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COMMISSION INTERNATIONALE DE L'ECLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

TECHNICAL REPORT

RECOMMENDATIONS ON MINIMUM LEVELS OF SOLAR UV EXPOSURE

CIE 201:2011

UDC: 612.014.481-06
535.31

Descriptor: Optical radiation effects on humans
Ultraviolet rays

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This Technical Report has been prepared by CIE Technical Committee 6-58 of Division 6 "Photobiology and Photochemistry" and has been approved by the Board of Administration of the Commission Internationale de l'Eclairage for study and application. The document reports on current knowledge and experience within the specific field of light and lighting described, and is intended to be used by the CIE membership and other interested parties. It should be noted, however, that the status of this document is advisory and not mandatory.

Ce rapport technique a été élaboré par le Comité Technique CIE 6-58 de la Division 6 "Photobiologie et Photochimie" et a été approuvé par le Bureau de la Commission Internationale de l'Eclairage, pour étude et emploi. Le document expose les connaissances et l'expérience actuelles dans le domaine particulier de la lumière et de l'éclairage décrit ici. Il est destiné à être utilisé par les membres de la CIE et par tous les intéressés. Il faut cependant noter que ce document est indicatif et non obligatoire.

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RECOMMENDATIONS ON MINIMUM LEVELS OF SOLAR UV EXPOSURE

Summary

This Technical Report addresses the issue of sensible exposure to solar ultraviolet (UV) radiation. The scientific evidence of beneficial effects of solar exposure has been reviewed, in particular on the incidence and mortality to cancers other than skin cancer. Although the evidence is not unequivocal, the committee has found considerable evidence to deem it plausible that solar exposure may reduce the incidence and mortality of colorectal cancer. The evidence for similar effects on breast and prostate cancer and on melanoma is less, but such effects are considered as plausible, too. Possibly the production of vitamin D plays a role in this respect.

Based on a review of the evidence of both the beneficial and the harmful effects of solar exposures it is concluded that people should not shun the sun, even not at noon. However, levels well below sunburn thresholds are generally sufficient to profit from the beneficial effects of solar exposure. Public health guidance should be developed on the basis of this evidence, but account should also be taken of prevailing solar UV levels that depend on latitude and time of the year and day. Special guidance may be necessary for dark skinned people that live at moderate latitudes and people that cover most of their bodies for cultural or religious reasons. The same holds for people who stay most of the time indoors.

The amount of solar exposure commensurate with good health depends on individual and population characteristics, as indicated above. To facilitate public health guidance it is recommended to extend the concept of the UV index promulgated by the World Health Organization to include the beneficial effects of solar exposure.

The report is split into two parts: The first part (Part I) gives guidance for a sensible exposure regime to profit from beneficial health impacts from moderate solar (UV) exposure, the second part (Part II) is a review of scientific data that underpin the guidance in Part I.

RECOMMANDATIONS CONCERNANT LES NIVEAUX MINIMUMS D'EXPOSITION AUX RADIATIONS SOLAIRES UV

Résumé

Ce rapport technique concerne la problématique de l'exposition raisonnable aux radiations solaires ultraviolettes (UV). Les preuves scientifiques d'effets bénéfiques de l'exposition solaire ont été examinées, en particulier sur l'incidence et la mortalité des cancers autres que les cancers cutanés. Bien que les preuves ne soient pas sans équivoque, le comité a estimé les preuves suffisamment importantes pour considérer comme vraisemblable que l'exposition solaire puisse réduire l'incidence et la mortalité du cancer colorectal. Les preuves d'effets similaires sur les cancers du sein, de la prostate et le mélanome sont faibles mais néanmoins de tels effets sont considérés comme plausibles. Il est possible que la production de vitamine D joue un rôle à cet égard.

Basé sur l'examen de preuves que les effets, bénéfiques et dangereux des expositions solaires, il a été conclu que la population ne doit pas fuir le soleil, même lorsqu'il est à son zénith. Cependant, des niveaux d'exposition bien au-dessous du seuil du coup de soleil sont généralement suffisants pour tirer profit des effets bénéfiques de l'exposition solaire. Un guide de santé publique devrait être créé sur la base de ces preuves mais il devrait également tenir compte des niveaux d'UV solaire dominants qui dépendent de la latitude, du moment de l'année et du jour. Des conseils spécifiques peuvent être nécessaires pour les populations à peau sombre qui vivent sous des latitudes moyennes et pour des populations qui recouvrent une grande partie de leur corps pour des raisons culturelles ou religieuses. La même remarque s'applique aux populations qui vivent la plupart du temps en intérieurs.

La quantité d'exposition solaire proportionnée à un bon état sanitaire dépend des caractéristiques individuelles et de la population comme indiqué ci-dessus. Pour faciliter les conseils de santé publique, il est recommandé d'étendre le concept d'index-UV répandu par l'Organisation Mondiale de la Santé en incluant les effets bénéfiques des expositions solaires.

Le rapport est présenté en deux parties. La première partie (partie I) fournit des recommandations pour un programme d'exposition raisonnable pour tirer bénéfice des impacts bénéfiques d'une exposition solaire modérée, la seconde partie (partie II) est une revue des données scientifiques qui étayent les recommandations de la partie I.

EMPFEHLUNGEN ZU MINIMALLEVELS DER SOLAREN UV-EXPOSITION

Zusammenfassung

Dieser Technische Bericht befasst sich mit der Frage der vernünftigen Exposition gegenüber solarer ultravioletter (UV-)Strahlung. Der wissenschaftliche Nachweis förderlicher Effekte solarer Exposition wurde überprüft, insbesondere hinsichtlich Auftretens und Sterblichkeit bei anderen als Hautkrebsarten. Obwohl der Nachweis nicht eindeutig ist, hat das Komitee deutliche Hinweise gefunden, die es als plausibel erscheinen lassen, dass solare Exposition das Auftreten und die Sterblichkeit durch kolorektalen Krebs mindern kann. Der Nachweis für ähnliche Effekte hinsichtlich Brust- und Prostatakrebs sowie Melanom ist geringer, aber entsprechende Effekte werden ebenfalls für plausibel gehalten. Möglicherweise spielt die Produktion von Vitamin D in dieser Hinsicht eine Rolle.

Basierend auf einer Überprüfung sowohl der förderlichen als auch der schädigenden Effekte solarer Expositionen wird der Schluss gezogen, dass man die Sonne nicht meiden sollte, selbst nicht zur Mittagszeit. Indes sind Niveaus beträchtlich unterhalb der Schwelle zum Sonnenbrand im Allgemeinen ausreichend, um von den förderlichen Effekten solarer Exposition zu profitieren. Eine Anleitung für die öffentliche Gesundheit sollte auf Basis dieses Nachweises entwickelt werden, aber es sollten ebenso allgemein geltende solare UV-Niveaus berücksichtigt werden, die vom Breitengrad sowie von Jahres- und Tageszeit abhängen. Spezielle Anleitung kann für dunkelhäutige Menschen erforderlich sein, die in gemäßigten Breitengraden leben und für Menschen, die den größten Teil ihres Körpers aus kulturellen oder religiösen Gründen bedecken. Dies gilt auch für Menschen, die sich meistens im Hause aufhalten.

Der Umfang solarer Exposition, der mit guter Gesundheit einhergeht, hängt, wie bereits erwähnt, von individuellen und Bevölkerungseigenschaften ab. Um eine Anleitung für die öffentliche Gesundheit bereitzustellen, wird empfohlen, das Konzept des UV-Index, welches von der Weltgesundheitsorganisation verbreitet wurde, um die förderlichen Effekte solarer Exposition zu erweitern.

Der Bericht ist in zwei Teile aufgeteilt. Der erste Teil (Part I) liefert eine Anleitung für ein vernünftiges Expositionsverhalten, um von förderlichen Gesundheitsauswirkungen durch moderate solare (UV-)Exposition zu profitieren, der zweite Teil (Part II) beinhaltet eine Übersicht wissenschaftlicher Daten, die die Anleitung in Teil I untermauern.

Part I: Guidelines

I-1 Introduction

I-1.1 Background

Popular attitudes towards sun light exposure have been ambivalent. Ancient men worshipped the sun as the source of life (Randle 1997). In the beginning of the 20th century Finsen was rewarded with a Nobel prize for his work on (sun)light (Randle 1997). Lack of sunshine was found to be a factor in the occurrence of rickets. In the second half of the 20th century a sun tan became a sign of good health but the attention of the medical and public health community focussed on the negative side of sun exposure, more specifically on skin cancer and on keratitis and cataract (Albert and Ostheimer 2002, 2003a,b).

For both the positive and negative (physical) effects of solar exposure the ultraviolet (UV) component of sunlight is commonly seen as the causal factor (Gezondheidsraad: Commissie UV-straling 1986, Advisory Group on Non-ionising Radiation 2002). Although the positive effects of UV exposure were acknowledged, especially with respect to vitamin D synthesis in the skin and the prevention of bone disease, public health guidance stressed the carcinogenic effects of excessive UV exposure and advised avoiding exposing bare skin to sunlight (WHO 1994, 2002). In recent decades data have become available that might lead to a reconsideration of the emphasis on the harmful effects of UV exposure in general and solar exposure in particular (Lucas et al. 2006b, Grant 2007, Lucas 2007). Technical Committee 6-58 of the CIE has further studied this issue.

I-1.2 Terms of Reference

The terms of reference of Technical Committee (TC) 6-58 (hereafter denoted as 'the committee') that compiled the present report were specified by the *International Commission on Illumination* (CIE) as

The fact that man cannot do entirely without UV is accepted by most scientists active in this field, but is not as well known as the widely accepted view that UV exposure should be limited to a sensible level thus avoiding or minimizing risks. The TC will formulate recommendations for a lower limit of UV exposure commensurate with good health.

The committee soon realized that defining a minimum exposure limit of a similar status as UV exposure limits for protection of workers and the general public (International Non-Ionizing Radiation Committee of the International Radiation Protection Association 1989, 1996, International Commission on Non-Ionizing Radiation Protection 2004) would probably not be feasible. As will be further detailed below this is due to the dependence of the (beneficial) effects of UV exposure on constitution, nutrition, behaviour and location. The committee therefore focussed on compiling input for scientifically underpinned public health guidance for solar exposure.

This report considers only exposure to solar UV radiation, the single UV source to which we are naturally exposed. The radiation from artificial sources varies greatly between sources, but is always different to the spectrum of sunlight. Thus the effects, and balance of positive and negative effects, will be different for artificial sources than they are for solar radiation.

I-1.3 Report

The present report was developed in three meetings of the committee in 2005, 2006 and 2007. Furthermore the committee members prepared reviews of the literature that are reproduced in the second part of this report (the reviews cover the literature until 2006-2007). The guidance in Part I is based on an assessment by the committee of the scientific evidence for the various effects of solar (UV) exposure. In Annex A to Part I recommendations of other

organizations are presented. Annex B to Part I reproduces recommendations from a working group of the *International Agency for Research on Cancer* (IARC).

I-2 Conclusions and Guidance

I-2.1 Objective

The focus of the committee's report is on the possible beneficial health impacts from moderate solar (UV) exposure. It provides guidance for a sensible exposure regime to profit from these beneficial impacts without being unduly harmed by the established damaging impacts of solar (UV) exposure. The committee did not include in its advice the effects of exposure to UV radiation generated by artificial sources.

I-2.2 Beneficial Health Impacts

The scientific literature reviewed by the committee (see Part II) provides evidence about beneficial health impacts related to well-being, adaptation to cope with damaging effects of UV exposure, blood pressure, bone and muscle development, various types of cancer (including skin cancer), multiple sclerosis and diabetes. Several of these effects appear to be vitamin D mediated. The role of vitamin D is established for bone and muscle function. Such a role is plausible for cancer, multiple sclerosis and certain forms of diabetes.

The committee generally agrees with the main message of other review groups, such as *Cancer Council Australia* and other professional organizations in the Pacific region (*Cancer Council Australia* 2007), and of the participants of a workshop organized by the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP) (McKinlay 2006). These other reviewers concluded (see Annex A): avoid the harmful effects of solar (UV) exposure on eyes and skin without losing the beneficial effects on human health. The committee's recommendations are targeted at rational public health policies. Where possible and scientifically defensible it should relate to earlier public health messages with respect to (solar) UV exposure.

The statements listed in Annex A recommend sun protection above a UV-index (WHO 2002) of 3. The committee has a slightly different view on the use of the UV-index. The index relates to the solar intensity (sometimes only at noon), which depends on latitude and local conditions. In some situations protection may be necessary below an index value of 3, whereas in other situations beneficial effects, such as vitamin D production, may only be realized by exposures to intensities exceeding this value.

In a recent report a working group of WHO's *International Agency for Research on Cancer* that studied the relationship between vitamin D and cancer, advocated no change in sun exposure recommendations (see Annex B) (IARC Working Group on Vitamin D 2008). Deficient or insufficient vitamin D status might be counteracted by an appropriate diet and supplements. Here again the committee has a different view and thinks, as will be detailed below, that a better balance between the beneficial and harmful effects of sun exposure on public health may be found.

I-2.3 Findings

I-2.3.1 Evidence Levels

In assessing the scientific evidence on health effects of UV exposure, the committee uses the evidence classification of Table I-1: In case of sufficient evidence (Level 1) the relationship between solar (UV) exposure and health effects has been studied empirically and the conclusion of a causal relationship is warranted (consistent scientific knowledge). In the case of Level 2 evidence the empirical data show inconsistencies, but there are strong indications for the plausibility of a causal relationship. When such indications are less strong, i.e. when scientific data appear to be inconsistent, a classification of Level 3 evidence is warranted.

With the classes of Level 4 and Level 5 empirical data are lacking. Level 4 relates to plausible scenarios that lead from exposure to impact, whereas in case of Level 5 the plausibility of the scenarios is low or lacking.

Table I-1 – Evidence classification (modified from (Wiedemann et al. 2001))

Level	Description
1	Sufficient evidence of effect. Proof of harmful or beneficial health effects
2	Presumption of effect is scientifically plausible
3	Presumption of effect is only partially plausible
4	Presumption of effect is hypothetical
5	Hypothetical effects, with no evidence

This evidence scale is used in Part I and in the reviews in Part II. In the reviews descriptive terms are sometimes used, but in all cases the level indication is pertinent.

I-2.3.2 Evidence for Health Effects Mediated by Vitamin D

There is sufficient evidence (Level 1) that vitamin D plays an important role in maintaining bone and muscle function. As solar exposure is instrumental in vitamin D production in the body, this exposure is beneficial for bone and muscle development (Level 1 evidence).

There is accumulating evidence that maintaining an adequate vitamin D status, e.g. by sufficient solar exposure, reduces the incidence of or mortality from a number of cancers, including colorectal cancer (Level 2) and possibly also of breast cancer, prostate cancer (Level 3), Non-Hodgkin lymphoma, and melanoma (Level 4)¹. There is good evidence that vitamin D plays a role in antimicrobial activity in the body (Level 2). The evidence that vitamin D enhances the outcome of tuberculosis patients is ranked as Level 4.

The committee notes that more empirical data from epidemiological and intervention studies would be welcome. Notwithstanding this, the committee concludes that, given the role of UV radiation in vitamin D production in the body, it is plausible that solar exposure reduces the incidence or mortality of these health effects and may also be instrumental in preventing other tumours types than the ones mentioned.

I-2.3.3 Evidence for Health Effects not Unequivocally Related to Vitamin D Status

The committee has identified other beneficial health effects related to solar exposure such as adaptation of the skin to cope with damaging effects of UV exposure (Level 1), blood pressure (Level 3), multiple sclerosis (Level 3) and type 1 diabetes (Level 4). Whether and how vitamin D production induced by UV exposure plays a role is uncertain for effects on blood pressure, and type 1 diabetes. Reported improvements in insulin secretion and glucose control in type 2 diabetes (Level 3) might be vitamin D related. Exposure to solar UV radiation induces effects, such as skin thickening and tanning², with the effect to diminish the UV exposure of cells below the skin surface (Level 1 evidence).

With respect to health effects mediated via immune suppression, the committee considers that the evidence points both ways, i.e. the effects may be beneficial or detrimental, also depending on the type of effect studied. With respect to multiple sclerosis evidence appears

¹ This statement does not imply that solar UV exposure is not involved in the induction of melanoma.

² Although reducing the UV exposure of sensitive skin cells to some extent, tanning may not be beneficial per se (Randle 1997).

to be somewhat stronger in the direction of beneficial effects. The committee adds that there is strong evidence that solar exposure below erythema levels suppresses human immunity to allergens (contact sensitizers). There is also strong evidence based on animal studies that UV immunosuppression is a key damaging effect of solar exposure that enables skin cancers to develop. However there is no conclusive evidence on level of the solar exposure that suppresses anti-tumour immunity in either animal models or humans. Allergens are of high affinity and therefore difficult to suppress, while tumour antigens are of low affinity and therefore easier to suppress. It is possible that much lower solar exposures than are required to suppress immunity to allergens may inhibit anti-tumour immunity, exacerbating skin tumour growth. Hence there is no evidence to indicate a safe dose of solar exposure which will not inhibit immunity to skin tumours. In general there is insufficient data to determine whether there is any beneficial dose of solar radiation on the immune system.¹

I-2.3.4 Basis

Given the nature of the scientific evidence the committee bases its guidance for beneficial UV exposures on vitamin D status. From medical and health research serum levels of 25(OH)D of at least 50 nmol·L⁻¹ to 80 nmol·L⁻¹ appear to be commensurate with good health (Dawson-Hughes et al. 2005). Lower levels are indicative of a vitamin D insufficiency or deficiency. Main sources of vitamin D are synthesis in the skin through solar (UV) exposure and nutrition. The latter is generally a minor source. For many populations, where there is a distinct seasonal cycle in availability of sunlight, vitamin D status tends towards lower values in the winter season with large fractions of the population below the range mentioned above.

For possible positive effects on health that are not mediated by vitamin D, the evidence is in general limited, with an exception for well-being and skin adaptation. Also information on the variation of such effects, with exception of the adaptive effects, within the population is lacking. However, the committee is of the opinion that adhering to its recommendations below would lead to obtaining the possible benefits identified, at least on a population level.

I-2.3.5 Relevant Solar (UV) Exposure

In recommending sensible exposure regimes for solar (UV) exposure the committee has taken into account that solar exposure has never been shown to lead to toxic vitamin D levels. The photochemical process instrumental in the production of vitamin D in the skin is self-regulating and thus toxic levels are avoided.

At present data are not sufficient to derive a quantitative relationship between solar (UV) exposure and an adequate vitamin D status, neither on a population level nor on an individual level. However, the committee proposes the following guidelines for a sensible solar exposure regime:

- In order to maintain vitamin D status in general, people should not totally avoid exposure to the sun but should allow exposure of sunscreen free skin several times a week involving a reasonable area of the body at a level well below personal sunburn risks.
- This recommendation is in line with recommendations of regular outdoor activities such as walking and cycling with bare hands, face and neck. Examples are a lunch time walk of a few quarters of an hour, cycling or walking to and from work or school, open air sports such as soccer and tennis etc.
- Sunscreens can significantly reduce the production of vitamin D under very strictly controlled conditions; their normal usage (which is often at far lower concentration than required to achieve the stated SPF) does not generally result in vitamin D insufficiency (Norval 2009). Nonetheless, best practice would be a short exposure of unprotected skin to ensure some vitamin D production, followed by full protection (clothing or properly applied sunscreen) to avoid excessive UV and sunburn.

¹ Given the variety and complexity of the effects of solar (UV) radiation on the immune system, the committee refrains from ranking this data on its evidence scale.

- Given the action spectrum for vitamin D synthesis in the skin (Commission Internationale de l'Éclairage 2006) it appears that the maximum activity is in the UV-B region. This implies that people should not shun being in the sun around noon. However, extra care should be taken to avoid sunburn as UV-B radiation is also most effective for erythema and skin cancer, in particular for non-melanoma skin cancer.
- For populations living at higher latitudes (above 40 degrees) exposure to solar radiation in winter time does not contribute significantly to vitamin D status. In order to maintain an adequate vitamin D status, public health policies should include advice on diet and the use of vitamin D supplements.
- For specific groups of people the recommended regime of solar exposure might not be appropriate and therefore would not lead to an adequate vitamin D status. These groups include:
 - people with skin types V and VI, especially those living at mid-high latitudes¹;
 - people, especially older people, without (or with only a few) outdoor activities;
 - people with habits of fully covering themselves with clothes when being outside;
 - people with skin diseases caused, promoted or aggravated by UV exposure;
 - people using photosensitive drugs;
 - immunological compromised people, such as renal transplant patients.
- For such groups public health authorities should develop specific guidance with respect to solar exposure, the use of sunscreens², supplements and diet, taking into account the health benefits and damages accrued by the these groups and their socio-culturally determined habits and lifestyles.

The committee suggests that WHO consider modifying or extending the concept of the 'UV index' (WHO 2002) to include an interpretation that addresses vitamin D production, e.g. by including an anti-parallel colour scale ranging from 'no' to 'very high' vitamin D production and guidance for determining an optimum between both scales.

I-2.3.6 Balancing Beneficial and Damaging Health Effects of UV Exposure

There is sufficient evidence (Level 1) that solar UV exposure induces skin cancer (primarily squamous cell cancer and also appears to contribute to basal cell cancer and malignant melanoma) and contributes to skin ageing and immunosuppression. This evidence also holds at exposure levels below the sunburn thresholds, be it that squamous skin cancer incidence appears to increase progressively with increasing exposure. This evidence has led to protective recommendations.³ It is difficult to recommend an exposure regime in quantitative terms in which harmful and beneficial health effects are well balanced. As reflected by the committee's recommendations this balance will differ from person to person and on a population level will depend on the health metric used.⁴ Also the biophysical and biochemical information for deriving such a regime is lacking. Therefore the committee takes the pragmatic point of view that acquiring sun exposures considerably below the sunburn threshold is commensurate with normal activities with respect to mobility and recreation, and given the

¹ Skin type classification I-VI is based on the ability to get a sunburn and a suntan: I Always burns easily, never tans (sensitive); II Always burns easily, tans minimally (sensitive); III Burns moderately, tans gradually (to a light-brown) (normal); IV Burns minimally, always tans well (to a moderate brown) (normal); V Rarely burns, tans profusely (to a dark-brown) (insensitive); VI Never burns, deeply pigmented (insensitive) (Cripps 1981).

² Vitamin D production is optimal in sunscreen-free skin. Applying a sunscreen will at least in principle inhibit this production (Sayre and Dowdy 2007). However, in practice the effect may be limited (Norval and Wulf 2009). On the other hand, with long term solar exposure, using sunscreens may help to avoid sunburn and other harmful effects.

³ See e.g. http://www.who.int/uv/sun_protection/en/ (accessed 2011-08-29).

⁴ The World Health Organization compares the impact of diseases in various countries and regions with the burden of disease metric expressed in disability adjusted life years. Such an aggregate metric would assist with determining optimum population exposure levels, that would be dependent, *inter alia*, on population characteristics, geographical location and nutritional status (Lucas et al. 2006a).

present knowledge would not lead to excessive harmful effects while furthering health by the beneficial effects described in this report. On this basis an extended UV-index, as recommended above, may be developed.

Annex I-A

Recommendations from Others

Findings from Others

Other organizations have dealt with the issue studied in the present report. The committee summarizes here the conclusions reached by the *Cancer Council Australia* and others, and of the participants of a workshop organized by the *International Commission on Non-Ionizing Radiation Protection* that advocated protection against the harmful effects of UV exposure, without forsaking the beneficial effects of such exposures.

Cancer Council Australia and others (Cancer Council Australia 2007)

- For most people, sun protection to prevent skin cancer is required when the UV index is moderate or above (i.e. UV index is 3 or higher). At such times sensible sun protection behaviour is warranted and is unlikely to put people at risk of vitamin D deficiency.
- Most people probably achieve adequate vitamin D levels through the UV-B exposure they receive during typical day-to-day outdoor activities. For example, it has been estimated that fair skinned people can achieve adequate vitamin D levels ($> 50 \text{ nmol} \cdot \text{L}^{-1}$) in summer by exposing the face, arms and hands or the equivalent area of skin to a few minutes of sunlight on either side of the peak UV periods on most days of the week. In winter, in the southern regions of Australia where UV radiation levels are less intense, maintenance of vitamin D levels may require 2-3 hours of sunlight exposure to the face, arms and hands or equivalent area of skin over a week.
- Some people are at high risk of skin cancer. They include people who have had skin cancer, have received an organ transplant or are highly sun sensitive. These people need to have more sun protection and therefore should discuss their vitamin D requirements with their medical practitioner to determine whether dietary supplementation with vitamin D would be preferable to sun exposure.
- Some groups in the community are at increased risk of vitamin D deficiency. They include naturally dark skinned people, those who cover their skin for religious or cultural reasons, the elderly, babies of vitamin D deficient mothers, and people who are housebound or are in institutional care. Naturally dark skinned people (Fitzpatrick skin type V and VI – rarely or never burns) are relatively protected from skin cancer by the pigment in their skin; they could safely increase their sun exposure. Others on this list should discuss their vitamin D status with their medical practitioner as some might benefit from dietary supplementation with vitamin D

Workshop of ICNIRP 2005 (McKinlay 2006)

- Sun exposure is responsible for a substantial burden of skin and eye disease, and may play a role in reactivating some viral diseases.
- A lack of adequate vitamin D is a serious health issue.
- There is still much to be learned about the quantitative relationship between 25(OH)D and human health and that much more research is necessary to address this issue.
- More research is needed on investigating optimal levels of vitamin D for different groups within the general population and on deriving “upper safe limits” of vitamin D intake.
- Little is known about the effects of UVR exposure on vaccination efficacy and infectious diseases and research is needed in this area.
- The use of sunbeds is not recommended for vitamin D enhancement.
- Sun protection messages need to be aimed at the individuals or groups at risk and the factors affecting that risk such as location and time of year and that the Solar UV Index should be actively promoted as part of sun protection programmes.
- Moderation of sun exposure is an important goal and a key message is to ensure that people protect themselves when the Solar UV Index is greater than 3.

Annex I-B

IARC Recommendations

A working group of WHO's *International Agency for Research on Cancer* presented the following recommendations for maintaining vitamin D status, including sun exposure [Chapter 19 f (IARC Working Group on Vitamin D 2008)]:

- **Chapter 19 – Should Recommendations for Sun Protection and Vitamin D Intakes be changed?**
- **19.1 On the Concepts of ‘Deficiency’, ‘Insufficiency’ and ‘Optimal’ Vitamin D Status**

The concepts of ‘deficient’, ‘insufficient’, ‘adequate’ or ‘optimal’ should not be defined according to results of ecological or observational studies for the following reason: if a disease is due to deficiency of some substance, then restoration of sufficiency of that substance should be followed by disappearance of the disease. This simple logical rule has been observed worldwide for rickets and osteomalacia, as these diseases are caused by vitamin D deficiency and are cured by vitamin D supplementation or sun exposure.

We do not know whether this simple logical rule also applies for the numerous conditions found by mainly ecological and some observational studies to be associated with low vitamin D status. It is only when demonstrated that restoration of some adequate vitamin D status is followed by decreasing incidence and/or mortality from health conditions hypothetically associated with low vitamin D status that one could acknowledge that maintenance of adequate vitamin D status is associated with lower disease burden, longer life expectancy, and absence of serious side effects. Only randomized trials may demonstrate this, and to date, trials have not been supportive of relatively low doses of vitamin D and calcium supplements in the prevention of colorectal and breast cancer, coronary heart disease, diabetes, and so on (see Chapter 14).

For the time being, the definition of vitamin D deficiency should be maintained as they are now, i.e. related to the prevention of rickets, osteomalacia or muscular pain.

- **19.2 Should Recommendations for Vitamin D Intakes be changed?**

The lower limit usually considered for serum 25-hydroxyvitamin D level is 10 ng/mL¹, as below this level, rickets in children and osteomalacia in adults may occur. Increased blood PTH levels are regarded as markers of vitamin D insufficiency for adequate bone metabolism, and serum 25-hydroxyvitamin D level between 10 and 19 ng/mL are often associated with undesirably high levels of this peptidic hormone. However, the upper limit for PTH clearance in the blood is still a matter of debate (see e.g. Lips et al. 2001).

Setting a lower limit of ‘adequate’ serum 25-hydroxyvitamin D levels at 20 or 30 ng/mL is currently inappropriate since there are no results from randomized trials suggesting that maintenance of such ‘adequate’ serum 25-hydroxyvitamin D level actually prevents any cancer and any other chronic condition.

Also, it would be premature to change current recommendations on vitamin D intakes, as at present, there is insufficient evidence of a lack of harm due to long term higher levels of vitamin D.²

¹ Unit corrected.

² In contrast (and this is beyond the scope of the objective of this report), there is sufficient evidence from other trials, expert consensus, reviews and studies outside the cancer domain, that adequate vitamin D status according to current recommendations should be maintained for optimal bone health and defence against infectious diseases, essentially among children and women in childbearing age (Cranney et al. 2007). The evidence is less clear in elderly subjects (Avenell et al. 2005, Cranney et al. 2007). The question of whether for bone health, elderly people in areas above 40° to 42° of latitude should take doses of vitamin D supplement of about 25 µg per day for maintaining serum 25-hydroxyvitamin D summer levels during the winter (Viljakainen et al. 2006) is still an open question beyond the scope of this report.

- **19.3 Should Recommendations for Sun Protection of Light-skinned Populations be changed?**

Discussions on sunlight and vitamin D often mix quite diverse issues: there is a difference between Muslim veiled women living in Northern Europe and suntan worshippers spending hours on Mediterranean beaches, preferably around noon. The former would most probably benefit from some more sun exposure, while the latter would most probably benefit from restricting overexposure. There is a difference between elderly people not longer eager to go outside and adults spending most of their time indoors but who are eager to maximize time spent in the sun when on holidays. Again, the former would most probably benefit from some more sun exposure, while the latter would most probably benefit from following sun protection recommendations.

Over-simplified messages on sun exposure timing, duration and potential for improving vitamin D status need to be questioned through an evidence-based approach (Kimlin et al. 2007). Answering this question would rest on answering first the two preliminary questions:

1. Does increase in vitamin D status decrease the risk of cancer or other chronic condition?
2. If the answer to question one was affirmative, then the next question would be about the safest way to increase vitamin D status. Given the well-established link of skin cancer risk and UV radiation on light-skinned populations, and the still increasing incidence of skin cancer in most light-skinned populations, use of oral supplements of vitamin D would probably represent the safest way for increasing vitamin D status.

UV-B radiation doses implicated in skin cancer occurrence (mainly the squamous cell cancer) are much higher than doses involved in endogenous vitamin D production. Maximum vitamin D₃ synthesis occurs within a relatively short period of UV-B exposure (less than one minimal erythemal dose); beyond this period, further synthesis of vitamin D₃ ceases (see Chapter 4). For children and adults, everyday casual exposure to sunlight provides vitamin D requirements (Holick 1995). Best estimates are that at around 40° of latitude during a sunny summer day, a fair-skinned person could achieve maximum pre-vitamin D₃ production in 5 to 10 minutes of exposure two or three times a week of the face and forearms to mid-day sunlight (Holick 1995, 2001, Gilchrest 2008).

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Part II: Reviews of Scientific Data that Underpin the Guidance in Part I

II-1 Overview of Vitamin D Photochemistry¹

II-1.1 Literature

In several texts diagrams of the chemical structures can be found and a more detailed discussion of the activity of the different forms of the compounds playing a role in the vitamin D metabolic pathway (Norman 1980, Webb and Holick 1988, Hurst et al. 2004, Commission Internationale de l'Éclairage 2006, Webb 2006, Webb and Engelsen 2006).

II-1.2 Overview

The two major forms of vitamin D are vitamin D₂ (D₂) or *ergocalciferol* and vitamin D₃ (D₃) or *cholecalciferol*. D₂ comes from UV irradiation of a yeast sterol (*ergosterol*) and D₃ comes from UV irradiation of a sterol in skin cells, 7-dehydrocholesterol (7DHC). Where 'vitamin D' is used it refers to either or both of D₂ and D₃.

The photochemistry of vitamin D occurs in the skin (for endogenous synthesis) and will be discussed in these terms i.e. for D₃. 7DHC is a four member ring steroid. The B ring has 2 conjugated double bonds at C5 and C7. The side chain identifies 7DHC from ergosterol.

7DHC present in cells is a precursor of cholesterol. In the skin cells where it is exposed to UV radiation it can be photolysed to previtamin D₃ rather than reduced to cholesterol by 7DHC-reductase. The radiation necessary for this reaction is in the UV-B (wavelengths less than 315 nm, Table II-1), which is at the short wavelength limit of the solar spectrum. The reaction can also occur at shorter UV-C wavelengths not available in sunlight, but present in artificial radiation sources. The double bonds absorb a UV photon, moving into an excited singlet state and there is a ring opening at C9-C10 to give previtamin D₃. Previtamin D₃ can undergo a number of further reactions. If there is further irradiation with UV then it may return to the parent 7DHC through ring closure; ring closure to form the isomer *lumisterol*; or isomerization to give a 6,7 trans isomer known as *tachysterol*. All these reactions are reversible and all occur under UV irradiation but with slightly different absorption spectra (MacLaughlin et al. 1982). The result of continued UV irradiation is thus an isomer mixture (7DHC, *lumisterol*, *tachysterol* and the central previtamin D₃) in a quasi-equilibrium state.

Table II-1 – Classification of ultraviolet radiation (Commission Internationale de l'Éclairage 2009)

Type	Wavelength range
UV-C	100 nm - 280 nm
UV-B	280 nm - 315 nm
UV-A	315 nm - 400 nm

The quasi-equilibrium of the isomer mixture is dependent on the irradiating spectrum. In sunlight (natural or simulated) the percentage previtamin D₃ in the mixture does not exceed about 12 %, *lumisterol* increases greatly and *tachysterol* modestly (both eventually plateauing), while 7DHC decreases (MacLaughlin et al. 1982, Webb et al. 1988).

Previtamin D₃, like *lumisterol* and *tachysterol*, is biologically inert. However, it can also spontaneously undergo a heat isomerization to the thermally stable 9,10-*secosterol*, vitamin D₃. It takes several hours for previtamin D₃ to completely convert to D₃ at body temperature. Older texts state the heat isomerization time from previtamin D to vitamin D as about 24

¹ This section is based on documents prepared by committee members Webb and Engelsen.

hours, but more recent research shows that the time is only several hours (Tian et al. 1993). The process occurs in the actively growing layers of the epidermis where temperature is relatively constant: it is little affected by either changes in skin surface temperature or core body temperature.

Vitamin D₃ enters the circulation attached to a vitamin D binding protein and is thus removed from the epidermis. Any D₃ remaining in the skin and exposed to UV radiation can itself undergo photodegradation to 5,6-transvitamin D and the *suprasterols I* and *II* (Webb et al. 1989), for which no biological significance has been shown. The photochemistry of vitamin D therefore controls cutaneous synthesis both by limiting the amount of previtamin D that can be formed in any single exposure, and by degrading vitamin D that is present in the skin during subsequent or prolonged irradiation. For a terminology of vitamin D and its metabolites, see Box 1.

Box 1 Vitamin D terminology (see also Figure II-1)

Vitamin D₃ is also called cholecalciferol.

25-hydroxyvitamin D₃ is also called calcidiol, and abbreviated as 25(OH)D.

1,25-dihydroxyvitamin D₃ is also called calcitriol and abbreviated as 1,25(OH)₂D.

II-1.3 Action Spectrum

The major path from 7DHC in the skin to the active form of vitamin D, 1,25(OH)₂D, by way of photochemistry and hydroxylation is well known and illustrated in Figure II-1. It is also well accepted that UV-B radiation dominates the action spectrum for the necessary first step of the conversion of 7DHC to previtamin D, although the precise definition of the action spectrum for human skin has been the subject of some debate. Only one experimental action spectrum using human skin has been obtained (MacLaughlin et al. 1982) and this does not exactly match the action spectra obtained in live animals or in solution. These issues are discussed in detail in a CIE report (Commission Internationale de l'Éclairage 2006), which provides the action spectrum in tabulated form (the original was only a figure) with a mathematical extrapolation to account for the statistical probability of some action, albeit at extremely low levels, at longer wavelengths.

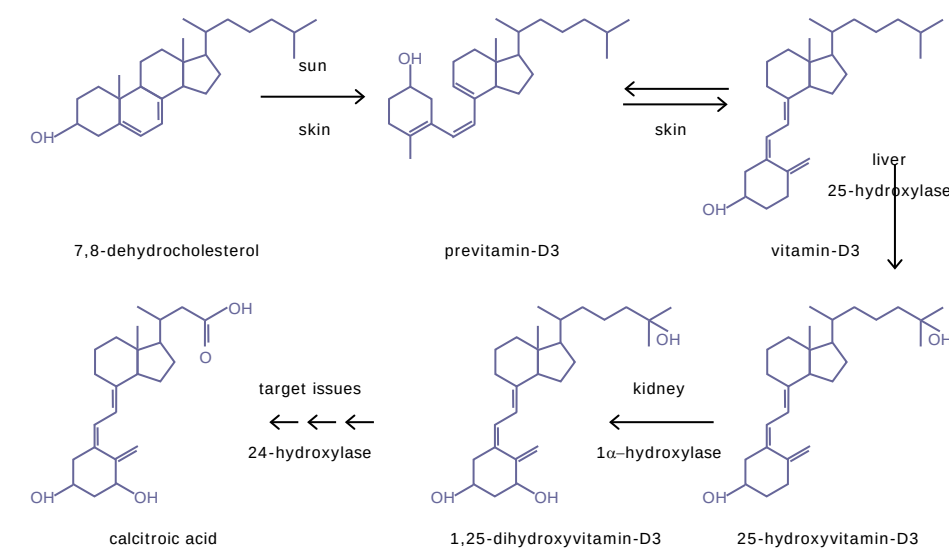
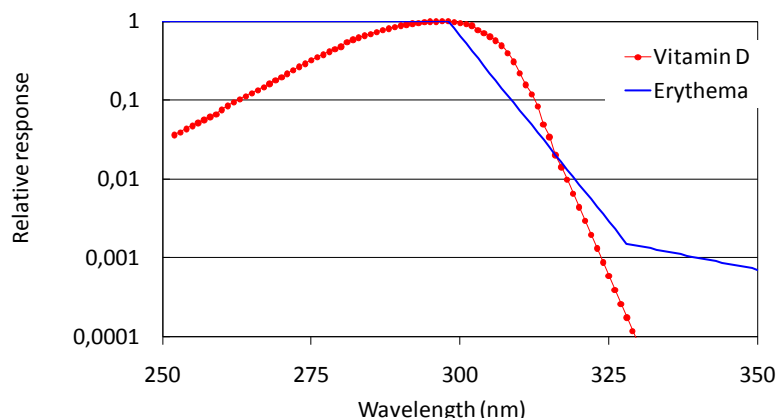


Figure II-1 – Conversion of 7,8-dehydrocholesterol in skin to the active form of vitamin D From (Dusso et al. 2005)

The data are presented in Figure II-2 together with the erythema action spectrum. When compared to alternative action spectra, not derived from human skin, the CIE version produces results intermediate to other options when applied to sunlight exposure (Webb and Engelsen 2006). There is still scope for debate over the fine tuning of the action spectrum at

the UV-B / UV-A boundary (315 nm, Table II-1), but uncertainties in the CIE spectrum are likely to be academic rather than of great practical significance for sunlight exposure and the human population where other variables provide for much greater uncertainty.



NOTE Data at wavelengths longer than 315 nm are the result of a mathematical extrapolation and are not based on experimental data (Commission Internationale de l'Éclairage 2006). For comparison purposes the erythema action spectrum is also depicted (International Organization for Standardization and Commission Internationale de l'Éclairage 1998).

Figure II-2 – Action spectrum for the conversion of 7-DHC to previtamin D₃ in human skin, normalized to 1 at 298 nm

It is relevant here to also discuss the metabolism of vitamin D in quantifying exposure, doses and vitamin D status. This is because while vitamin D is formed in the skin, it is the circulating metabolite 25(OH)D that is used as a measure of vitamin D status, and 1,25(OH)₂D that is the active form.

Vitamin D₃, cholecalciferol, is provided via photoconversion of 7-dehydrocholesterol (7DHC) in skin. Both vitamin D₂ and D₃ can also enter the circulation via food (mainly oily fish and eggs) and nutritional supplements (Holick et al. 1994). These compounds are transported by the vitamin D binding protein (*specific alpha1 globulin*). In the liver the vitamin D is hydroxylated by hepatic mitochondrial and microsomal enzymes into 25-hydroxyvitamin D (25(OH)D) (Mehta and Mehta 2002). This is the major circulating metabolite, the measure of which is used to determine vitamin D. Hepatic hydroxylation is not tightly controlled and increases in dietary intake or cutaneous synthesis will increase serum 25(OH)D. It is measured by competitive binding assay that does not usually distinguish between D₂ and D₃ or by immunoassays, some of which discriminate against D₂ derivatives. Typical levels are in the range 8 ng·ml⁻¹ - 80 ng·ml⁻¹, but may rise to 100 ng·ml⁻¹ with extensive sunlight exposure, or as much as 500 ng·ml⁻¹ with excessive intake of vitamin D. 25(OH)D is not generally considered biologically active at physiological levels in the traditionally understood role of calcium metabolism, though it does seem to have some action on calcium absorption in healthy adults (Heaney et al. 1997), if much less than 1,25(OH)₂D.¹

Once more attached to vitamin D binding protein, the 25(OH)D is taken from the liver to the kidneys (Mehta and Mehta 2002) where a further hydroxylation occurs on either C1 or C24. 1 α -hydroxylase activity (C1) produces 1,25-dihydroxyvitamin D (1,25(OH)₂D) which is the active metabolite of vitamin D necessary for calcium absorption and bone remodelling (20 pg·ml⁻¹ - 60 pg·ml⁻¹ in normal serum).² Renal mitochondrial 25(OH)D-1 α -hydroxylase activity is tightly controlled via serum calcium concentrations and parathyroid hormone (PTH).

¹ The role of 25(OH)D in other cells and disease prevention is not addressed here.

² Hydroxylation may also occur in several other tissues, including some cancer tissues (Berger et al. 1988, Zehnder et al. 2001).

1,25(OH)₂D itself also reduces the 1 α -hydroxylase activity and enhances the alternative hydroxylation path to 24R,25-dihydroxyvitamin D (C24). This is one route to the degradation of both 25(OH)D and 1,25(OH)₂D as 24,25 is converted to 1 α -24R,25-trihydroxyvitamin D and thence to the biologically inactive calcitric acid (Figure II-1). 25(OH)D and 1,25(OH)₂D can be converted to over 35 metabolites, most of which seem to be degradation products.

There is also evidence that vitamin D₂ and D₃ are not exactly equivalent in their hydroxylation. Although there are D₂ equivalents to the D₃ metabolites from liver and kidney, D₂ can also form 1 α ,24-dihydroxyvitamin D, an active metabolite which has been detected in human serum after large, or prolonged, dosing with vitamin D₂ (Mawer et al. 1998). Thus there can be different metabolic pathways for D₂ and D₃.

The different efficacies of D₂ and D₃ (D₃ being the more potent in humans of the two at raising 25(OH)D levels in humans (Trang et al. 1998, Armas et al. 2004)) is relevant to the debate about the equivalencies of cutaneous synthesis and oral supplementation of vitamin D. Many supplements and fortified foods use D₂ rather than D₃.

II-1.4 Relationship between UV Exposure and Vitamin D Activity

Even though the underlying processes of vitamin D synthesis and circulation is known, the relationship of UV exposure of humans and the resulting vitamin D status is inadequately described. Some *in vitro* models (Galkin and Terenetskaya 1999, Lehmann et al. 2001) and experiments (Matsuoka et al. 1989, Holick 1994, Obi-Tabot et al. 2000) describing photoconversion of 7DHC to previtamin D exist, but are not well validated or associated with critically low vitamin D weighted irradiances at which vitamin D production in human skin is initiated under natural daylight conditions. Furthermore, they are not necessarily representative for the dermal and systemic conditions in the human body. However, they are useful indicators for how much vitamin D is produced under various solar conditions. With respect to the wavelength dependence of vitamin D production, see Figure II-2.

Various factors determine the nature and amount of UV radiation that reaches the skin and may play a role in vitamin D synthesis (Webb 2006, Webb and Engelsen 2006):

- *Clouds* can both attenuate and enhance UV-B radiation. Completely overcast clouds attenuate UV-B rays always, even up to 99 % of UV-B radiation in extreme cases (Estupinan et al. 1996).
- *Solar zenith angle* (season and latitude) have a substantial impact on UV-B radiation. At low solar zenith angles, photons must travel longer distances through the ozone layer, increasing the probability of absorption. There is also an enhanced possibility of interaction with air molecules, leading to absorption or scattering back into space, thus effectively attenuating UV radiation (Figure II-2).
- *Ozone* effectively absorbs UV-B radiation, and more so at the shortest wavelengths (Bass and Paur 1985).
- *Surface reflection (snow)*. Snow reflects up to 95 % of UV-B radiation (Blumthaler and Ambach 1988). The reflection of sand, other soils, paint and skin is much lower and generally increases with increasing wavelength (Slaney and Wolbarsht 1980).
- *Sunscreen* blocks UV-B radiation effectively (Matsuoka et al. 1988, Matsuoka et al. 1990). The role of sunscreen on vitamin D status is questionable because it is rarely applied completely and adequately.
- *Outdoor behaviour*. In affluent societies there is a tendency towards more stays indoor, either through preferences in leisure activities or work. For instance, children in the USA now only spend about 0,5 hour outdoors per day during week-ends, and only minutes during week-days (Wood et al. 1997). It is to be expected that outdoor behaviour varies greatly from country to country.
- *Skin type*. Melanin absorbs UV radiation that might otherwise initiate vitamin D production. Dark (type VI (Fitzpatrick 1988)) skins produce up to six times less vitamin D than pale

(type I) skins (Lo et al. 1986, Webb and Engelsen 2006) given the same absolute amount of sunlight. However, if the UV delivered is measured as a fraction of the body's personal MED then all skin types produce vitamin D with approximately the same efficiency given the same starting point.

- **Obesity.** Fat people have a reduced bioavailability of vitamin D, which might lead to vitamin D insufficiency (Wortsman et al. 2000).
- **Age.** Elderly skins have a lower 7DHC content, and consequently are less capable of synthesising vitamin D in their skin (MacLaughlin and Holick 1985).
- **Sun beds.** To what extent the use of sun beds contributes to vitamin D status is unclear and will depend on the spectrum emitted by the sunlamps in relation to the action spectrum (Figure II-2). In a few studies it was found that people who use sun beds regularly had a satisfactory vitamin D status (Brustad et al 2004, Porojnicu et al. 2008).
- **Clothing (temperature).** At cold temperatures the population wears more clothes for comfort, exposing less skin area to UV-B radiation, and thereby inhibiting vitamin D synthesis (Matsuoka et al. 1992). At high latitudes, face, neck and hands are generally exposed at best. During freezing temperatures, only the face is exposed.

II-1.5 Comparative Effect of Diet and UV Exposure on Serum Calcidiol Levels

Holick and co-workers found that one full body UV exposure causing a slight pinkness in skin (one minimum erythemal dose, 1 MED) is equivalent to an oral intake of somewhere in the range 250 µg - 625 µg (10 000 IU - 25 000 IU) of vitamin D₃ (Adams et al. 1982, Lo et al. 1985, Holick 1994). This relationship has been confirmed by at least three other studies (Stamp et al. 1977, Davie et al. 1982, Chel et al. 1998) (see below), including outdoor solar exposure. A weakness of the laboratory experiments lies in the fact that the experiments made use of fixed broadband UV lamps. The lamp spectral characteristics are unclear, and assimilation to natural conditions is difficult due to uncertainties in the vitamin D action spectrum. Furthermore, the laboratory experiments are generally done for very small cohorts, and this was also the case here. On the basis of the results of Holick and coworkers above, Holick (Holick 2004c, Holick 2004b) recommends a daily UV exposure of 25 % of personal MED on the bare skin of hands, face and arms or hands and legs. Now assuming that one minimal erythemal dose (MED) yields the equivalent of somewhere between 250 µg and 625 µg (10 000 IU and 25 000 IU) of vitamin D, e.g. 400 µg (16 000 IU), then one quarter of a MED at one quarter of the body yields a dietary equivalent vitamin D dose of roughly 25 µg (1 000 IU)¹. The exposure times to obtain this recommended UV dose depend greatly on skin type, time and location (Holick 2004b) as well as ambient conditions and clothing (Webb and Engelsen 2006). The latter paper (Webb and Engelsen 2006) has resulted in a freely accessible internet page, which gives an estimate of how long exposure is required to obtain any vitamin D dose from the sun under user-specified conditions.² Limitations of the method are discussed in the article.

As mentioned above, at least three additional studies (Stamp et al. 1977, Davie et al. 1982, Chel et al. 1998) support the concept that one full-body exposure to sunlight can be equivalent to an oral vitamin D intake of 250 µg (10 000 IU) (Vieth 1999). Stamp et al. compared oral vitamin D to the effects of ultraviolet radiation treatment sessions and found that the rise in 25(OH)D was the same in subjects treated with ultraviolet radiation as in those given 250 µg (10 000 IU) vitamin D per day. In a study of institutionalized elderly, Davie et al. exposed 600 cm², about 5 % of skin surface, to ultraviolet light treatments over a 2-3-month period and compared the resulting 25(OH)D concentrations with those achieved with oral vitamin D doses. They calculated a production of vitamin D in the skin equivalent to 0,045 nmol·d⁻¹·cm⁻² exposed skin. This is equivalent to 10,9 µg (435 IU) vitamin D per day for 5 % of skin surface. If the results in a similar study are extrapolated to total body surface area, it works out to 218 µg (8 700 IU) vitamin D per day that can be acquired by the elderly

¹ 400 µg × ¼ × ¼ = 25 µg (16 000 IU × ¼ × ¼ = 1 000 IU)

² http://nadir.nilu.no/~olaeng/fastrt/VitD_quartMED.html

(Chel et al. 1998). It is well established that the elderly are less capable of synthesizing vitamin D in their skin (Vieth 1999).

There are several studies on the separate effects of dietary intake and UVR exposure on serum calcidiol levels. An extensive list is given in Tables 2 and 4 of a publication of Vieth (Vieth 1999) (see also (Matsuoka et al. 1989, Holick 1995, Prystowsky et al. 1996, Chuck et al. 2001, Heaney et al. 2003, Vieth 2005a)). Davie devised empirical formulas describing the effect of both dietary intake and UV radiation on the serum calcidiol levels based on results from about 25 subjects (Davie et al. 1982). Devising exact, general formulas is not straightforward because the effect of vitamin D intake on vitamin D status depends on the initial 25(OH)D level. It seems that the effect of vitamin D intake and synthesis is enhanced when the initial vitamin D status is low (Snell et al. 1978, Mawer et al. 1984, Vieth 1999). An important problem in interpreting and comparing many *in vivo* studies of the effect of UVR exposure is that evaluation of the exact doses of ultraviolet light is complicated because there are variations in the surface area of skin exposed, skin type, starting levels of serum calcidiol, and in the frequency and duration of exposure. Furthermore, the spectra of the radiation sources are usually variable and inadequately specified, and computing comparable vitamin D effective doses from the given information is not straightforward. Exact assimilation of the various studies is thus difficult.

There are several journal papers describing the statistical relationships of vitamin D status and an incomplete set of indirect parameters such as latitude, hours of exposure, etc. Unfortunately many of those extensive cohort studies do not contain adequate information to reconstruct the relevant UVR doses at a desirable accuracy.

It has been often claimed that adequate vitamin D is obtained within a few minutes out in the sun. This is commonly true only if the equivalent of 10 µg (400 IU; corresponding to one spoonful of cod liver oil) is desired (Table II-2, Figure II-3). However, many research scientists advocate for higher intakes of vitamin D. This is usually not available from casual exposure (e.g. waiting for the bus to work). Also, the gap between beneficial UV exposure to obtain desirable vitamin D and harmful exposure leading to erythema (i.e. 1 MED) narrows. In fact, the face needs to be sunburnt in order to produce 100 µg (4 000 IU).

Table II-2 – Exposure time, in hours and associated MED (in parentheses) for Boston at the spring equinox for all permutations of the variables dietary intake (IU), skin types II, V, and skin area of exposure (F: face, N: neck, H: hands, A: arms, L: legs)
From (Webb and Engelsen 2008)

Vit. D		400 IU		1 000 IU		4 000 IU	
Skin Type		II	V	II	V	II	V
Area	F,N,H (11,5 %)	0,15 (0,21)	0,35 (0,21)	0,36 (0,54)	0,89 (0,54)	1,49 (2,16)	3,95 (2,16)
	F,N,H,A (25,5 %)	0,07 (0,09)	0,16 (0,09)	0,17 (0,24)	0,40 (0,24)	0,67 (0,97)	1,62 (0,97)
	F,N,H,A,L (57,5 %)	0,03 (0,04)	0,07 (0,04)	0,07 (0,10)	0,18 (0,10)	0,29 (0,43)	0,70 (0,43)