

# An analysis of cumulative lifetime solar ultraviolet radiation exposure and the benefits of daily sun protection

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**ABSTRACT:** Cumulative exposure to ultraviolet radiation (UVR) increases the risk of developing skin cancer, particularly squamous cell carcinoma and basal cell carcinoma. Thus, the need for protection from the sun is widely advocated, but consumers generally associate such protection with the occasional extreme exposure and tend to ignore the risk of long-term exposure. In fact, a sun exposure model predicts that over a lifetime, a person will receive tens of thousands of minimal erythema doses worth of UVR through normal, daily, incidental exposure. The cumulative effect of casual sun exposure over the years underscores the need for everyday basic UVR protection in which even low level (SPF 4–10) sunscreens are shown to offer significant benefit. Analysis shows that daily protection can reduce lifetime exposure by 50% or more.

**KEYWORDS:** minimal erythema dose, skin cancer, solar exposure, sun protection factor value, sunscreens, ultraviolet radiation.

## Introduction

The American Academy of Dermatology has estimated that more than 50 000 new cases of melanoma, 200 000 of squamous cell carcinoma, and more than one million occurrences of basal cell carcinoma (BCC) will be diagnosed in the USA each year. Long-term exposure to ultraviolet radiation (UVR) is believed to be a contributing factor in all cases, particularly those of BCC (1). It has long been hypothesized that the real danger of skin cancer does not result from a few acute exposures, but from cumulative exposure received over a lifetime, particularly that acquired during childhood (2).

Studies in Europe in the 1980s and 1990s, and more recently in Australia, measured the average daily exposure levels of schoolchildren and adult

workers in a variety of occupations. The findings showed that people are persistently exposed to solar UVR from early age. In one study, 180 children received between 5% and 10% of ambient daily UVR (3). In other studies, adult indoor and outdoor workers received ambient UVR ranging from approximately 5% to 30%, respectively (4–6). What is not clearly evident from these studies is how daily exposure to suberythemal levels of UVR becomes the equivalent of substantial cumulative exposure levels over a lifetime.

With this in mind, the present authors revisited data collected by the National Institutes of Health (NIH) in which UVR was measured daily for a full year in nine locations throughout the USA. They used these data to project cumulative lifetime exposure for unprotected skin and to understand the potential impact of daily UVR protection. Their analysis shows that cumulative exposure can reach the equivalent of 20 000 minimal erythema doses (MEDs) by the age of 30 years. Thus, the present paper reviews the risks of UVR,

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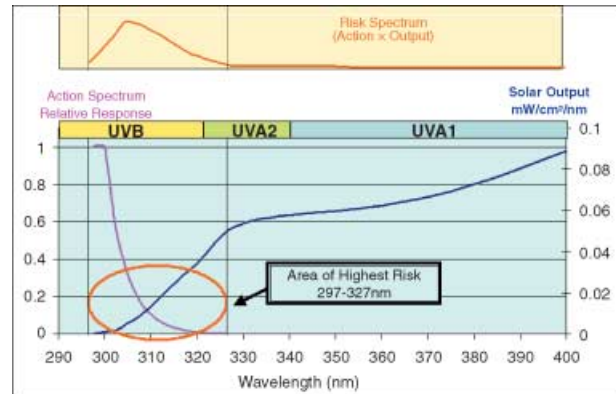
and a model that seeks to elucidate the risks of long-term UVR and the benefits of year-round sun protection as part of everyday fundamental skin care.

## Sun, ultraviolet rays, and sun protection factor

An important consideration in sun protection is the relative biological impact of the solar spectrum components. Solar UVR is delineated into four regions: UVC (< 290 nm), UVB (290–320 nm), UVA2 (320–340 nm), and UVA1 (340–400 nm). Wavelengths above UVA1 mark the beginning of the visible light spectrum. Ultraviolet C is absorbed by stratospheric ozone and does not reach the earth's surface, whereas the shorter wavelengths of UVB—which constitute just 10% of terrestrial UVR—are the more biologically active, but also the less penetrating. Ninety per cent of received UVB is confined to the epidermal layer (7). On the other hand, UVA penetrates the epidermis to a depth of 0.2 mm, although its activity decreases as the wavelength increases. Thus, given the variable activities of the UV components, the biological effects of a specific wavelength of light or radiation are often better described in terms of action spectra.

The erythema action spectrum shows that skin is much more reactive to UVB rays than to UVA (8,9). For midday sun, the predominant risk for burning and cancer is from UVB, although there is a smaller but still significant contribution in the UVA2 range (~19% of the total), with a negligible contribution from the UVA1. Wavelengths within the 306–310-nm range present the highest risk of burning. Since the erythema and carcinogenicity action spectra are similar, this wavelength region also makes the greatest contribution to skin cancer risk (Fig. 1).

While the action spectrum defines the relative ability of a wavelength of light to affect a biological system (i.e., skin tissue), the solar spectrum, comprising the full range of radiation actually emitted by the sun, is equally important. Perhaps more informative is the product of both—commonly called the risk spectrum—obtained by multiplying the action and solar spectra. The risk spectrum provides a useful metric for understanding the interaction of energy emitted by the sun with the energy absorbed by the skin. Specifically, risk spectra help to identify the relative cancer-causing potential of various wavelengths and the differential ability of sunscreen formulations to



**Fig. 1. Solar ultraviolet radiation (UVR) spectral output plotted against the erythematol action spectrum of skin. Increasing output (and skin penetration) as wavelength increases is balanced by decreasing biological activity. The crossover point marks the risk peak in the UVB region and tailing into UVA2.**

absorb and/or reflect wavelengths associated with a risk of skin cancer.

### Effects of ultraviolet radiation on skin

Ultraviolet B, the short wave component of solar UV, may cause serious sunburn in the short term and predispose one to skin cancer in the long term. On the other hand, UVA tends to damage the structural proteins of the dermis (e.g., collagen and elastin), and thus, is responsible for premature skin aging (photo-aging). Chronic solar radiation also contributes to dry skin by disrupting differentiation in the granular layer, including the processing of profilaggrin, the precursor to the natural moisturizing factor (NMF), as discussed in pp. 43–48 of this supplement.

The most visible reaction to UV exposure is the formation of melanin, and the thickening of the epidermis and horny layers, a natural defense mechanism intended to decrease further penetration to the basal layer where proliferation is taking place. The UVB action spectrum overlaps the absorption spectrum of nucleic acids and proteins. Thus, penetration of the shorter-wavelength UV into the basal layer can induce damage to the nitrogenous bases of DNA and RNA, and the aromatic amino acids of proteins, the cumulative effects of which may lead to dysfunctional cellular activity. Ultraviolet B has been specifically associated with mutations causing the uncontrolled activation of the *ras* family of oncogenes and the inactivation of the p53 tumor-suppressor gene (10,11).

While the role of UVB in skin damage and oncogenesis is well understood, the role of UVA is less clear. Shorter wavelength UVA2 is widely believed to have a role in enhancing UVB-induced skin cancers. Studies in animal models suggest that high doses of longer wave UVA1 may well be carcinogenic, although far less so than UVB (12). The immunosuppressive effect of UVR, mediated by the SC component urocanic acid (13), plays a role in UVR carcinogenicity as well.

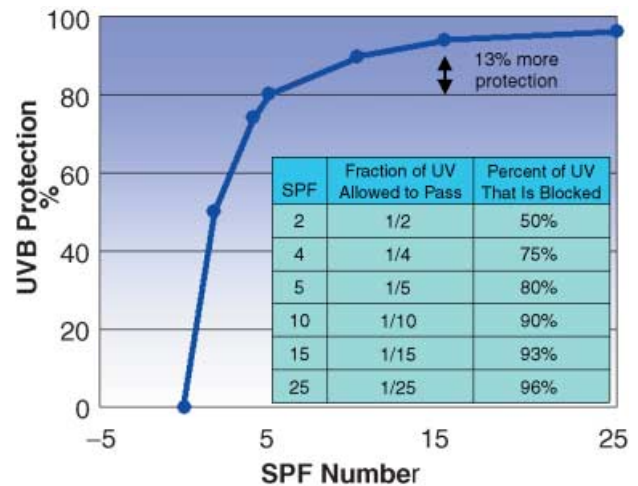
Repeated low doses of UVR have also been shown to produce a number of deleterious changes in the epidermis and SC. These include depletion of Langerhans cells (believed to be a further factor in UV-induced immunosuppression), epidermal hyperplasia, and thickening of the SC (14). Furthermore, UVR reduces levels of vitamin A (15) and antioxidants including vitamin E (16).

### Sun protection

An understanding of the solar, biological action, and risk spectra underscores the potential danger of UV to skin, and the need for sunscreen product technology. Sunscreen products are designed to either absorb or physically block the penetration of UV rays into skin. Each organic sunscreen—including octyl methoxy cinnamate, oxybenzone, or parsol 1789, among others—offers a unique spectrum of UV absorption activity. Inorganic sunscreens such as micronized titanium oxide and zinc oxide play an absorptive and reflective role as well. It is the particular combination of UV-absorbing ingredients and excipients that determines the overall performance of a sunscreen. In order to assess and compare the skin protecting ability of the wide variety of products available, a standard test method is used to determine a product's sun protection factor (SPF).

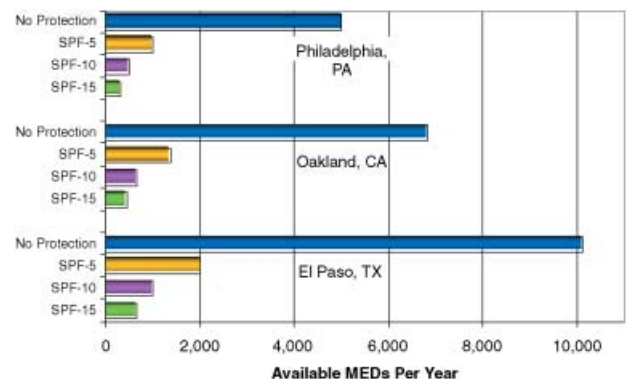
### Demystifying sun protection factor

Although the concept of SPF is widely known and accepted as a measure of protection, there is little understanding of how an individual SPF value is derived, and of the relationship between different SPF values. It is generally assumed, but actually quite wrong, that there is a simple arithmetical relationship between SPF values, with double the SPF number meaning double the protection. Sun protection factor is defined as the ratio of UV energy required to produce 1 MED on protected skin to the UV energy required to produce 1 MED on unprotected skin (Fig. 2). Thus, the SPF value is, by definition, inversely related to the amount of



**Fig. 2. Inverse relationship of sun protection factor (SPF) value and percentage of ultraviolet burning (UVB) protection means that greater benefit is realized in the range of no protection to SPF-5 than from SPF-5 to SPF-15. Even so-called low-level sunscreens can have a real benefit in reducing the accumulation of casual exposure.**

UV light transmitted to the skin. Since an SPF of 4 permits 25% of the UVR to pass through, 75% of the UVR is absorbed and/or reflected. Thus, even a relatively low SPF values provide a beneficial amount of UVR protection from casual exposure. In fact, there is a diminishing return on higher SPF sunscreens: an SPF of 5 delivers 80% protection while an SPF-15 delivers only 13% more. As shown in Fig. 3, the inverse relationship between the SPF value and UV protection helps to



**Fig. 3. Available solar ultraviolet radiation, expressed in minimal erythema doses (MEDs), for one year for three locations in the USA, showing exposure to unprotected skin, as contrasted with use of agents containing values at levels of sun protection factor (SPF) 5 (80% reduction), SPF-10 (90% reduction), and SPF-15 (93% reduction).**

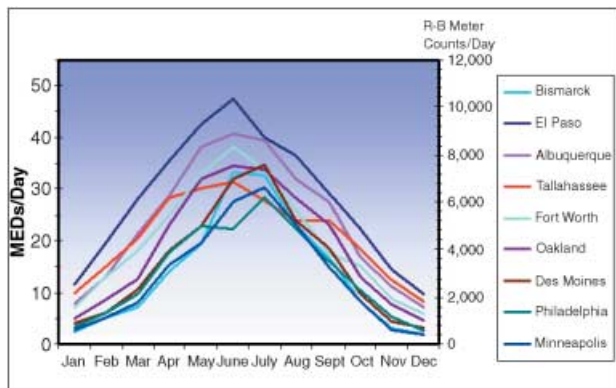


Fig. 4. Mean daily solar radiation for nine cities in the USA. Data taken from Robertson-Berger (R-B) meter counts and converted to equivalent minimal erythema doses (MEDs) per day for a person with Fitzpatrick type II skin.

explain why a much greater benefit is obtained by going from SPF-2 to SPF-4 (25% greater protection) than from going from SPF-20 to SPF-40 (2.5% greater protection).

### Ultraviolet radiation in the USA

In 1974, a study was commissioned by the NIH to monitor geographic and seasonal changes in solar UVR across the USA (17). Robertson-Berger (R-B) meters were installed on rooftops of nine weather stations in the continental USA. The R-B meters were filtered to measure the erythetically weighted UVB (i.e., burning doses) in a dimensionless R-B meter unit, and the data were collected every 30 min for a complete year.

Although Robertson-Berger estimated that 440 RB units would be equal to 1 MED, subsequent work by Agin-Poh and Sayre (18) correlated R-B meter counts with MED and skin type and reported that 221 RB units equaled 1 MED for Fitzpatrick type II skin. Using this refined conversion, the progression of UVR across months and locations can be traced in terms of MEDs per day (Fig. 4). The data show that there are high levels of burning UV rays available during the summer peak months in the USA, whether in the north or south of the country, averaging from 20 to 45 MEDs each day. Equally important, although UVR peaks in the summer, significant levels of UVR still reach the earth throughout the year and at all locations.

As shown in Fig. 5, the equivalent of 5 000–10 000 MEDs of solar UVR are available in the USA for a full year (again, based on type II skin).

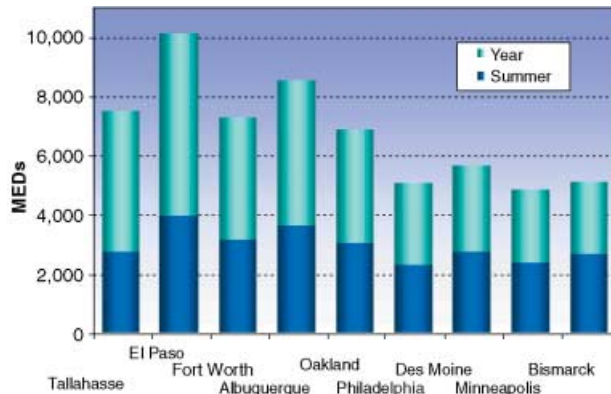


Fig. 5. Annual total ultraviolet radiation (UVR), expressed in minimal erythema doses (MEDs) for Fitzpatrick type II skin, showing the relative proportion available during summer (June through August) versus the rest of the year.

Although UVR intensity peaks in the summer, over half of the annual total still shines down during the rest of the year when people are not generally concerned about sun protection. The present authors believe that few people understand the need for continuous protection because so much actual exposure is in sub-erythemic doses in the off-season. Market research data show less than 15% of consumers use a sunscreen daily throughout the year (19).

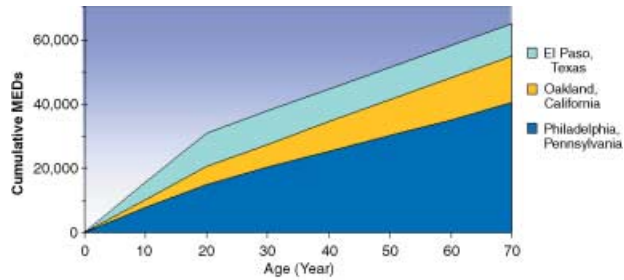
### Lifetime exposure to ultraviolet radiation

Numerous experiments have been conducted in Europe and Australia to measure actual cumulative daily UVR exposure (3–5). Although details differ, the general conclusion is that people are regularly exposed to solar UVR from an early age. The most vulnerable areas are unprotected skin on the neck, face, hands, and lower arms.

By projecting typical exposure levels at different ages against the amount of solar UVR actually available, the present authors developed a model for an average individual as follows:

- age 1–20 years: exposed to 6% available UVR September to May and 25% June to August; and
- age 20–70 years: exposed to 10% available UVR year-round (typical office worker).

This model, based on an average individual living in Philadelphia, PA, USA, predicts that the person will be exposed to more than 15 000 MEDs by 20 years of age and another 25 000 MEDs by 70 years of age. Living in a sunnier locale such as Oakland, CA, USA, will add another 15 000 MEDs over a lifetime, and residence in El Paso, TX, USA,



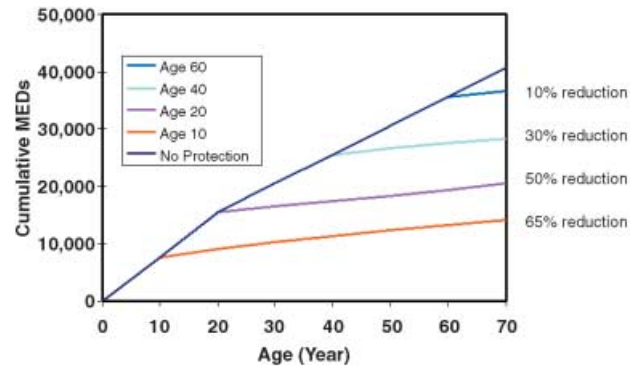
**Fig. 6.** Cumulative exposure to ultraviolet radiation (UVR) over a lifetime can exceed 30 000 minimal erythema doses (MEDs) worth of UVR in the northeast USA, and be even higher in sunnier locations. For any individual, actual levels can be lower or even very much higher, depending on habits and lifestyle. The danger is that the majority of this exposure goes unnoticed and, therefore, is not prevented because it is received in sub-erythema doses each day.

adds yet another 10 000 MEDs (Fig. 6). Individual lifestyle and habits will greatly influence total exposure, but the potential for cumulative lifetime exposure is clear.

### Everyday protection

Sunscreen products are still typically viewed as necessary only for periods of expected, intense exposure. The enormous potential benefit from everyday protection is not sufficiently recognized. Using their Philadelphia model, the present authors found that daily protection can reduce total UVR exposure by more than 50% if good habits begin in childhood (Fig. 7). The equivalent of SPF-5 protection every single day is enough to achieve real benefit. Later in life, everyday protection is still beneficial. Daily SPF-5 use begun at 40 years of age can still pare 15 000 MEDs worth of UVR from a lifetime total (19).

For effective long-term protection against incidental UVR, high-level, broad-spectrum sunscreen products are important tools, particularly when exposure and the potential to burn are high,



**Fig. 7.** Effect of low-level (sun protection factor 5) daily protection from casual ultraviolet radiation (UVR) exposure, even if begun after childhood, can provide a large reduction in lifetime cumulative UVR exposure. Percentages are based on an exposure model for Philadelphia, PA, USA: (MEDs) minimal erythema doses.

but consumers continue to be reluctant to use them every day. Therefore, daily protection needs to be as much about awareness and changing habits as it is about convincing consumers to use sunscreen products. Being careful about UVR protection must not be limited to sunny-day activities. The US Environmental Protection Agency SunWise program provides simple and effective tips for reducing exposure (Table 1) (20).

### Lifetime benefits

With skin cancer levels rising, there is an urgent need to reduce UVR exposure. Sun protection is usually associated with acute exposures. The present authors' exposure model indicates that the equivalent of tens of thousands of MEDs of solar UVR can accumulate over a lifetime through casual daily exposure. For intense UVR exposure, there is no denying the necessary protection of SPF-15, SPF-25, or higher. However, to reduce lifetime totals derived from incidental UVR exposure, the model demonstrates that long-standing use of even SPF-4–10 can help. This suggests an

**Table 1.** US Environmental Protection Agency SunWise tips

- Limit your time in the sun between 10:00 and 16:00 h
- Whenever possible, seek shade
- Use a broad-spectrum sunscreen with an sun protection factor of at least 15
- Wear a wide-brimmed hat and, if possible, tightly woven, full-length clothing
- Wear UV-protective sunglasses
- Avoid sun lamps and tanning salons
- Watch for the UV index daily

opportunity for skin-care companies to build in low-level protection as an easy way of delivering basic protection to the consumer. It is also an opportunity to raise consumer awareness that shielding from UV rays necessitates more than simply using high exposure/high SPF. Basic, sustained protection is crucial to help prevent the rising incidence of skin cancers. The goal should be basic sun protection, as provided by sun avoidance, adequate clothing and the appropriate use of sunscreen products.

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