible erythema doses determined 8 hours after irradiation of a sensitive part of the body should at least reflect lower energy requirements and possibly other differences as well, when compared to the traditional curve.

Relatively minor damage to the conjunctiva or cornea from ultraviolet results in photophobia, pain, epiphora, and blepharospasm. Although the response is acute and incapacitating at the time, it regresses after several days leaving no permanent damage.<sup>119</sup> The action spectrum for photokeratitis developed by Pitts and Tredici,<sup>10</sup> based on animal and human data, is slightly more conservative than the recent skin erythema curves and reflects maximum efficiency at 270 nm rather than 250 nm. Nevertheless, this curve and the recent erythema action spectra are in reasonably good agreement. This is in keeping with previous statements that the action spectrum for conjunctivitis

is the same as that for skin erythema.

<sup>8</sup> Sliney compared the action spectra, both for erythema and for photokeratitis, with the "standard" erythema action curve. Plotting energy versus wavelength, the recent action spectra are at considerably lower energies than is the traditional curve. Additionally, these action spectra are, in general, similarly distributed. Therefore, Sliney <sup>8</sup> drew a minimum hazard curve which conformed to the general distribution of the new data. This curve, recommended herein as the standard for the 200 to 315 nm range, was drawn with several considerations in mind.

In the 300 to 315 nm range, the Pitts and Tredici <sup>10</sup> data seemed overly conservative since, when weighted against the ultraviolet spectrum of indirect daylight in the tropics, it indicates that almost everyone there would develop keratoconjunctivitis in a few hours outdoors. Therefore, Sliney's curve in the 300 to 315 nm region excluded the Pitts and Tredici data and paralleled the "standard" erythema curve, although displaced slightly below it.

In the 200 to 300 nm range, the curve was drawn to include all action spectra while a general shape was maintained that would lend itself to the construction of a practical instrument for measuring the entire range from 200 to 315 nm. Constructing an instrument capable of following this smooth curve is more feasible than attempting to track a curve, such as the traditional erythema action spectrum, with several high and low points.

<sup>9</sup> Human photokeratitic thresholds recently determined by Pitts and Gibbons do not vary greatly between 220 and 310 nm, i.e. an almost flat curve results. Like the Pitts and Tredici <sup>10</sup> animal data, the reported human thresholds at 300 and 310 nm are more conservative than the recommended standard. Similarly,

the energy requirements for human thresholds are lower at and below 240 nm than is the recommended standard. The reported threshold values for 250 to 290 nm are all higher than the recommended standard.

While the Pitts and Gibbons data are informative, they should not be given great weight in establishing a standard for several reasons. First, the Pitts and Gibbons data are based upon exposures of relatively few individuals. Additionally, the reported thresholds are the threshold response of a single individual at each waveband tested since the experiment was terminated at each waveband as soon as a threshold response was observed in one subject.

Second, the curve is, as mentioned, almost flat. This is in contrast to the animal photokeratitic curves reported by Pitts and Tredici<sup>10</sup> and again in the Pitts and Gibbons<sup>9</sup> paper. While it may well be true that the human response varies slightly, if at all, with wavelength, the present results alone are not strong enough to support such a conclusion. Consequently, the curve drawn by Sliney<sup>8</sup> is believed not to be invalidated by the data of Pitts and Gibbons.

Assigning a relative spectral effectiveness of 1.0 to 270 nm, the low point of the recommended standard, the relative spectral effectiveness of other wavelengths can be calculated (Table I-1). The formula required for determining the effective irradiance of a broad-band source assumes a single erythema mechanism rather than a combination of different mechanisms for different wavelengths.

As discussed by Johnson, Daniels, and Magnus,<sup>31</sup> the shape of the "standard" erythema action spectrum suggests two mechanisms in erythema

production, one with peak efficiency at 297 nm and the other at 250 nm. This is supported by differences in the latent period, duration, and appearance of erythema produced by the shorter (260 nm) and the longer (297 nm) erythematic ultraviolet radiation. On the other hand, the action spectra of Everett and associates<sup>32</sup> and of Freeman and associates<sup>33</sup> suggested a single erythema mechanism since these action spectra reflect a steadily decreasing efficiency with increasing wavelength above the single peak of efficiency at 250 nm. Using 254, 280, and 297 nm ultraviolet radiation, Sayre, Olson, and Everett<sup>125</sup> have demonstrated experimentally that minimal perceptible erythema can be produced by subthreshold doses of two wavelengths acting in combination when the sum of the fractional doses equal one. These results support the idea of a single erythema mechanism.

The recommended standard (Figure I-1) is based upon action spectra both for erythema and for keratoconjunctivitis and is intended to protect the skin and eyes against acute effects. Therefore, separate skin and eye standards are not recommended. The American Conference of Governmental Industrial Hygienists proposed the limits expressed in this recommended standard and they specified its applicability for protection of both eyes and skin. The recommended standard is more readily applicable to the eye since the eye, unlike the skin, does not acquire protective capabilities after repeated exposures.

On the other hand, the skin does acquire resistance to ultraviolet damage after repeated exposure. Additionally, individual variations in threshold response are great. Matelsky<sup>119</sup> states that, despite the extensive industrial exposures to ultraviolet radiation, no cases of industrially-induced skin cancer or keratosis have been reported and concludes that protection against the painful acute effects adequately

protects against tumorigenic doses. Nevertheless, it is believed that there is not enough information to be completely sure that industrial exposures to ultraviolet energy will not cause chronic effects on eyes or skin, such as cataracts or skin tumors.

While erythematic and carcinogenic activity is limited to wavelengths shorter than 320 nm,<sup>33,90,119</sup> the lens of the eye absorbs strongly in the 300 to 400 nm range. "Black-lights" have a powerful emission line of 366.3 nm, which can cause the lens to fluoresce. This apparently causes some people, when looking at "black-lights", to experience a "tired" feeling, blurred vision, discomfort, and sometimes headache, but apparently no permanent damage ensues.<sup>126</sup>

There is some evidence from animal studies to implicate ultraviolet in this range as contributing to cataract formation.<sup>81</sup> While few industrial sources emit strongly in this range, the standard for 320 to 400 nm is recommended to prevent occupational exposures in this range from exceeding levels normally encountered in the out-of-doors.

Normal individuals should be adequately protected by these standards. Photosensitive individuals, however, may respond at extremely low energy levels and over very wide wavelength ranges, even into the visible wavelengths.<sup>122</sup> Therefore, these standards may not be adequate for photosensitive individuals. More research is needed before the adequacy of these standards in protecting against chronic effects on skin and eyes can be assured.



## VI. PROTECTION AND CONTROL MEASURES

Skin and eyes can be protected from the effects of ultraviolet radiation by shielding of sources of radiation, by goggles or face shields, by clothing, and, for special purposes, by absorbing or reflecting skin creams.

Principles and procedures in selecting suitable protection are summarized in this section, and studies of various protective measures are reviewed. Specific topics discussed are (1) sunscreens, (2) protective clothing and barrier creams, (3) transparent material for skin and eye protection and (4) reflection of ultraviolet radiation.

### (1) Sunscreens

Sunscreening preparations are usually classified as chemical or physical. The former include para-aminobenzoic acid and its esters, cinnamates, and benzophenones, all of which act by absorbing radiation so that the energy can be dissipated as radiation of lower energy. The physical agents act as simple physical barriers, reflecting, blocking, or scattering light. They include titanium dioxide, talc, and zinc oxide. Largely because of cosmetic objections, the physical barriers are infrequently used in sunscreen formulations.

Sunscreen protection from absorbing chemicals depends on maintenance of film thickness. Robertson<sup>127</sup> reported that a series of sunscreens of 0.01 mm thickness protected fair skin during four to five hours of sunshine if the protective layer was fully maintained for the whole period. When the thickness of the layer was halved, erythema occurred within a maximum of one hour.

Pathak, Fitzpatrick and Frenk<sup>128</sup> produced evidence suggesting that para-aminobenzoic acid and its esters in ethanol afforded protection against the sunburn range (290 to 320 nm) for several hours with one application and that the protective action was unaffected by bathing, swimming, or vigorous exercise. MacLeod and Frain-Bell<sup>129</sup> confirmed the effectiveness of para-aminobenzoic acid in ethanol and observed that protection was provided for up to seven hours after the initial application. They found, however, that the agent was easily removed as a result of bathing or exercising. Katz<sup>130</sup> also noted that para-aminobenzoic acid is not water-resistant; he found that a consistently satisfactory protection against the erythemalogenic rays of the sun was lost after a 10-minute swim.

Goldman and Epstein<sup>131</sup> reported that a commercial suncreening agent containing the ultraviolet-absorbing chemical glyceryl para-aminobenzoate was a photosensitizer and that it had produced severe dermatitis in a patient who applied it prior to exposure to sunlight. The agent was an ordinary contact allergen as well as a photosensitizer. Turner, Barnes and Green<sup>132</sup> found that a preparation containing vitamin A and calcium carbonate reduced the unpleasant effects of solar radiation without affecting normal tanning. The beneficial effect was most marked in subjects with blond hair. This observation could not be repeated, according to Findlay.<sup>133</sup>

Red veterinary petrolatum is cosmetically less acceptable than other agents, but has a long history of effective protection of normal skin from the damaging effects of the ultraviolet sunburn spectrum. Like the benzophenones, it also gives some protection in the long ultraviolet waveband (MacEachern and Jillson<sup>134</sup> ; Luckiesh, Taylor, Cole and Sollman<sup>135</sup>).

Fusaro and his coworkers approached the problem of protection against sunlight by altering the stratum corneum chemically so that the keratin had new ultraviolet transmittance characteristics. They believed that this could be accomplished with a dihydroxyacetone/napthoquinone mixture (DHA/Lawsone) made up in a vanishing cream base rather than in an isopropyl alcohol/water solution. This preparation was thought to be effective in patients with erythropoietic protoporphyria, but Donaldson et al.<sup>138</sup> doubted its efficacy with their patients.

For individuals with chronic photosensitivity diseases, it is desirable to add a light-scattering and reflecting agent (e.g., titanium dioxide, talc, and zinc oxide) in combination with a light absorber in a hydrophilic ointment.

## (2) Clothing and Barrier Creams

Protective clothing consists of long-sleeved garments to protect the arms while a small cape sewed to the cap protects the back of the neck and the sides of the face. Flannelette and poplin give maximum protection, while other materials give less protection (Table X-4).

Where it is impossible to shield the skin by clothing, polyvinyl chloride gloves, masks, shields or by redirecting the radiation by suitable reflectors, a barrier cream should be applied to the skin before irradiation. Ordinary soft paraffin is an excellent barrier, but its greasiness will often preclude its use on hands. Barrier creams contain ingredients which absorb ultraviolet radiation. The benzophenones are the best compounds for this purpose because of their great absorption capability throughout most of the near and far ultraviolet spectrum (Parrish et al.<sup>139</sup> ).

### (3) Transparent Materials for Eye and Skin Protection

Protection of the eyes in industrial applications such as welding requires materials which are strong absorbers of ultraviolet radiation. A large number of protective glasses have been developed for this purpose. Many of them also absorb strongly in various portions of the visible and infrared regions. The earliest of these glasses was developed almost 60 years ago, and subsequently, many others have been developed. Their characteristics are described in "Spectral-Transmissive Properties and Use of Eye Protective Glasses" by R. Stair.<sup>140</sup> The transmission of Noviol, slightly yellow glasses which cut off sharply at about 400 nm, is shown in Figure X-6 and Table X-5.

For protection of the eyes and skin from limited exposure to ordinary ultraviolet lamps, common window glass is usually adequate. Ordinary window glass in thickness of 2 mm or more is practically opaque to ultraviolet radiation of wavelengths shorter than 300 nm. Thus an ordinary window pane, although it emits much of the incident visible radiation, excludes practically all the ultraviolet wavelengths of the erythema and therapeutic ranges. Figure X-7 shows the percent transmission as a function of wavelength for two thicknesses of window glass.<sup>141</sup> As can be seen from the curve, the transmission falls off rapidly with wavelength below 360 nm. Window glass 1/8 in. in thickness is adequate protection for the eyes and skin against ultraviolet radiation from ordinary ultraviolet sources. In the case of very intense sources of ultraviolet radiation, it may not be sufficient.

Full protection against 253.7 nm radiation is provided by shields of clear ultraviolet-absorbing plexiglass, ordinary (glass) spectacles, crookes glass, and similar ultraviolet-absorbing materials. Crown glass, an alkali-lime silicate glass, (2 mm-thick) will significantly reduce exposure hazards. Flint glass, a heavy glass containing lead oxide, (2 mm-thick) affords essentially complete protection at all wavelengths. Noviol glasses or Polaroid ultraviolet filters can be used where high intensity ultraviolet is anticipated, as in welding. If an individual is working in a room with an ultraviolet source for any length of time, he should wear protective glasses or a face shield because many materials reflect 253.7 nm radiation (Table X-6).

Glass workers, arc welders and people engaged in similar types of work may be exposed to infrared radiation as well as ultraviolet radiation, and may need eye protection from both types of radiation. Such people should wear goggles with an infrared absorbing glass and an infrared reflecting surface. Ordinary glass, plastics and other materials are usually transparent to infrared rays which can cause thermal damage to the eye. A glass that absorbs in both the ultraviolet and infrared regions of the spectrum will be needed in such cases. For listings of absorbing glasses refer to ANSI-Z 49.1.<sup>142</sup>

#### (4) Reflection of Ultraviolet Radiation

When a number of ultraviolet generators are operating in one room, protection of personnel poses several problems. In many applications, little difficulty is encountered in properly shielding the source so that most, or all, of the output is restricted to the exposed material. Stray radiation can be reduced, but reflection from glass, polished metal, and

high-gloss ceramic surfaces can be harmful to people working in the room. Absorption of ultraviolet radiation therefore becomes an important item to consider in planning a safe work environment. Since painted walls and ceilings can be a significant source of ultraviolet reflection, it is necessary to consider the ultraviolet reflective properties of the paint used.

The reflection of incident ultraviolet radiation from pigments can range from negligible to more than 90%. A given material's ability to reflect visible light is no indication of its ability to perform similarly with ultraviolet. Table X-7 gives the reflection from a number of white pigments and other materials at several wavelengths in the ultraviolet. The table shows that ordinary white wall plaster has a reflection of 46% at 253.7 nm, whereas zinc and titanium oxides, which are equally good reflectors for visible light, reflect only 2.5% and 6%, respectively, at this wavelength.

Oil-vehicle paints usually have low reflectances because of the absorption by the oil. However, some paints using synthetic plastic vehicles with high ultraviolet transmission may have high reflectances. Walls surfaced with gypsum products tend to have high reflectances.

Table X-8 shows the ultraviolet reflectance of a number of dry white pigments in the region between 280 and 320 nm. These measurements were made with the unresolved radiation from a S-1 lamp as a source and a cadmium phototube as a detector. These measurements may be assumed to be predominantly at the wavelength 302.4 nm.

No assumptions regarding the reflections of white pigments should be made without investigating their composition. The reason for this is demonstrated by the difference between two white pigments, zinc oxide and white lead. Although both of the pigments are very good reflectors of visible radiation, zinc oxide reflects only 3% of the ultraviolet, whereas white lead reflects about 60%. Colored pigments are almost invariably poor reflectors of ultraviolet. Stutz<sup>143</sup> studied 38 colored pigments and found that only turquoise blue had a reflectance of as much as 25% at 331.1 nm. At 253.6 nm turquoise blue had a reflectance of 22%, whereas none of the others exceeded 7.5%.

Table X-9 shows the ultraviolet reflectance of a number of paints with different white pigments suspended in silicone.

The basic requirements which determine the reflecting power of an ultraviolet-reflecting paint have been given by Koller<sup>141</sup> :

1. Particles of the pigment must be low in absorption (except metallic pigments), so that a large portion of the incident radiation is returned by multiple reflection and refractions.

2. The binder or vehicle must be transparent to the radiation to be reflected.

3. The difference in refractive index between pigment and medium must be large so that reflection and refraction at pigment-medium interfaces will be appreciable.

The properties of a paint depend upon the nature and amount of the pigment and the state of its aggregation. The addition of a small amount of colored pigment to a white paint may result in a large decrease in the ultraviolet reflection. The reflectance decreases with increase in amount of added colored pigment.

Two materials with a high reflectance in the visible and the ultraviolet are magnesium oxide and magnesium carbonate. Reflection curves are shown in Figure X-8. Tellex and Waldron<sup>144</sup> reported that for a sufficiently thick coating (8  $\mu$ m) the reflectivity of magnesium oxide is about 98% and is almost independent of wavelength over the visible spectrum. For thinner coatings the reflection decreases slightly and there is a rather flat maximum of 98% at 540 nm.



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