Optica Applicata, Vol. XXIX, No. 1–2, 1999

Effect of layer thickness of dermatological sunscreens and cosmetics on UVB-solar carcinoma protection

B. Stádník

Institute of Radioengineering and Electronics, Academy of Sciences of the Czech Republic, Chaberská 57, 182 51 Prague 8, Czech Republic.

M. Jirásková

2nd Dermatological Clinic of the Faculty of Medicine, Charles University of Prague, U nemocnice 2, 128 08 Prague 2, Czech Republic.

We show that the protective properties of dermatological sunscreens and cosmetics against the harmful UV-solar radiation are strongly dependent on the cream layer thickness deposited on the skin. We define the dermatological effective thickness for which the protection effect is optimal, giving the protection declared by a cream producer. We give an illustrative example of the F-factor layer thickness dependence, and show the main protection characteristics for various dermatological creams. Optical parameters of the various optical creams are summarized in tables.

1. Introduction

When ultraviolet radiation impinges on a human cell, the multitude of photochemical reactions may occur. Photoproducts, chemical reactants as well as various mediators can be released from cell membranes, lysosomes and other organelles. Although many cellular components can be damaged by UV-radiation, many authors believe that the DNA is the critical target involved in the killing of cells. Mutation of basal cells may lead to malignant transformations, keratinocytes in stratum basale and stratum spinosum, and the majority of skin cancers in humans.

Despite of many kinds of artificial optical sources which are commonly used in various branches of human activity as, for example, various arc-lamps, lasers, solar simulators *etc.*, the sun is the most important source of the UV-radiation. Stratospheric ozone operates effectively as a screen, filtering out the short-wavelength radiation as it passes through the atmosphere, and allowing only a small part of the longer wavelengths to penetrate to the surface of the earth. Although the UVB-radiation forms only a small part of the whole solar radiation, less than 1%, it can have a major impact on the human cells because, as is generally known, it is a very active carcinogen.

Dermatological sunscreens and cosmetics may reduce the harmful effect of the UVB-radiation. However, the successful effect is strongly dependent on many factors such as, for example, temperature, humidity of air, time of the day, type of human skin, *etc*. This article concentrates mainly on the protection properties of selected dermatological sunscreens depending on their layer thickness. Recommendations for practical use of sunscreens are concluded.

2. Effective layer thickness

From the optical point of view, the main problem of the right application of dermatological sunscreens and cosmetics to the skin is the use of the proper cream thickness. As we know, if this thickness is smaller than the effective thickness, the protection effectivity of the cream is low. If, on the contrary, the thickness of the cream is bigger than the effective thickness, the efficiency of the cream is also low.

The main goal is the proper cream layer thickness. We define the effective cream layer thickness as the one which ensures that the cream protection capability is in agreement with that declared by a producer. Because of different absorption properties of various dermatological creams at optical wavelengths, it is different for every cream. In practice, the real cream thickness is different from the effective thickness and, as a consequence, the protection properties of the cream are not effective. If the cream layer thickness is optimal, the cream has maximum efficient effect.

Our study of the protective effect of dermatological creams and its dependence on the cream layer thickness is based on the cream absorption properties. For this reason, we introduce the optical F-factor, the F_0-factor, not only for the UVB-radiation where the optical representative wavelength is 302 nm but also for other optical bands such as, for example, UVC (representative wavelength – 254 nm), UVA (representative wavelength – 369 nm), VIS (visible band, representative wavelength – 700 nm), and NIF (near infrared band, representative wavelength – 880 nm). We define the F_0-factor as the reciprocal value of the transmittance.

3. Experimental method

We focused our attention on spectral measurements of absorption properties of 24 dermatological sunscreens and cosmetics of various thicknesses. These measurements were made in the wavelength range from 254 nm to 880 nm and for layer thicknesses from zero to several tenths of a micron using the setup comprising optical source, spectrophotometer, optical analyser, photodetector, and optical filters. The details of the measuring method are given in paper [1].

Our procedure will be shown using the "Banana boat" cream. Summary data concluded from these 24 measurements are given in the tables.

3.1. The "Banana boat" cream

This cream is declared to be the chemical-free sunblock containing natural agents reflecting and absorbing UVA- and UVB-radiation. It is suitable for a sensitive skin and especially for the allergics. It contains neither fat nor compounds irritating the skin.

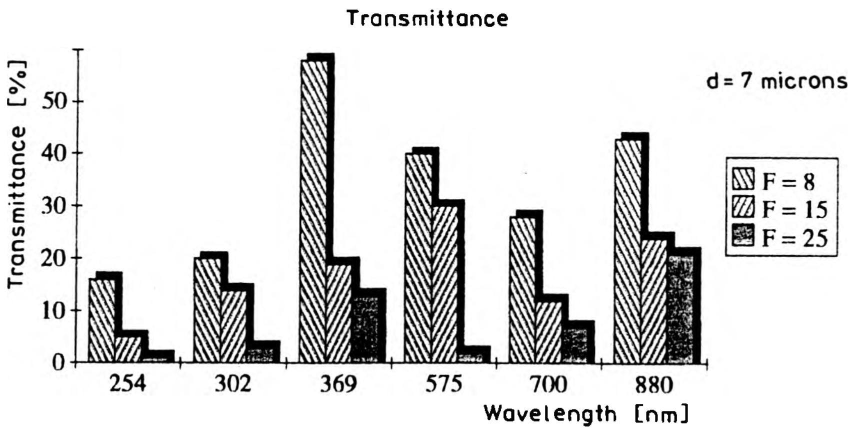

Fig. 1. Transmittance of the "Banana boat" cream (*d* is the cream layer thickness).

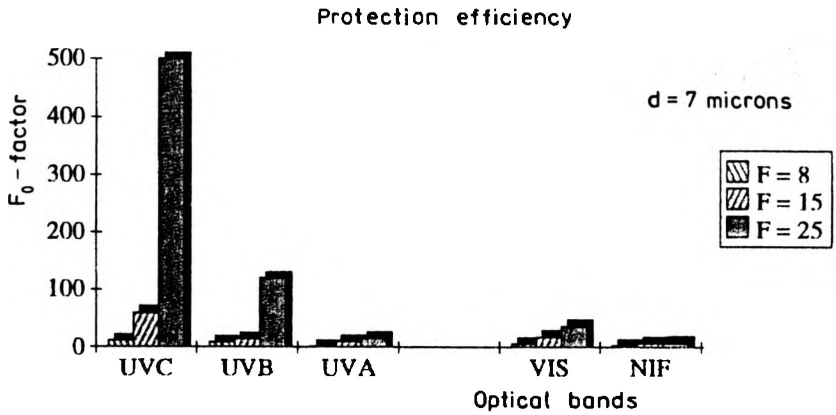

Fig. 2. Optical protection factor, F_0-factor, of the "Banana boat" cream for various optical bands. UVC, UVB, UVA, VIS and NIF mean optical bands represented by wavelengths 254, 302, 369, 700 and 880 nm, respectively.

"Banana boat" is produced in 3 modifications: factor 8, factor 15, and factor 25. Optical transmissions of these modifications are shown in Fig. 1, the F_0-factors are given in Fig. 2. The thickness of each cream is constant ($d = 7$ µm), being the effective thickness. It corresponds to the value of the declared F_d-factor. This cream thickness is recommended to be used for the skin. With increasing thickness, the protection of the skin becomes lower, and vice versa. The measured values are given in Tab. 1. The protection efficiencies are as follows: 0.5 for factor 8, 0.53 for factor 15, and 0.85 for factor 25.

3.2. Cream thickness dependence

Figure 3 shows the dependence of the transparency of "Banana boat" cream on the layer thickness. This thickness ranges from 0 to 15 µm. Various values are labelled

Table 1. Measured values of transmittance REF – reference values BIN, GAIN

Wavelength	254 nm	302 nm	369 nm	575 nm	700 nm	880 nm
REF	12– 1.1	48–10.1	36–10.1	40–10.1	39–10.1	41–10.1
F = 8	19–10.1	10–10.1	21–10.1	16–10.1	11–10.1	18–10.1
F = 15	26–10.4	7–10.1	7–10.1	12–10.1	5–10.1	10–10.1
F = 25	7–10.4	1–10.1	5–10.1	8–10.1	3–10.1	9–10.1

by arrows. The proper thickness of 7 μm is shown as the effective one. We see that the transparency of the cream is very low. Such a layer should be applied to the skin if the protection factor declared by the producer is to be achieved.

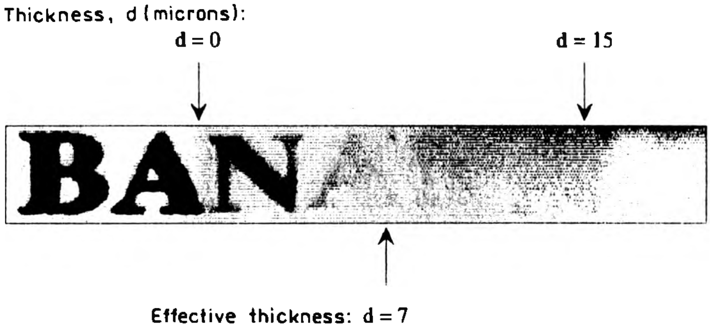

Fig. 3. Visual transparency of the "Banana boat" cream.

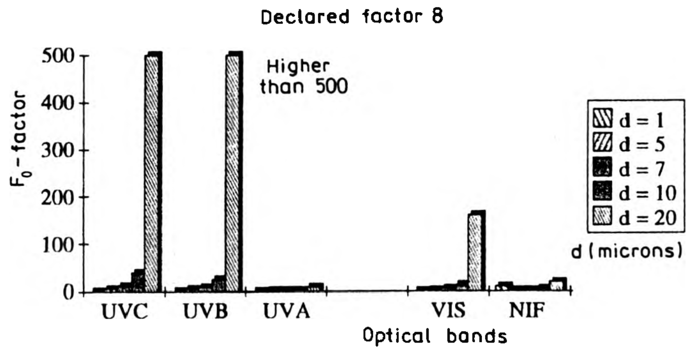

Fig. 4. Effect of the cream layer thickness on the F_0-factor of the "Banana boat" cream modification declared as factor 8.

The dependence of the F_0-factor on the cream layer thickness is shown in Figs. 4–6. The computed values corresponding to these figures are given in Tabs. 2–4, respectively. We see that the computed F_0-factor values do not agree exactly with the declared values, being 5 for the modification value F = 8 (Tab. 2), 7 for the modification value F = 15 (Tab. 3), and 33 for the modification value F = 25 (Tab. 4).

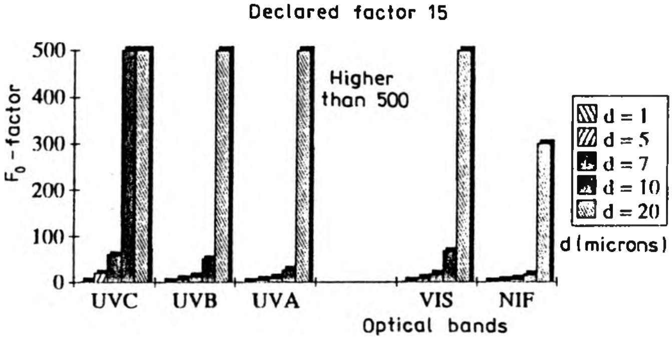

Fig. 5. Effect of the cream layer thickness on the F_0-factor of the "Banana boat" cream modification declared as the factor 15.

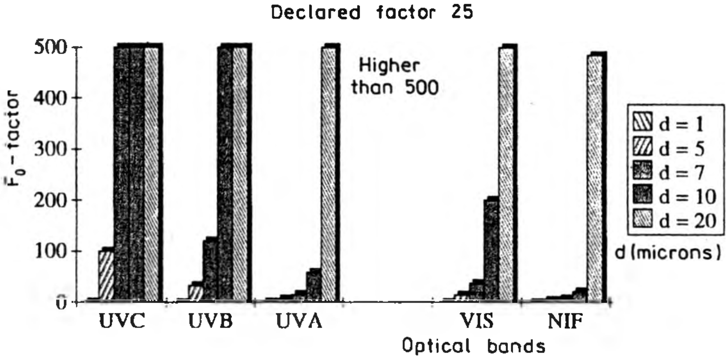

Fig. 6. Effect of the cream layer thickness on the F_0-factor of the "Banana boat" cream modification declared as the factor 25.

Table 2. Computed values of the F_0-factor for "Banana boat" factor 8

	254	302	369	575	700	880
$d = 1$	1	1	1	1	1	1
$d = 5$	6	5	2	3	4	2
$d = 7$	15	9	2	2	6	3
$d = 10$	39	25	33	6	13	5
$d = 20$	v.g.	629	9	39	161	20

(v.g. — very great value, practically higher than 500. This cream is not used in practice.)

Table 3. Computed values of the F_0-factor for "Banana boat" factor 15

	254	302	369	575	700	880
$d = 1$	2	1	1	1	1	1
$d = 5$	20	7	5	3	8	4
$d = 7$	60	15	10	5	18	7
$d = 10$	400	51	27	11	68	17
$d = 20$	v.g.	v.g.	729	121	462	299

Table 4. Computed values of the F_0-factor for "Banana boat" factor 25

	254	302	369	575	700	880
$d = 1$	3	1	2	1	2	1
$d = 5$	100	33	8	5	14	5
$d = 7$	v.g.	120	16	9	37	8
$d = 10$	v.g.	v.g.	59	25	201	22
$d = 20$	v.g.	v.g.	v.g.	v.g.	v.g.	486

4. Evaluation of experimental results

The main characteristics of every dermatological cream and cosmetic are the F-factor and the effective cream thickness.

As the new parameters in Figs. 5 and 6, we give the optical protection factor, the F_0-factor, and the effective cream thickness, the E.F., which we measured for 24 dermatological creams and cosmetics in the same way as it was done with the "Banana boat" cream. As usual, both the F_d-factor and the F_0-factor express statistically the multiplicative time value for which the normal person skins do not burn when exposed to the sun. The P.E. means the effective thickness, and N_m means the number of cream modifications.

5. Conclusions

The increasing UV solar radiation which reaches the Earth as a result of ozone depletion layer affects all live organisms on their surface. An exact evaluation of this impact is, however, very difficult because the sun spectrum at the ground level varies with the ozone protection, weather, time of the day, *etc.* Exact UV radiometry is also difficult to provide, and basic photochemistry and the photobiology of the sun radiation have not been fully ellucidated yet.

Very exact and reliable data can be obtained from the satellite measurements of the ozone concentration. These data enable us to assess damage done to the live organisms at various Earth latitudes over the ten-year period. It has been shown that the sensitivity to the effect of the UVA is very low, while the effect of the UVB is very high.

Although the photocarcinogenic action of the sunlight has been proved, the cosmetic and pharmaceutical industries play no sufficient and effective preventive role. As a result, there are not enough effective sunscreens available which could effectively protect the human organism.

The main aim of this study is to emphasize the problems connected with the effective use of protection capabilities of some selected dermatological sunscreens.

Table 5. Main optical characteristics of selected chief dermatological creams and cosmetics. (N_m – number of cream modifications, F_d-factor – declared F-factor, F_0-factor – measured F-factor, E.T. – effective thickness, P.E. – protection effectivity)

Name	N_m	F_d-factor	F_0-factor	E.T. [μm]	P.E. [%]	Remark
Ahava Sun Care	2	8	10.0	2	98	high sun protection
		15	13.3	2	98	– " –
Anthelios	4	15	20.0	9	99	gel for a fat skin
		20	22.0	9	98	– " –
		30	29.0	9	98	– " –
		60	32.0	9	99	– " –
Banana boat	3	8	5.0	7	50	UVA and UVB protection
		15	7.0	7	53	– " –
		25	33.0	7	85	– " –
Biomed	1	8	8.0	0.3	99	UVA and UVB protection
Blue for you	1	6	6.0	0.8	99	medium protection
Daylong	1	16	24.3	1.7	42	water resistant
Delph	6	2	3.0	2.7	60	low protection
		4	3.0	2.7	57	– " –
		8	14.0	2.7	57	medium protection
		10	14.0	2.7	84	– " –
		15	37.0	2.7	75	high protection
		20	37.0	2.7	86	– " –
Dermosum	1	1	10.0	5	95	UVA and UVB protection
L'eau thermale avene	1	20B, 7A, IR	17, 13, 6	6.2	81	very high protection
Ecran total	3	15	6.0	1.5	89	total sunblock
		20	20.0	1.5	99	– " –
		25	24.0	1.5	88	– " –
Hawaii	1	12	12.0	3.3	72	UVA and UVB protection

Table 6. Continuation of Table 5

Name	N_m	F_d-factor	F_0-factor	E.T. [μm]	P.E. [%]	Remark
Herbalona	1	9	9	1.3	98	UVA and UVB protection
Indulona	1	8	8	1	98	UVA and UVB protection
Johnson's suncare	2	12	12.2	1.3	60	UVA and UVB protection
		20	13.5	1.3	67	– " –
Ladival	1	15	15.0	5	96	UVB filters
Microsun	1	20	20.0	10	81	UVA and UVB protection
Nivea sun	1	12	12.0	3.7	77	UVA and UVB protection
Photoderm special	1	75B, 15A, IR	73, 25	3	99	maximum photoprotection
Sonnen concept carotin	2	6	5.9	3	97	tanning milk
		15	15.7	3	99	– " –
Sun mix	3	12-milk	12.0	13.4	36	UVA and UVB protection
		12-cream	12.0	1.4	99	very high protection
		15-cream	15.0	2.6	8	UVA and UVB protection suitable also for children
Sun orilon cosmetics	1	11	11.0	1.8	99	milk against ageing
Sundya's	1	20	20.0	1.2	98	lotion
Sympathic	2	15	15.0	1.3	95	sun milk
		20	20.0	0.7	20	sun cream
Sun block	1	15	15.0	1.8	99	high sun block

Acknowledgements — This research was supported by the Grant UK 248/95, Grant CR 312/96/0518 and the Foundation "Nadace CS-Srdce".

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Received September 28, 1998