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UV Radiation

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Human exposure to ultraviolet radiation

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UV RADIATION

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HUMAN EXPOSURE TO ULTRAVIOLET RADIATION

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recommendations from a committee of the Health Council of the Netherlands

submitted to

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the Minister and the State Secretary of Welfare, Health and Cultural Affairs

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the Minister of Housing, Physical Planning and the Environment

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No 1986/9E, The Hague, June 10, 1986

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Gezondheidsraad (Health Council of the Netherlands)
PO Box 90517, 2509 LM The Hague, The Netherlands

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PREFACE

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This report has been prepared by the Committee on UV-appliances of the Health Council of the Netherlands. The members of the committee are listed in Chapter 2 of the report. In presenting this report to the Chairman of the Health Council the committee considers its mandate to be fulfilled.

The Hague, June 7, 1986.

Dr WF Passchier,
secretary

Prof JC van der Leun,
chairman

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PREFACE TO THE ENGLISH EDITION

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The committee of the Health Council which prepared this report on UV radiation noted that in several other industrialized countries the increasing use of UV appliances has given rise to concern and that regulations for the safe use of this equipment are in the process of being prepared or revised. Information about these developments elsewhere proved quite helpful to the committee and the committee presumes that its report will likewise be of interest to other scientific advisory bodies.

This English edition is an abridged version of the original report in the Netherlands language. Those chapters which contain background information are presented in summarized form only, as it was assumed that the foreign reader is familiar with this information. However, the recommendations of the committee and their underlying arguments, have been translated in full.

As is indicated in the report further research about the effects of human exposure to UV radiation is necessary. The Health Council is interested in receiving information about the results of this research and any other comments that this report might evoke.

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The Hague, November 1, 1986

Dr L Ginjaar,
President of the Health Council of the Netherlands.

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The sections marked with * have been translated in abridged form only.

SUMMARY

This report presents recommendations for the safe use of artificially generated ultraviolet (UV) radiation. Exposure to radiation from UV lasers is not considered here, although some of the recommendations are also valid for radiation from this type of equipment.

This report revises and extends the 1978 recommendations of the Health Council of the Netherlands on 'micrometer' radiation, insofar as UV radiation (wavelength range of 100-400 nm) is concerned. The 1978 report mainly discussed unintentional exposure to electromagnetic radiation. The present report also deals at length with the intentional use of UV radiation sources, like sunlamps, suncouches, solaria, etc., by the general public.

The introductory part of the report is followed by a review of the physical properties of UV radiation and UV radiation sources (Chapter 5). The following two chapters deal with the effects of UV radiation on the skin and the eyes. Effects on or in the skin include the production of vitamin D, thickening of the epidermis, pigmentation, erythema (sunburn), ageing of the skin and skin cancer. For skin carcinomas the doseresponse relationship is relatively well known. The action spectrum however, i.e. the spectral effectiveness as a function of the wavelength, is still rather uncertain, especially in the wavelength region of 350-400 nm. There are indications that melanomas of the skin are related to radiation from the sun (and therefore to UV radiation, according to some authors); quantitative data are lacking, however (Chapter 6).

The chapter on eye effects discusses keratitis and

conjunctivitis. It is possible that cataracts, preventing the transmission of visible light by the lens of the eye, are caused by UV radiation in the wavelength range where the cornea is transparent for UV (about 350-400 nm). The dose-response relationship is not well known however (Chapter 7).

The committee proposes to base standards on two different action spectra. In the case of intentional exposures, an erythema-action spectrum can be used; a so-called skin/eye-action spectrum should be applied in the case of unintentional exposures to UV radiation. In defining these action spectra international recommendations have been taken into consideration (Chapter 8).

Exposure guides for intentional exposures to UV radiation only take skin effects into account. In these situations the eyes may (and should) be protected by glasses, goggles, etc., or by closing the eyes (Chapter 12). The committee is of the opinion that the erythema-action spectrum can be used for deriving measures of acute skin damage. Animal experiments show that this action spectrum also gives a reasonable approximation for the risk of skin carcinomas. Using the erythema-action spectrum, erythema-effective radiant exposures (doses) can be derived; it is practical to express these in a reference value of the dose just sufficient to cause erythema. This reference value, the MED, is by definition equal to a radiant exposure of 200 J/m^2 of UV radiation with a wavelength of 297 nm (Chapter 6).

The committee bases its recommendations on a limit for the annual erythema-effective radiant exposure of 100 MED (20 kJ/m^2, Chapter 12). This value is less than the difference in radiant exposure from the sun between outdoor and indoor workers in the Netherlands and is of the order of magnitude of the radiant exposure during a few weeks 'sun holiday' in Mediterranean regions (Chapter 9). Manufacturers of UV appliances should base their instructions for irradiation courses on this value or a lower one. The radiant exposure of the first irradiation session should be restricted to 0.5 MED (100 J/m^2) and the interval between the first and second irradiation session should be at least two full days. These recommendations, together with the advice not to use cosmetics shortly before and during irradiations, are intended to make any acute irradiation effect noticeable at an early stage of an irradiation course (Chapter 13).

The committee also proposes guidelines for the construction of UV appliances and the accompanying instructions. Adequate information, labelling of the appliances and lamps, and automatic time switches may prevent problems caused by the irradiation (Chapter 13).

The standards for unintentional exposures to UV radiation are based on an action spectrum that takes into account both acute skin and eye effects. Contrary to the situation with intentional exposures, the standards are also meant to protect persons with sensitive skin. In the wavelength region below 310 nm the action spectrum, which is normalized to 1 at 270 nm, is in agreement with international recommendations (Chapter 15).

The committee proposes as a daily exposure limit a skin/eye-effective radiant exposure of 30 J/m^2. This value can be used both for occupational and non-occupational exposures. The committee concludes that applying this exposure limit also restricts the risk of developing skin cancer. There is no indication of a threshold value for skin cancer; this implies that a further reduction of the radiant exposure below the exposure limit is desirable in principle. However one should also take into account the positive influence which UVB radiation in particular has on the body, i.e. the production of vitamin D (Chapter 15).

International recommendations also restrict the irradiance in the UVA spectral region (315-400 nm) to 10 W/m^2, in view of the possible induction of cataracts. The committee however deems such an exposure limit superfluous for exposures which do not extend over many years (say, more than 10 years); this position is in accordance with the recommendation in the 1978 report of the Health Council. Where exposure to UVA radiation over extended periods of time cannot be avoided, irradiation of the eyes should in general not exceed 1 W/m^2 so as to limit the risk of causing a cataract. Incidental exposure to a higher irradiance will not unavoidably lead to harmful effects on the eyes. This proposal differs from international recommendations (Chapter 15).

The main report concludes with recommendations for further research on the exposure to and the effects of UV radiation. The appendices discuss the induction of skin carcinomas by UV radiation and present a short review of medical applications of UV radiation*. The final appendix presents a popular description of the effects of UV radiation on the skin and eyes*.

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* Omitted in the English version of the report.

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PART 1 INTRODUCTION

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1 The request for a report

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2 The committee

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3 Background

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4 Plan of the report

1 THE REQUEST FOR A REPORT

The former State Secretary for Health and Environmental Protection asked the president of the Health Council to prepare a report about the health consequences of the wide use of UV appliances. Recommendations on the need for measures in the field of radiation protection would be appreciated.

This request, contained in a letter no 188388 of September 8, 1982, was formulated as follows:

I herewith ask you to prepare a report on the following problem. It appears that both consumers and medical professionals, like physicians and physiotherapists, increasingly question the safety of solaria and other sources with an ultraviolet component that are thought to be or promoted as benificial to health. The need for an evaluation of the available scientific knowledge in this field is also felt within the scientific community.

Dated 30 March 1978 a Committee of the Health Council published a report entitled 'Acceptable levels of micrometer radiation' in which the effects of ultraviolet radiation on the skin and the eyes are dealt with. The Committee stated in the report that the recommended acceptable levels should be evaluated after, five years at the outside.

You might be aware of the studies on the biological and health physics aspects of ultraviolet radiation that have been initiated and supported financially by this Ministry. With regard to radiation protection, ultraviolet radiation plays an increasing role in the field of medical applications, occupational exposure and exposure of the general public. With respect to the latter category one can distinguish between exposure from ultraviolet appliances (sunlamps, mercury lamps etc.) and the increase of the amount of natural ultraviolet radiation from the sun that may be caused by a reduction of the protective ozone layer.

As this last question is being studied at length within the framework of the International Coordinating Committee on the Ozone Layer (CCOL) and the World Plan on Action on the Ozone Layer, I will leave this problem aside in the present request for advice. Ultraviolet radiation emitting appliances, too, are the subject of international deliberations, but formal discussions have only just started.

In this respect I want to refer to the activities of the International Non-Ionizing Radiation Committee.

In the United States and in Canada the use of sunlamps and mercury lamps has been regulated for a number of years. A study of the necessity of such regulations in the Netherlands is a matter of importance.

I should appreciate receiving your report about the health consequences of the wide use of appliances and light sources that emit in normal or in exceptional situations substantial amounts of ultraviolet radiation. In preparing your report, you should take the present exposure to natural background radiation from the sun into account.

I should also like to know your opinion on the need for protective measures with respect to those sources (the use of ultraviolet radiation for medical, paramedical or cosmetical purposes, or illumination) that might lead to significant exposure of the population general public or the workers. I should ask you to pay attention in particular to the possibility of laying down technical requirements for appliances or lamps in order to prevent undesirable exposure to ultraviolet radiation.

signed
The State Secretary of Health and Environmental Protection,

ms JJ Lambers-Hacquebard

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The present report contains the recommendations prepared by a committee of the Health Council of the Netherlands in response to the State Secretary's request.

2 THE COMMITTEE

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Partly due to staff changes in the bureau of the Health Council work on this report did not commence until the end of 1983. After the preliminary work had been completed, the 'UV appliances' committee was in augurated by president of the Health Council on February 1, 1984. The committee had to convene on 21 occasions before the preparation of the present report was completed.

The letter of the State Secretary refers to a report of the Health Council from 1978 about acceptable levels of micrometer radiation, in which exposure to ultraviolet (UV) radiation was also dealt with. To make optimum use of the information gathered at that time, some of the experts who prepared the earlier report were also asked to sit on the new committee. The chairman of the committee was one of them.

The committee was composed of:

- Prof JC van der Leun, chairman
  Professor of the Physics of the Skin, Institute of Dermatology, State University of Utrecht
- Dr BFM Bosnjakovic, advisor
  Radiation Protection Division, Ministry of Housing, Physical Planning and the Environment, Leidschendam
- Dr AWM van der Kamp
  Department of Cell Biology and Genetics, Erasmus University, Rotterdam
- Dr H Pauw
  Department of Occupational Health and Safety, Nederlandse Philips Bedrijven BV, Eindhoven
- Dr GP van der Schans

Medical Biological Institute TNO, Rijswijk (ZH)

- Prof D Suurmond
  Professor of Dermatology and Venereology, Department of Dermatology, State University of Leiden
- Dr JWM Visser
  Radiobiological Institute TNO, Rijswijk (ZH)
- Dr JJ Vos (since July 24, 1984)
  Institute for Perception TNO, Soesterberg
- B van der Werf, advisor
  Radiation Department, Ministry of Social Affairs and Employment, Voorburg
- Dr WF Passchier, secretary
  Health Council of the Netherlands, The Hague

Ms W van Bladel-Tactor was responsible for the committee administration.

The committee studied the scientific literature and standards and regulations proposed elsewhere, and compiled a list of the types of sun lamps, sun couches and similar appliances that are being sold on the Dutch market. The committee initiated a study on the use of these UV sources by the general public. This study was commissioned by the Ministry of Housing, Physical Planning and the Environment. Mr WE de Jong from the Nederlandse Philips Bedrijven BV in Drachten helped to interpret the results of this survey.

On November 27, 1985 the committee organised a hearing for manufacturers of UV appliances for personal irradiation (non-medical applications). This meeting enabled the manufacturers to comment on the draft recommendations of the committee concerning the construction and use of these radiation sources. This meeting proved to be quite useful to the committee and made the committee reconsider certain points in the draft report. This led to a number of additions and clarifications.

3 BACKGROUND

3.1 Recommendations of the Health Council on micrometer radiation

In 1978 the Health Council recommended 'acceptable levels of electromagnetic radiation of wavelengths between 100 nm and 1 mm (micrometer radiation)' (Gr78). The report presented acceptable levels for exposure to artificially generated UV radiation during an 8-hour working day. At these levels erythema of the skin ('sunburn') and inflammation of the cornea (photokeratitis) is avoided.

In the case of prolonged exposure to UV radiation the risks of skin ageing and of skin cancer become significant. It was proposed to keep the exposure within 10% of the average radiant exposure of the sun (using a combined erythema and photokeratitis action spectrum). Such an exposure level was considered to be insignificant with respect to the natural UV radiation dose.

The 1978 report mentioned however that scientific knowledge of the biological effects of radiation was still incomplete and that further research was in progress at several institutes. It was therefore recommended that the conclusions be reviewed after a number of years. The review is presented in this report though it concerns the UV part of the radiation spectrum only.

3.2 Applications of UV radiation sources

A distinction can be made between intentional and unintentional exposure to UV radiation from the sun or from an artificial radiation source. Examples of intentional exposure are sunbathing, the use of sunlamps and the irradiation of patients for diagnostic or therapeutic reasons. The application of UV-sources in industry or outdoor activities can lead to unintentional exposure. It is possible to have both types of exposure at same time; with radiation therapy, e.g., the irradiation of the patient is intentional contrary to the exposure of the personnel effectuating the treatment.

The 1978 Health Council report (Gr78) mainly dealt with unintentional exposure. The basic principle here is to prevent harmful effects as far as possible. In recent years the use of UV sources such as sunlamps, suncouches, etc., by the general public, has become increasingly popular. In these situations of intentional exposure, harmful effects should also be minimized. However, the harmful effects should be balanced against the intended effects on the irradiated person, which might lead to different standards. In this respect the scope of the 1978 report needs to be extended.

Industrial applications of UV radiation sources are also increasing. One recent example is the use of UV radiation for the curing of inks and lacquers; UV radiation is already much longer applied in processes such as air cleaning. Medical applications of UV sources in the treatment of skin diseases are the subject of a renewed interest. Table 1 summarizes situations in which people are exposed to UV radiation.

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3.3 New scientific results

Since 1978 scientific research has led to several discoveries. Dutch scientists have contributed substantially to the progress made.* The knowledge relating to the induction of skin cancer and the dose-effect relationship has increased. Biological and biochemical studies have revealed several details of the mechanisms of UV induced damage and how it can be repaired. Scientists also have a better idea now about the

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* The Dutch research has been financed partly by the Ministry of Housing, Physical Planning and the Environment.

Table 1 Summary of situations in which persons may be exposed to UV radiation.

Purpose of the irradiation	nature[1]	persons[2]
Exposure from the sun:		
. sunbathing	I	P
. recreational activities outdoors	I,U	P
. work outdoors	U	W
Exposure from artificial sources:		
. cosmetic (tanning)	I	P
ditto	U	W
. medical	I	P
ditto	U	W
. photochemical processes	U	W
. curing of inks and lacquers	U	W
. curing of dental soppings	U	P,W
. sterilization of objects and air	U	P,W
. research applications	U	W
. welding	U	W
. entertainment industry	U	P,W
. illumination	U	P

Explanations:

1 - I = intentional exposure of persons
U = unintentional exposure of persons

2 - P = members of the general public (including patients)
W = workers
At work persons not directly engaged in applying the radiation sources may also become exposed.

interactions at different wavelengths. Not all the problems have been solved, but the knowledged gained can at least provide a better basis for laying down standards for exposure to UV radiation.

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3.4 Regulations

The 1978 recommendations of the Health Council have not been 'translated' into official regulations. However, the letter from the State Secretary (Chapter 1) indicates that following the lead taken by other countries, regulating UV exposure is currently being considered by the Dutch government. Given the developments mentioned above, a new report, providing the scientific rationale for regulatory measures, is warranted.

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4 PLAN OF THE REPORT

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There is quite a variety of situations in which humans can become exposed to UV radiation. This report only deals with applications of artificial sources of UV radiation. Exposure from the sun will be used as a reference. The use of UV lasers is outside the scope of the present report. The standards for unintentional exposure, however, are often applicable in the case of UV lasers.

The interaction of UV radiation with several chemicals may lead to photochemical reaction products. The possible toxicity of these compounds may entail an additional risk for the user. An example is the interaction of UV radiation with welding fumes and oxygen during arc welding. The committee does mention such processes, but confines its remarks in the report to the direct interaction of UV radiation with the human body. Photochemical reactions with foreign substances in or on the skin or the eyes are not dealt with either.

The foregoing chapter mentioned the increase of medical applications of UV radiation. The committee did not consider itself competent to advise on the efficacy of such uses or to recommend protocols. The most important medical applications are summarized in an appendix*.

The present report does not refer back to information contained in the 1978 report. A complete description of the principles and problems relating to human exposure to UV radiation is presented here.

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* Omitted in the English version of the report.

After the introductory part (Chapter 1 - 4), the report discusses the physical properties and biological effects of UV radiation (Chapter 5- 9).

Part 3, starting with Chapter 10, deals with the application of sunlamps for tanning and general health purposes. Chapter 13 proposes radiation protection guidelines for such applications.

Applications in which people are unintentionally exposed to UV radiation, either at the workplace or elsewhere, are dealt with in the fourth part (Chapter 14 - 16). The committee recommends ways in which such exposure can be limited.

The final part of the main report (part 5) summarizes the most important conclusions and recommendations of the committee. Areas for further scientific research are also indicated. The mechanism of skin cancer induction by UV radiation is discussed in greater detail in an appendix. Appendix B summarizes the medical applications of UV radiation.*

Finally, appendix C presents a more popular description of the interaction of UV radiation with the human body.* This appendix may be helpful in informing the general public about the effects of UV radiation.

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* Omitted in the English version.

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PART 2 PROPERTIES AND EFFECTS OF UV RADIATION

5 PHYSICAL PROPERTIES AND SOURCES OF UV RADIATION

5.1 Physical properties*

Ultraviolet radiation is a form of electromagnetic radiation. The applications of the different types of electromagnetic radiation are listed in Figure 1.

UV radiation, like all other forms of electromagnetic radiation, can be scattered, reflected, and absorbed by matter. In Figure 2 the reflection factor for the interaction with several materials is given. As can be seen in the figure, the reflection factor is strongly wavelength dependent.

After absorption of the radiation in a material photochemical reactions may follow. It is also possible for part of the radiation to be emitted with a larger wavelength (fluorescence).

On the basis of its biological effects the UV spectral region has been subdivided into three parts (CI70):

- UVC: 100 nm - 280 nm;
- UVB: 280 nm - 315 nm;
- UVA: 315 nm - 400 nm.

5.2 Quantities and units*

Exposure to UV radiation is characterized by the quantities irradiance and radiant exposure (CI70). The radiant exposure is the amount of UV radiation energy that reaches a certain flat surface, expressed per unit of surface area. The unit in the international system of units (SI) is J/m^2. The

* Summary of the original Dutch version of the report.

Translation of terms:

'frequentie'	= frequency
'golflengte'	= wavelength
'hoogfrequent'	= highfrequency
'infrarood'	= infrared
'kortegolf'	= short wave
'middengolf'	= medium wave
'radar'	= radar
'radio'	= radio
'röntgenstraling	= X-rays
'televisie'	= television
'toepassing'	= application
'ultrakorte golf'	= very short wave
'ultraviolet'	= ultraviolet
'warmtestraling'	= heat
'zeer hoogfrequent'	= very high frequency
'zichtbaar (licht)'	= visible (light)

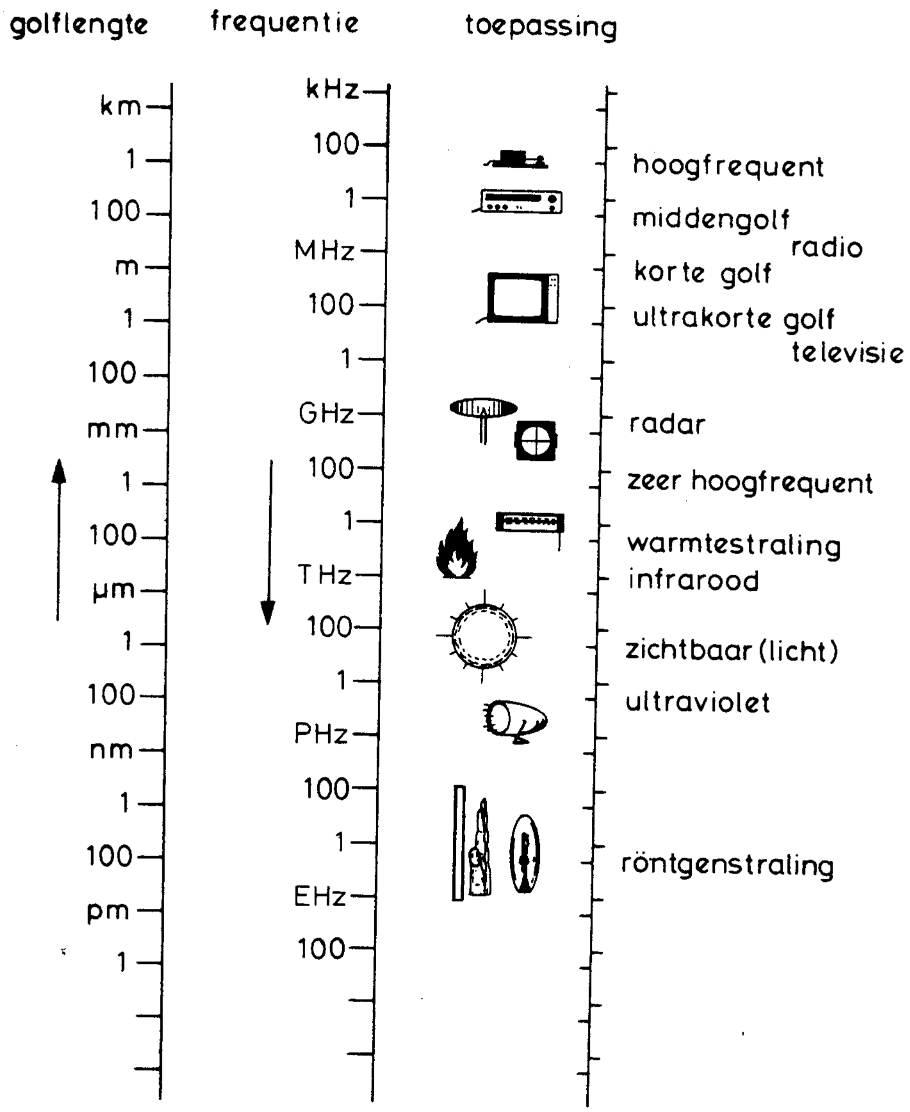

Figure 1 The electromagnetic spectrum and applications of electromagnetic radiation.

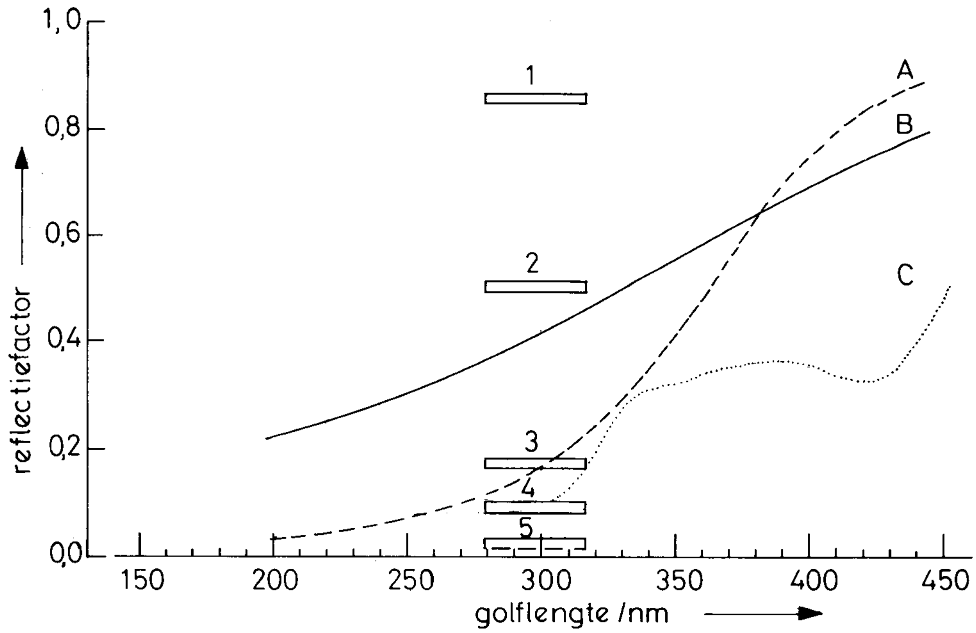

Figure 2 Reflection factor ('reflectiefactor')of normally incident UV radiation as a function of wavelength ('golflengte') for (A) white oil paint (Ko85), (B) white water paint and wall paper (Ko85), (C) white skin (Ja55). Reflection factor for UVB radiation for (1) fresh snow, (2) old snow, (3) bright dry sand dune, (4) bright wet sand, (5) sandy grass area and heather (Sl85).

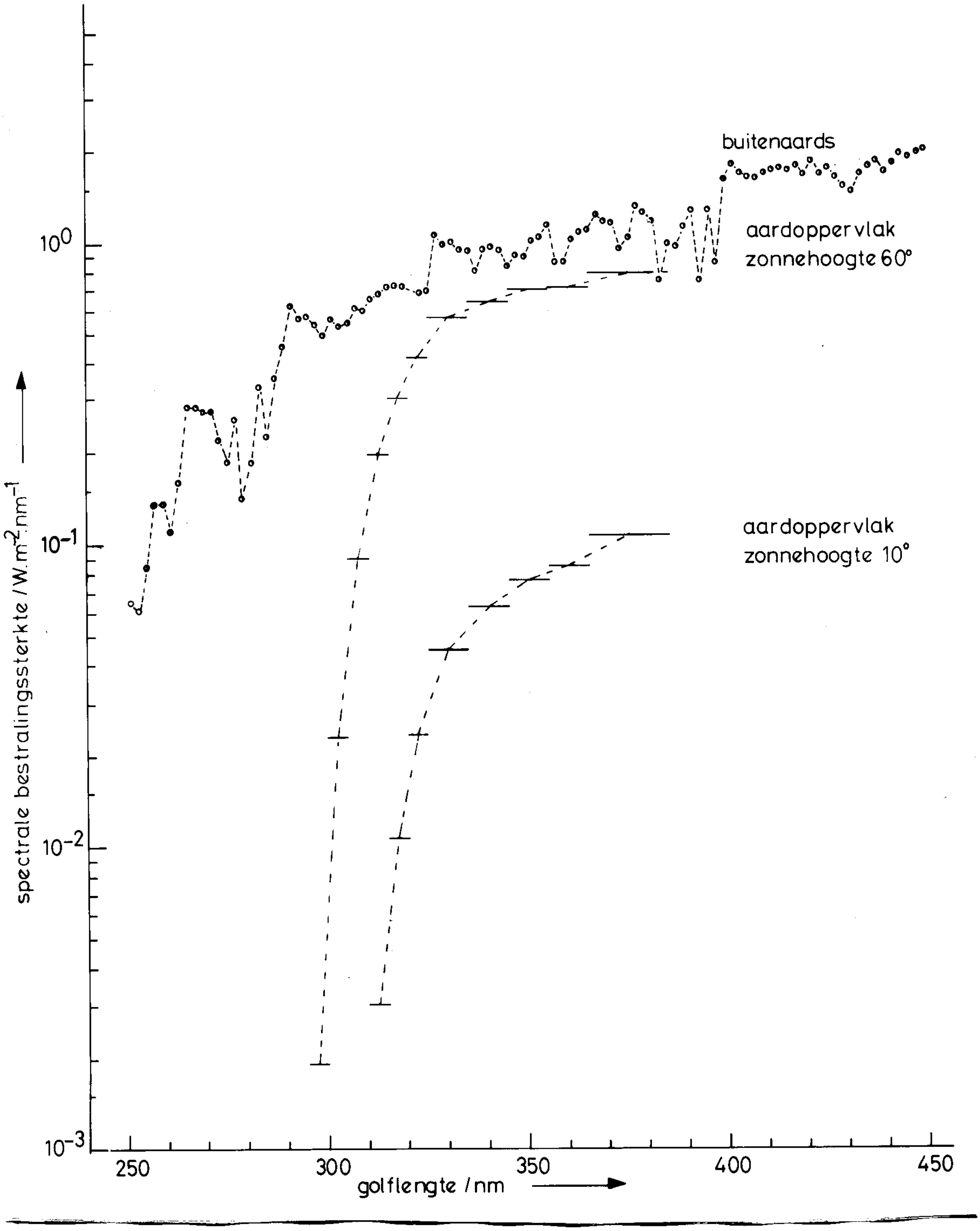

Figure 3 Spectral irradiance ('spectrale bestralingssterkte') of the solar radiation outside the atmosphere ('buitenaards') and at the earth's surface ('aardoppervlak'). In the latter case spectra are given for a sun angle ('zonnehoogte') of 60° and of 10°, roughly comparable to the noon hour at a bright day in the end of June, and a bright day in the end of December in the Netherlands (De83, Gr80).

recommended symbol is H.* The irradiance gives the change of the radiant exposure with respect to time. The SI-unit is W/m^2. The recommended symbol is E. The spectral irradiance is the derivative of the irradiance with respect to the wavelength. A similar definition holds for the spectral radiant exposure.

In order to describe the biological effects of UV radiation quantitatively, (biologically) effective quantities have been introduced. The effective irradiance, E_{eff} is defined as:

$$E_{eff} = \int_S s(\lambda)\, E_\lambda \, d\lambda$$

in which E_λ is the spectral irradiance at wavelength λ and S denotes integration over the (UV) radiation spectrum. The quantity $s(\lambda)$ expresses the biological effectiveness or action spectrum. Its usefulness depends on the mutual independence of the effects of radiation of different wavelengths. The action spectrum is specific for a given biological effect. The effective radiant exposure can be defined similarly.

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5.3 UV radiation from the sun**

The most important source of UV radiation on earth is the sun. The short-wavelength radiation (UVC and UVB) is strongly absorbed by the ozone in the atmosphere. The radiation spectrum at the earth's surface will also depend on meteorological conditions and on the amount of air pollution. Examples of the UV spectrum from the sun are given in Figure 3.

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5.4 Overview of artificial UV-sources**

The artificial UV sources can be divided into three major groups:

- incandescent sources;

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* To avoid confusion with photometric quantities a subscript e is added. In this report the subscript can be omitted.

** Summary of the original Dutch version of the report.

- gaseous discharge sources;
- special sources.

An example of the spectrum emitted by an incandescent source is given in Figure 4. The spectrum of a high pressure gaseous discharge lamp is presented in Figure 5. The figure shows the selective suppression of a part of the UV spectrum by a filter. In the fluorescent lamp the radiation generated by the gaseous discharge is modified by a fluorescing substance (the phosphor). By selecting an appropriate phosphor a radiation spectrum required for a given application can be obtained. An example of the spectrum of an UV fluorescent source is given in Figure 6.

UV appliances for tanning purposes contain fluorescent lamps or high intensity mercury halide sources with filters to remove the UVC and (part of) the UVB radiation. Examples are presented in Figures 5 and 6. In recent years a trend towards using sources with a very small fraction of UVB radiation has manifested itself, especially in Europe.

Sterilization is usually performed with a low pressure mercury discharge lamp with a powerful emission at 254 nm (germicidal lamp). Industrial applications make use of gaseous discharge sources with the main emission in the UVA or the UVB spectral region. The so-called 'black light' lamps are fluorescent sources with an emission in the UVA spectral region and are used to produce all sorts of fluorescent light effects.

Normal sources for illumination, of both the incandescent and fluorescent type, also emit a certain amount of UV radiation. This radiation will not usually give rise to observable biological effects. However, in the case of high intensity sources or of gaseous discharge sources with a damaged outer bulb, acute effects cannot be excluded.

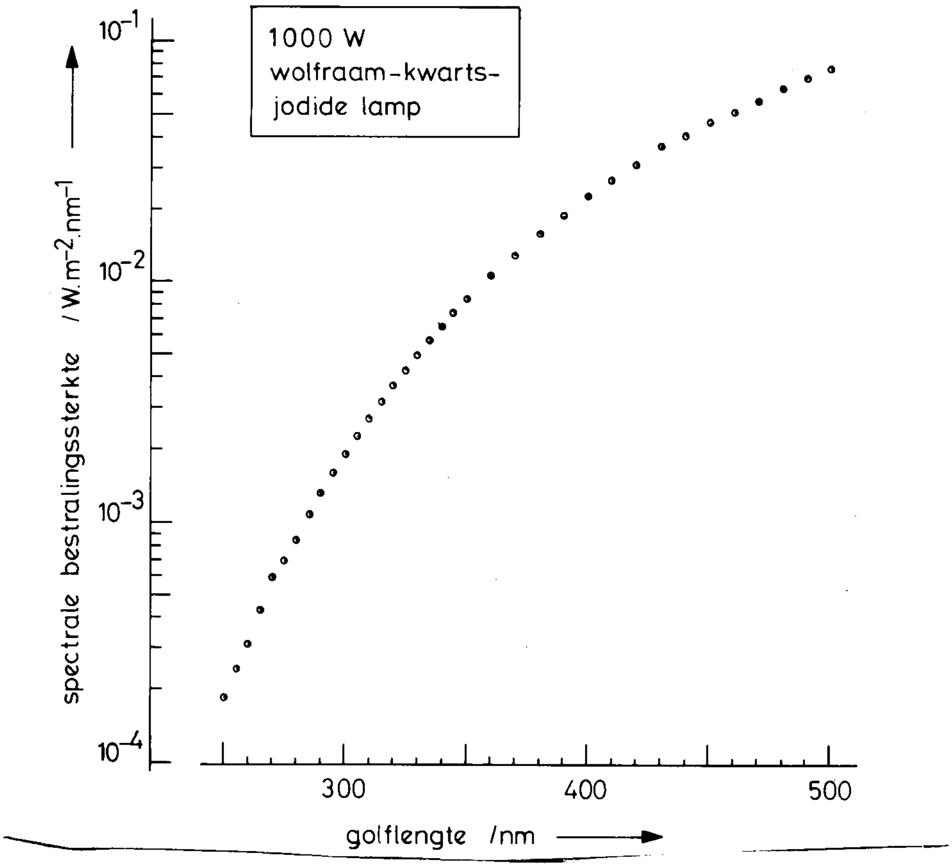

Figure 4 Spectral irradiance ('spectrale bestralingssterkte') as a function of wavelength ('golflengte') of a tungsten-quartz-iodide ('wolfraam-kwarts-jodide') incandescent source. The tungsten filament is positioned inside a quartz bulb filled with iodine gas. This lamp has a relatively large emission of UV radiation because quartz glass is fairly transparent for UV (S180).

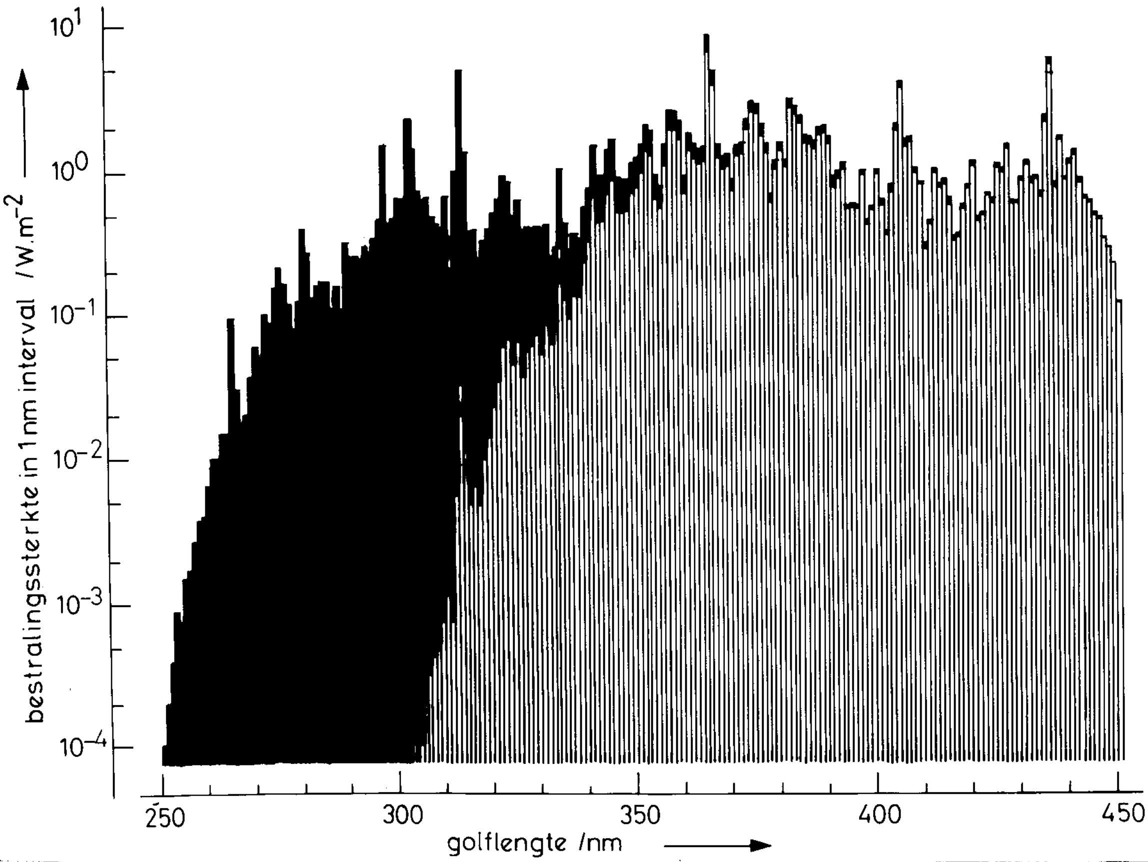

Figure 5 Irradiance ('bestralingssterkte') in 1 nm intervals as a function of wavelength ('golflengte') of a metal halide gaseous discharge lamp. This lamp contains mercury and several metal halides in a quartz bulb. Because of the high gas pressure the spectrum has a continuous character. The lamp has an important emission in the UVC and UVB spectral region. In face tanning appliances these radiations are removed by a filter (black in the figure). Data supplied by Philips.

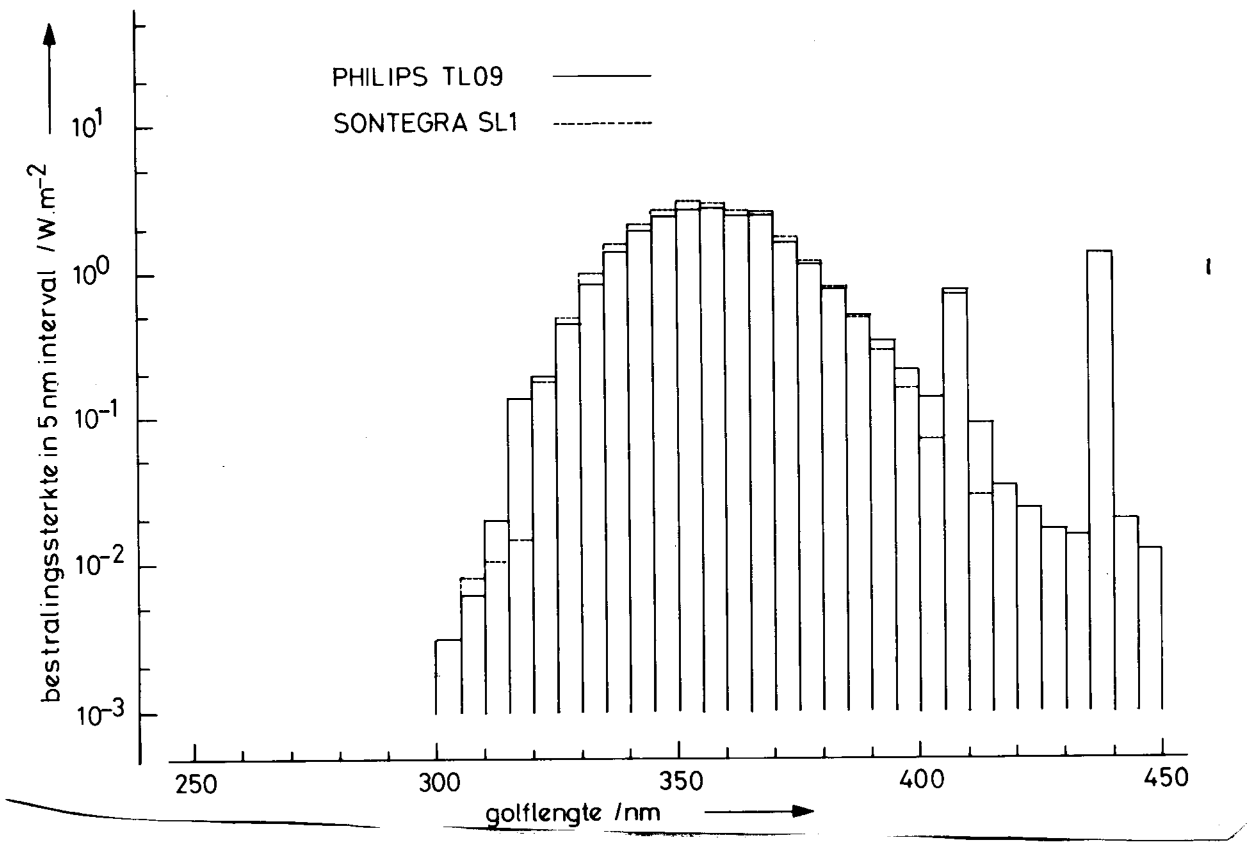

Figure 6 Irradiance ('bestralingssterkte') in 5 nm intervals as a function of wavelength ('golflengte') of UV fluorescent lamps. The lamp bulb contains low pressure mercury gas. The radiation generated by the discharge (254 nm) produces fluorescent radiation in the phosphor. In these examples the UVB irradiance is less than 0.5% of the UVA irradiance. These lamps are used in sun couches and sun canopies, and also for medical purposes (PUVA therapy). Data supplied by Philips and by Schotten.

6 EFFECTS OF UV RADIATION ON THE SKIN

6.1 Overview

UV radiation is absorbed in most biological tissues in layers less than 1 mm thick. The biological effects of UV radiation on humans therefore start with the interaction of the radiation with the skin and the eyes. This chapter discusses the skin effects. This introductory section presents an overview.

A distinction can be made between thermal and photochemical effects of UV radiation. In the former case the skin temperature is raised by the absorption of the radiation energy. Irradiance levels of 1 kW/m^2 produce a noticeable heat sensation (S180). For skin burns higher irradiance values are required. In this chapter the discussion is limited to photochemical effects. In that case the effect is caused by a chemical transformation of certain compounds in the skin after the absorption of the radiation energy.

The interaction of UV radiation with the skin plays an important role in the production of vitamin D in the body; this vitamin is essential for the formation of bone. The literature also mentions other positive effects on health, like a decreased susceptibility for influenza and colds and an increase in physical and mental capacities. These effects, however have not been adequately studied scientifically. The extent to which irradiation by the sun or an artificial source plays a role is not well known.

UV radiation further induces protective reactions against irradiation of the skin. Skin thickening decreases the penetration of the radiation in the living cell layers of the

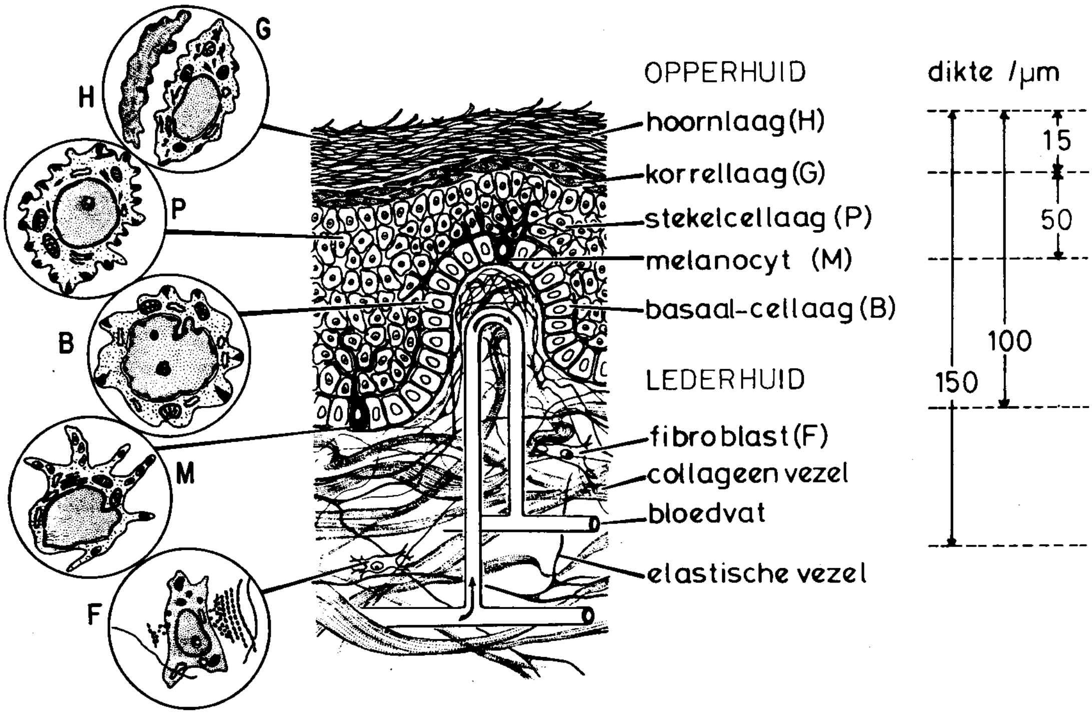

Figure 7 Cross section of the human skin showing the main types of cells in the epidermis ('opperhuid') and the dermis ('lederhuid'). The horny cells of the horny layer (H; 'hoornlaag') are continuously shed. In the granular layer ('korrellaag') the keratinization of the keratinocytes is completed (G). The interconnected keratinocytes ('stekelcel') (P) are produced from cell division in the basal layer (B). The basal cell layer ('basaal-cellaag') also contains the melanocytes (M). Epidermis and dermis are separated by a membrane. In the epidermis fibroblasts (F) and collagenous and elastic fibres ('collageen', 'elastische vezels') can be distinguished. Blood is supplied to the skin through strongly-branched capillary vessels ('bloedvaten'). (Adapted from Gi76).

skin. The increased pigmentation of the skin (tanning) has the same effect, albeit to a lesser extent.

Erythema of the skin or sunburn is a harmful effect of the radiation, experienced by nearly everyone. This effect manifests itself a short period after the exposure if a certain radiation dose has been exceeded. This threshold value depends on the skin type.

UV radiation is the most important factor in the induction of skin carcinoma. There is latent period of several decades between the interaction of the UV radiation with the skin and the appearance of the tumour. Data about the occurrence of skin carcinoma have been obtained from animal experiments and epidemiological studies on the relation with exposure to radiation from the sun. Radiation from the sun may also play a role in the induction of melanoma (malignant tumours of the pigment cells). This role however will be different and much more complicated than in the case of other types of skin cancer.

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6.2 The skin

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6.2.1 The structure of the skin*

Figure 7 shows a cross section of the skin. In the basal cell layer the keratin producing cells (keratinocytes) are formed. The basal cell layer also contains the melanocytes. These cells pass pigment granules to the keratinocytes. Skin tanning occurs, e.g. after irradiation by the sun, through an increase in the amount of pigment in the skin above the genetically determined, constitutional level.

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6.2.2 Skin types

The effect of UV radiation on the skin and the organism depends on the structure of the skin. It is possible to distinguish between different skin types on the basis of the degree of pigmentation and the sunburn sensitivity after irra-

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*   Summary of the original Dutch version of the report.

Table 2 Classification of the skin on the basis of the relative photosensitivity and degree of pigmentation (Cr81).

Skin type	Effect of irradiation from the sun (on the basis of an anamnesis and inspection of the skin)	Examples of populations in which a certain skin type frequently occurs
I	Always burns easily, never tans	Redhead, freckled Celtic, Irish-Scots
II	Always burns easily, tans minimally	Fair-skinned, fairhaired, blue-eyed Caucasians
III	Burns moderately, tans gradually (to a light-brown)	Darker Caucasians
IV	Burns minimally, always tans well (to a moderate brown)	Mediterranean type Caucasians
V	Rarely burns, tans profusely (to a dark-brown)	Mid-Eastern, some Latin American and Indo-European types
VI	Never burns, deeply pigmented	Black-skinned Negroids

diation by the sun. A common classification is given in Table 2 (Cr81). Although there is a certain relationship between the appearance of the skin and this classification, it is not possible to determine the skin type from the outward appearance only.

Other methods to classify the skin type use the surface structure of the skin (Ho84a).

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6.2.3 Optical properties of the skin

The reflection of UV radiation from the skin surface and the absorption and scattering of the radiation in the skin depends on the structure of the skin and the radiation spectrum. These three processes cause a wavelength dependent decreasing penetration of the radiation with skin depth. The wavelength dependence of this penetration for the horny layer and for the epidermis as a whole is shown in Figure 8 (Br82). The penetration of UV radiation in the skin is shown in the diagram in Figure 9. Differences in penetration influence the biological effects, as the interaction between the radiation and the skin occurs at different skin depths with different compounds.

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6.3 Health-promoting effects

In this section special attention is paid to the production of vitamin D3 in the skin by UV irradiation. This effect has been well documented. There is no positive scientific proof that UV radiation has other benificial effects on health.

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6.3.1 Production of vitamin D*

UV radiation interacts with 7-dihydrocholesterol (also called pro-vitamin D) in the epidermis to produce pre-vitamin D3. This compound is further metabolized to vitamin D3, which is then transformed in the liver and kidneys into 1,25-dehydroxyvitamin D3. This process is shown in the diagram in Figure 10.

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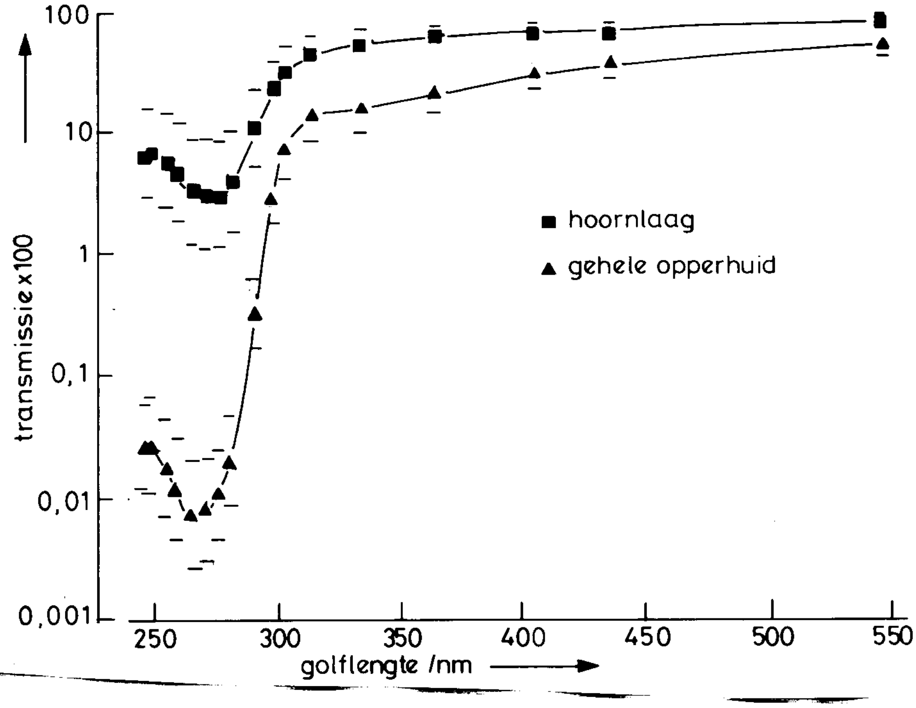
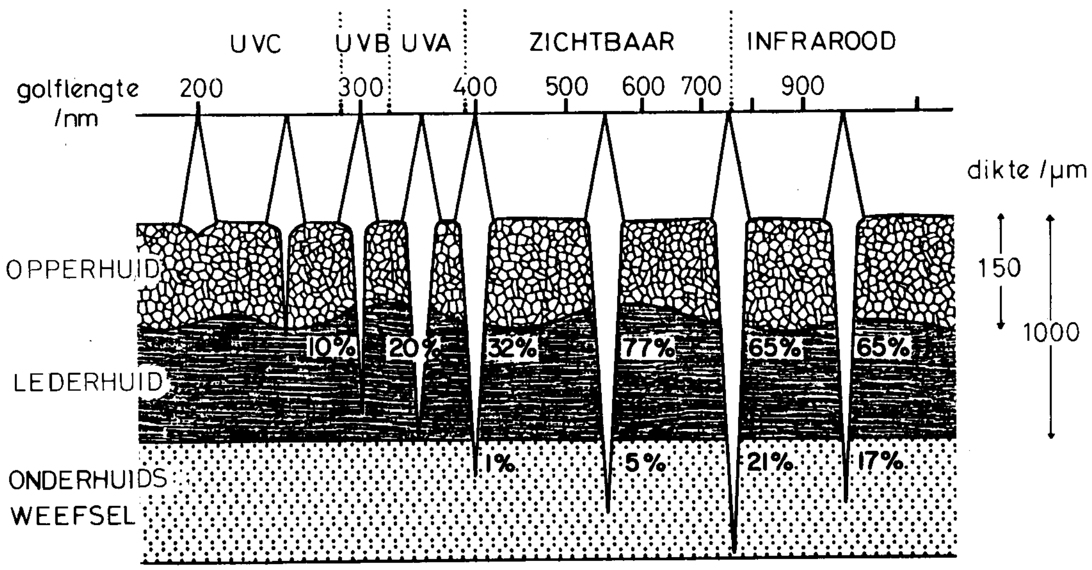
* Summary of the original Dutch version of the report.



<u>Figure 8</u> Transmission ('transmissie') of the horny layer ('hoornlaag') and the full epidermis ('gehele opperhuid') as a function of wavelength ('golflengte') as a whole for Caucasian skin (Br82). The dashes below and above the measured points indicate the spread of the experimental results.



<u>Figure 9</u> Transmission of electromagnetic radiation by the skin. Note that an important amount of UV radiation penetrates the epidermis ('opperhuid') and reaches the dermis ('lederhuid') and that longer wavelength radiation reaches the subcutaneous tissue ('onderhuids weefsel'). (Adapted from Gi76 and Pa78). ('golflengte' = wavelength, 'zichtbaar' = visible, 'infrarood' = infrared, 'dikte' = thickness).

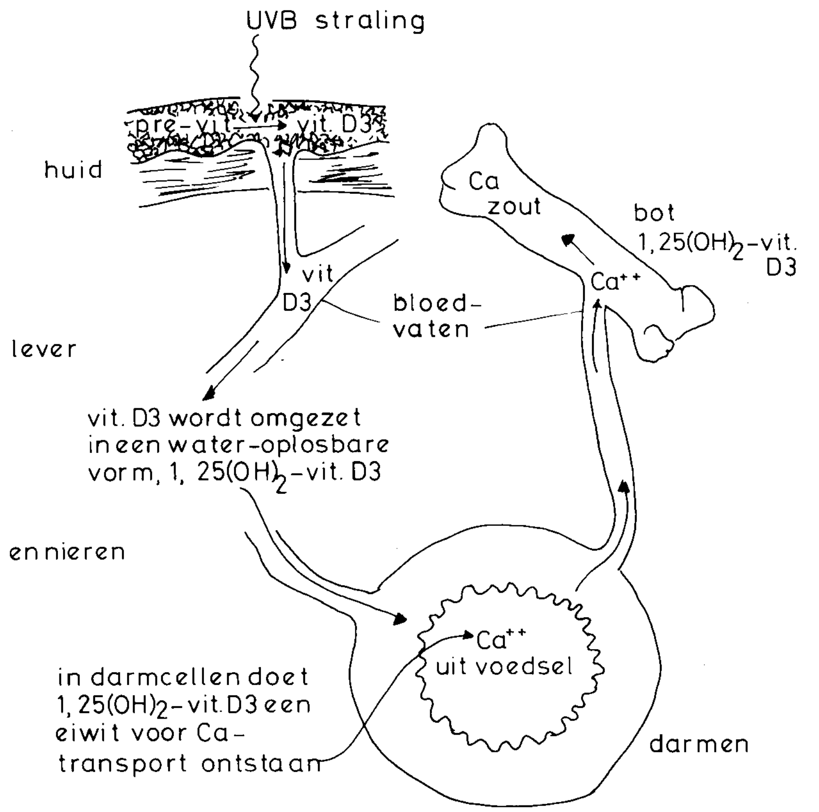


Figure 10 Diagram of the production and metabolism of vitamin D in the human body. (Adapted from Gi76).

Translation of terms:

'straling'	= radiation	'bloedvaten'	= blood vessels
'huid'	= skin	'bot'	= bone
'lever'	= liver	'darmen'	= gut
'water-oplosbaar	= water-soluble	'voedsel'	= food
'nieren'	= kidneys	'eiwit'	= protein
'darmcellen'	= gut lining cells		

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The action spectrum of vitamin D3 production is not well known. Slaper and Van der Leun (Sl85) conclude from published animal experiments and experiments with human cells in vitro that the action spectrum resembles that of erythema. This means that UVB radiation in particular is effective. UVA radiation on the other hand seems to interact with pre-vitamin D3 so as to regulate the pre-vitamin D3 concentration in the body fluids (Ma82).

Quantitative data about the vitamin D production in the skin are lacking. The exposure necessary to produce sufficient vitamin D can therefore only be roughly estimated. Slaper and Van der Leun (Sl85) derive an erythema-effective radiant exposure* accumulated in the course of a year of about 12 kJ/m^2 with an uncertainty of 50% to both sides. This value would hold for Caucasians with a 'normal' type III skin. People with a higher constitutional pigmentation may need a radiant exposure four times higher.

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6.3.2 Other effects

Several authors have claimed since the 1920's that the interaction of UV radiation with the human body has beneficial physiological, biochemical and also mental effects. Some studies refer to the production of vitamin D as a possible primary cause. An example is the work of Ronge, who irradiated schoolchildren with UV sources (Ro48). The physical improvement of the children was not confirmed by a later Scandinavian study (Be63). This shows that if exposure to UV radiation has any influence on the physical fitness at all, it is only one of many factors that play a role.

Many of the studies that claim to show that UV irradiation leads to an improvement in physical or mental capacities (cf. Gre82) or resistance to infection (Be75) are methodologically imperfect or have been insufficiently documented for the reported results to be evaluated.

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* This concept is explained in section 6.6.

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6.4 Protection against UV radiation

UV radiation induces two types of protection against further interaction between UV radiation in the skin. These are skin thickening, in particular thickening of the epidermis, and an increased pigmentation (tanning). The former effect is the most important. Increased pigmentation and so-called direct pigmentation, a process whose biological role is unclear, are discussed in section 6.4.2.

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6.4.1 Skin thickening

Exposure of the skin to UVB radiation suppresses the cell division process. After some hours the cellular activity is back to normal again, after which there follows a period of increased cell division. This period lasts from several days to a week. This results in an increased thickness of both the dead and the living part of the epidermis. The increased skin thickness decreases the penetration of UV radiation into the skin and protects the deeper cell layers against the harmful effects of the radiation. Without further irradiation the skin thickening disappears within a few months.

A single exposure of the skin to UVB radiation may result in an increase in thickness of the horny layer by a factor of 1.5 to 3. Repeated irradiation results approximately in a two-fold increase in this factor (cf. S185). The increased thickness diminishes the transmission of the horny layer by one order of magnitude. The wavelength dependence of the thickening effect is not well known. Observations with humans show that UVA radiation is much less effective than UVB radiation (Ka78). All skin types show the thickening effect.

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6.4.2 Pigmentation

Pigmentation is due to both the migration of pigment from the basal cell layer to keratinocytes in the epidermis and the increase in the number of pigment grains. It is induced by UV irradiation of the skin. Repeated exposure to UV irradiation supposedly also increases the number of melanocytes. Hormones too may influence the facultative pigmentation of the skin.

Two effects play a role in the changes in skin colour, i.e. the direct and the delayed pigmentation. The former effect can be observed after a few minutes exposure to sunlight. The delayed pigmentation or tanning occurs some days after the irradiation.

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Direct pigmentation

The direct pigmentation appears within 5 to 10 minutes after the beginning of the radiation exposure and increases during the following hour. The darkening of the skin (often to a grey-brown colour) persists during several days after the irradiation. Direct pigmentation is best observed with people with a naturally dark skin: with white skinned people the effect is not always clearly noticeable.

The pigment darkening may be caused by radiation with wavelengths between 320 and 700 nm and is most pronounced with exposure to radiation with wavelengths between 380 and 500 nm. Direct pigmentation appears after an (UVA) radiant exposure of more than about 40 kJ/m^2 (Ka79). The direct pigmentation mechanism is not quite clear. A photo-oxidation of the melanin and a redistribution of the pigment is often suggested (Pa69, Pa78). Recently however some doubt has been thrown on this explanation (Hö84).

To which extent direct pigmentation has any long term protective effect is unclear. It has been reported that no reduction of erythema susceptibility occurs (Sp78).

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Delayed pigmentation (tanning)

Delayed pigmentation, also called 'real melanogenesis', is associated with an increase in pigment production. About three days after the UV radiation exposure a tanning of the skin is observed.

Figure 11 presents the minimum radiant exposure that induces tanning as function of the wavelength. The measurement results pertain to Caucasians (Pa82). UVC and UVB radiation

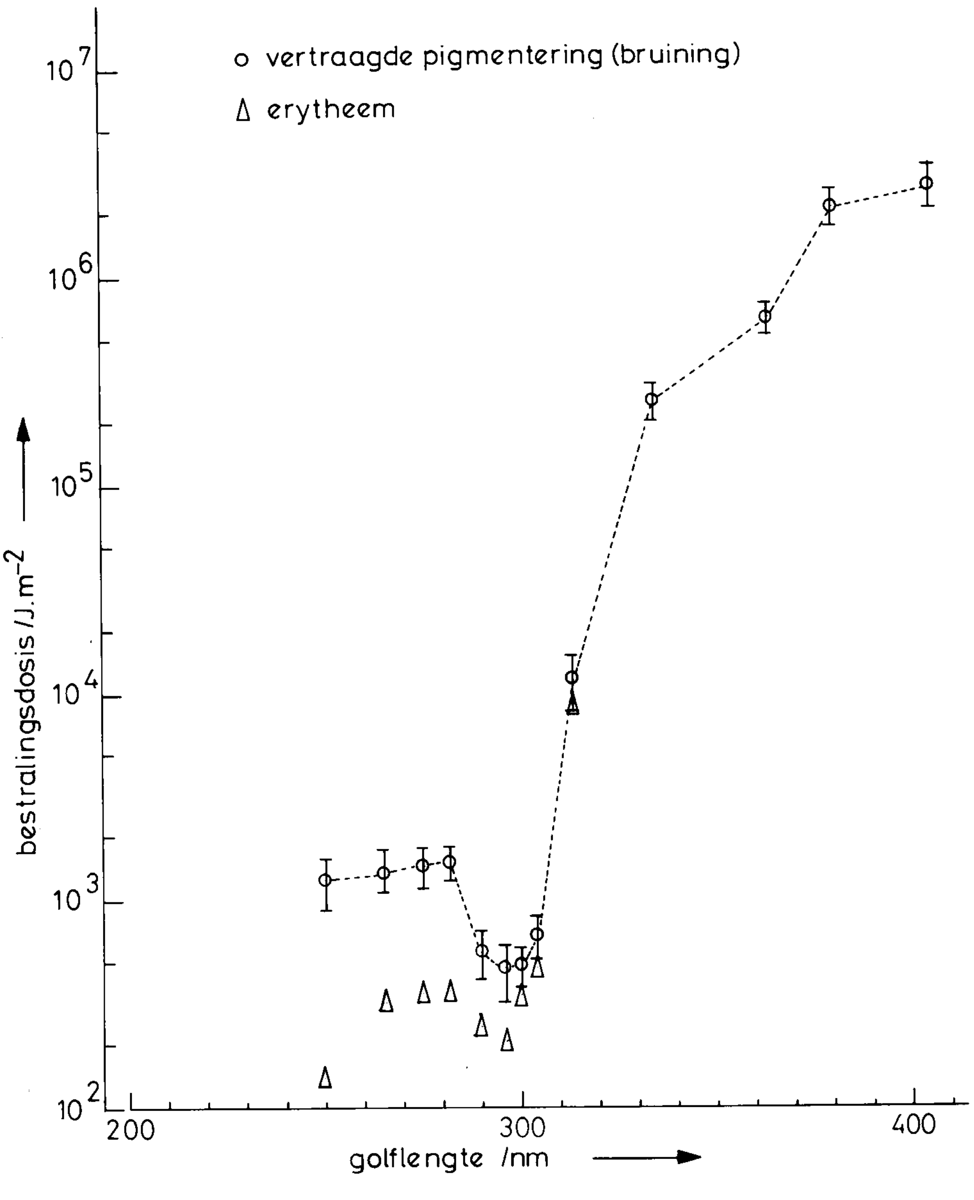

Figure 11 Minimal radiant exposure ('bestralingsdosis') necessary for delayed pigmentation (tanning) ('vertraagde pigmentering (bruining)') for Caucasian test subjects as a function of wavelength ('golflengte') (Pa82). At each measuring point the spread (± 1 standard deviation) has been shown. The triangles indicate the minimum radiant exposure for erythema ('erytheem') after 8 hours. These results have been omitted in the UVA spectral region, as they practically coincide with the pigmentation values. The minimal radiant exposure for erythema after 24 h in the UVA region is larger than the minimal radiant exposure for tanning.

induce skin tanning above radiant exposures between 0.5 and 2 kJ/m^2. In the UVA spectral region the required radiation doses are a factor 1000 higher. With repeated exposure to radiation the tanning threshold value diminishes. Compared with erythema induction the UVB threshold for tanning is higher; in the UVA spectral region this relationship is reversed.

Tanning induced by UVC radiation manifests itself about one day after the irradiation. The skin colouring is usually weak and disappears after a few days to weeks. The tanning effect of UVA and UVB radiation is most pronounced after 3 to 4 days. The skin colouring is more intense and may remain visible for several weeks or even months.

The protective effect of a tanned skin is related to the decrease in penetration of the UV radiation into the skin. With UVB irradiation the skin is also thickened. This latter process has a much larger protective effect. It has been found that UVA induced skin tanning offers protection of a factor of 3 to 5 against erythema induction by UVB radiation (Ka78, Ro82).

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6.5 Histological changes*

UVB and UVC radiation are found to damage skin cells. The formation of the so-called (dead) sunburn cells is a specific effect. The effects of UVA radiation are mostly restricted to the dermis.

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6.6 Erythema of the skin

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6.6.1 Mechanism*

Several hours after the UV radiant exposure has exceeded a certain threshold value the skin reddens. This localized effect, called erythema ('sunburn'), is caused by a widening of the blood vessels in the skin. The painful and irritating effect usually disappears after a few days. The effect probably starts with a photochemical reaction and diffusion of

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* Summary of the original Dutch version of the report.

the reaction products into the dermis, followed by interaction with the blood vessels. A direct interaction with the blood vessel walls e.g. in case of UVA induced erythema, cannot be excluded however.

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6.6.2 Minimal erythema dose

The radiant exposure necessary to induce erythema depends on the wavelength, the sensitivity of the skin and the extent of the irradiated skin area. The body site and are relevant variables (Ba79a, Ba79b). The erythema threshold also depends on the individual irradiation history (degree of skin adaptation).

Experimental values of the minimal radiant exposure necessary to induce erythema vary according to the experimental definition chosen; the sharpness of the boundaries, the intensity of the erythema and the time lapse since the exposure play a role. The usual visual way of observing erythema has been compared with a measurement of the diffuse skin reflectance. The results were found to be quite comparable (Wa83).

An example of the differences in the minimal erythema dose between persons with different types of skin is presented in Table 3 (Cr81). Individuals with a type IV skin require a radiant exposure four times higher than persons with a type I skin. In the latter case the erythema also lasts longer (Wi83).

UVC and UVB radiation are much more effective in producing erythema than UVA radiation. Sunburn is nearly fully due to exposure to UVB radiation from the sun; the UVA contribution is hardly of importance and the UVC radiation is absorbed by the earth's atmosphere (cf. section 5.3). There is quite a large amount of data on the spectral sensitivity of the skin. Several of the experimental results are shown in Figure 12.

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6.6.3 Exposure to polychromatic radiation

Practically all exposures are from polychromatic sources. Attention must therefore be given to the possibility of a mutual interaction of radiation of different wavelengths.

Table 3 Relative average minimal radiant exposure necessary to induce erythema for different skin types (cf. Table 2). The radiation source was a Xenon lamp, the spectrum of which was modified by filters to approximate the UV spectrum from the sun. The results have not been weighted with a spectral effectiveness function or action spectrum (Cr81).

Skin type	Number of test subjects	Minimal radiant exposure for erythema relative to type I skin
I	21	1.0
II	27	1.7
III	10	2.5
IV/V	5	3.9
VI	2	9.7

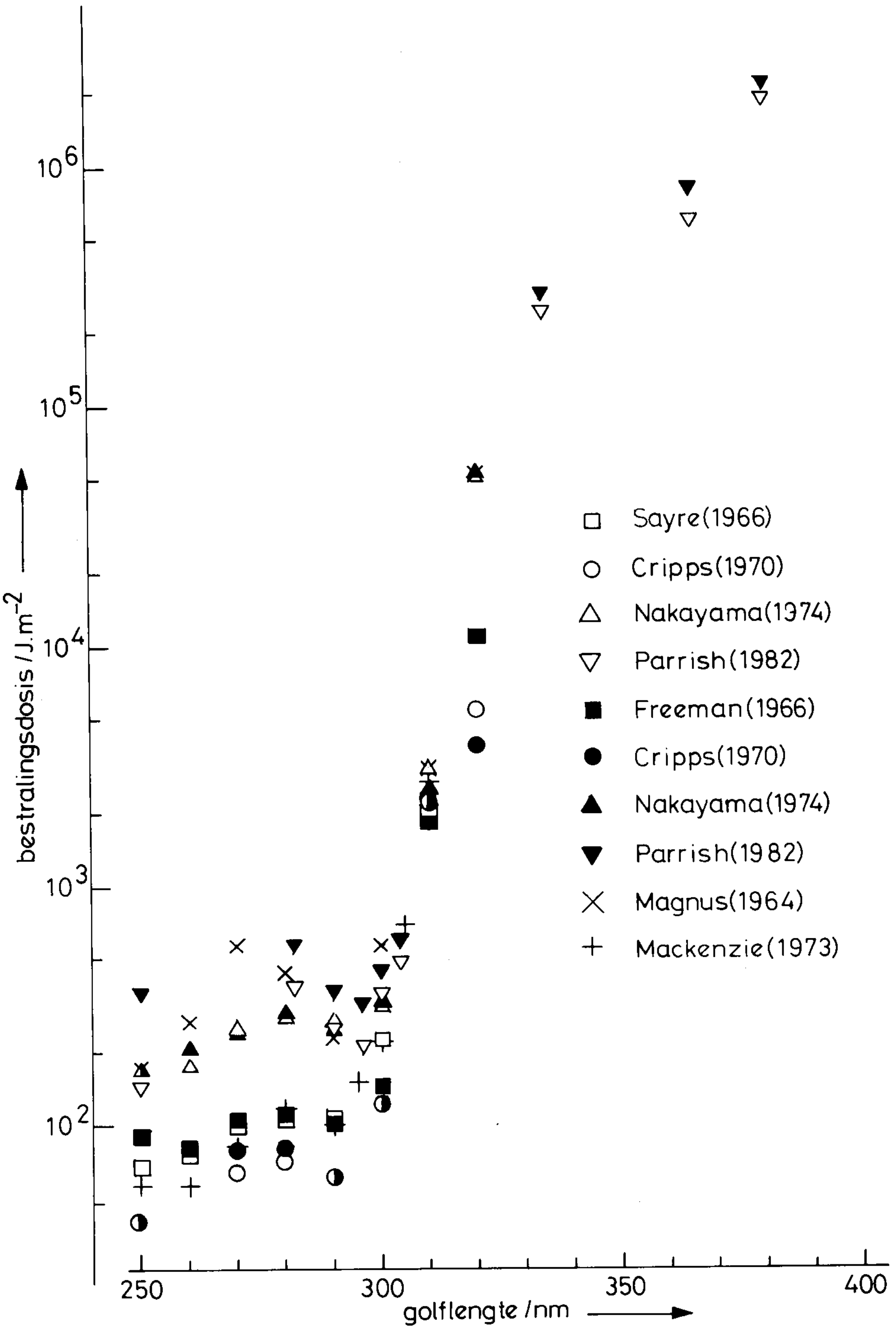

Figure 12 Minimal radiant exposure ('bestralingsdosis') necessary to induce erythema as a function of wavelength ('golflengte'; Ma64, Sa66, Fr66, Cr70, Ma73, Na74, Pa82). The open symbols refer to erythema observable after 8 h and the closed symbols to erythema observable after 24 h. The crosses and plus-symbols represent data with a variable period between the irradiation and the observation of the erythema.

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Sayre (Sa66) determined the erythemal effect of monochromatic and 'mixed' irradiations of three different wavelengths in the UVB and the UVC spectral region. The effects with the mixed irradiations could be explained by an addition of the effects at the separate wavelengths. It is not clear to what extent this additivity holds in case of more intense types of erythema.

Use by the public of UV appliances with a significant UVA component is increasing. What is the combined effect of exposure to the UVA radiation from the appliance and UVB radiation (e.g. from the sun)? The experimental results are contradictory. Van Weelden (We80) reports that the effect after a concurrent exposure to UVA and UVB radiation (or UVA after UVB) is less than additive. Others found addition, with a slight indication of a reduced effect (Pa82). However, increased effects have also been reported (Ka75, Bo81). Skin adaptation (like skin thickening) has not been taken into account in these studies.

It seems at present that simple addition is the most practical way of determining the erythemal effectiveness of polychromatic radiation. Reported departures from the additivity rule do not exceed ± 30%.

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6.6.4 Action spectrum and MED

The additivity of the effects of radiation of different wavelengths is a condition for the use of an action spectrum to determine the erythemal effectiveness of polychromatic radiation (see section 5.2). The action spectrum can be determined by taking the reciprocal of the minimal radiant exposure values for erythema induction at different wavelengths. One usually normalizes the action spectrum to 1 at the wavelength of maximal effectiveness.

In 1935 the Commission Internationale de l'Eclairage (CIE) published an erythema action spectrum. Although never officially adopted by the CIE, this action spectrum has been used frequently since that time. This curve is shown in Figure

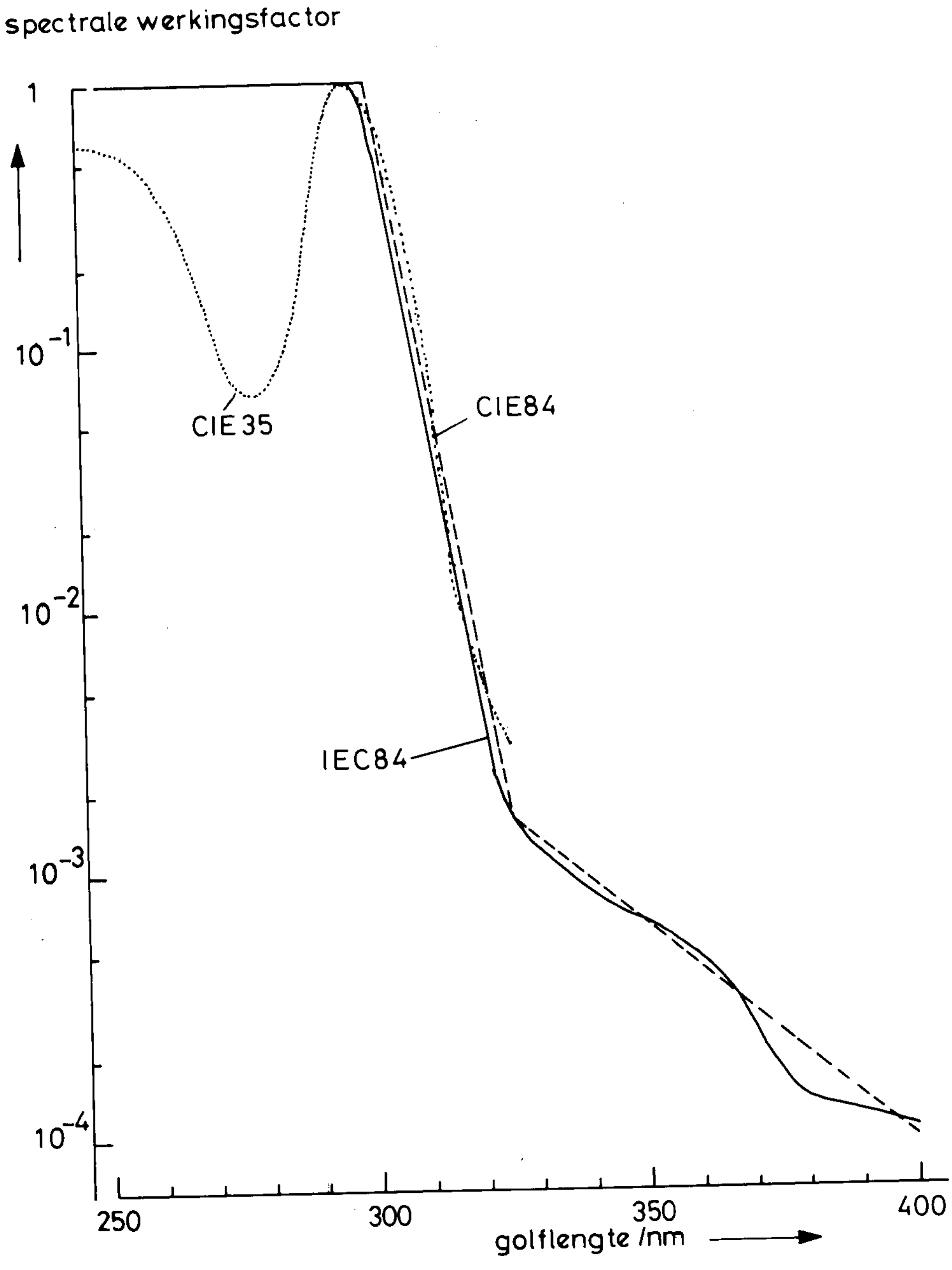

Figure 13 Spectral effectiveness ('spectrale werkingsfactor') as a function of wavelength ('golflengte') or action spectrum for erythema induction. Curve CIE35 represents the action spectrum published by the Commission Internationale de l'Eclairage (CIE) in 1935; curves CIE84 and IEC84 are currently being discussed by both the CIE and the International Electrotechnical Commission (IEC).

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13 together with more recent proposals. The action spectra at present being discussed by the CIE and by the International Electrotechnical Commission (IEC) are quite similar. The main difference is that in the CIE proposals the (logarithmically scaled) experimental results are fitted with a few straight lines contrary to the IEC-curve. All spectra have been normalized to 1 at 297 nm.

Figure 14 presents the experimental data of Figure 12 after multiplication by the IEC action spectrum. Most of the resulting effective radiant exposure values lie between 50 and 350 J/m^2.

To interpret a radiant exposure value in terms of erythema induction it is helpful to introduce a reference value of the minimum effective radiant exposure necessary to induce erythema. This reference value, called the MED, is usually defined as the erythema threshold for lightly pigmented, unadapted Caucasian skin. Given that definition a value of 200 J/m^2 is not unreasonable. The CIE is currently discussing a value of 100 J/m^2. The committee prefers the former value of 200 J/m^2. In comparing these proposals with the experimental results (Figure 14) it should be borne in mind one should take into account that the MED pertains to the skin parts that are regularly exposed to sunlight (head, neck, hands). The experimental results are usually derived from irradiation of the more sensitive skin of the trunk.

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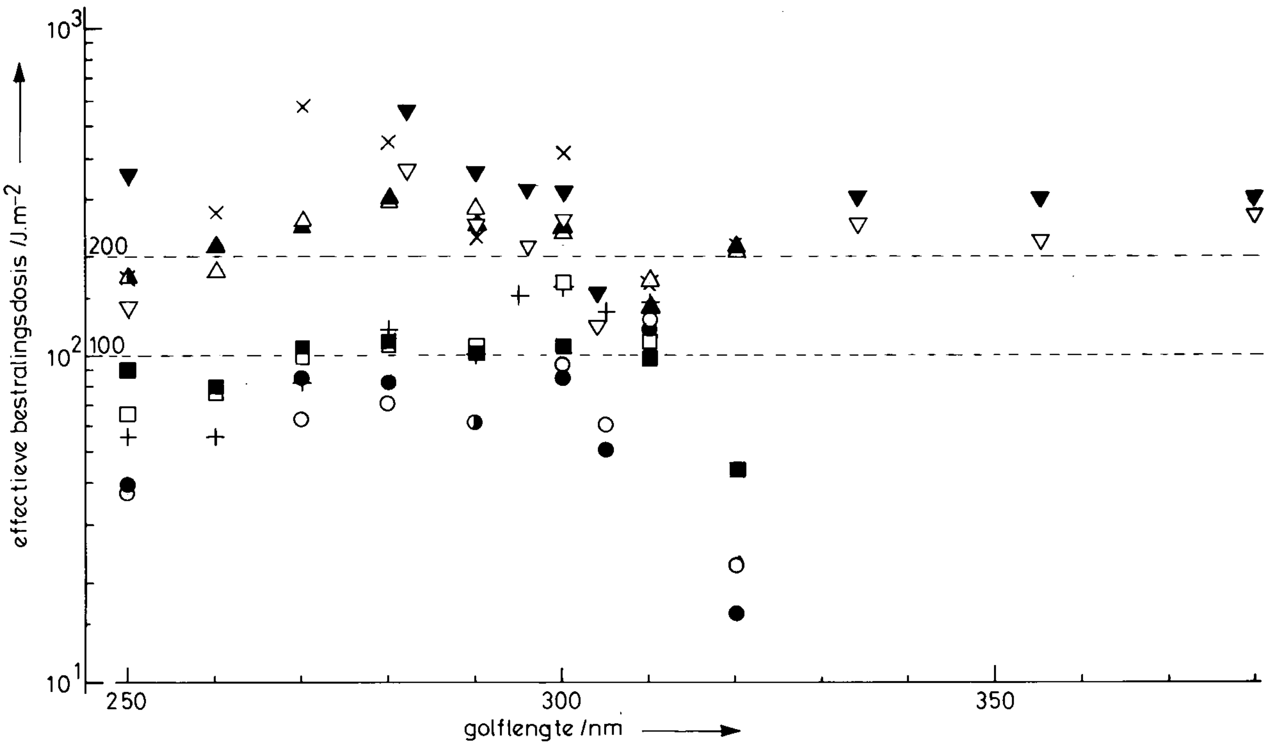
6.7 Chronic effects of UV radiation

Erythema of the skin occurs after a threshold value of the radiant exposure is exceeded. The effect is reversible. The dose-effect relationship for chronic effects is much more complicated. Both the accumulated radiant exposure and the rate of accumulation will influence the resulting effect. Furthermore, the chronic effects are not reversible.

In this report the chronic effects of skin ageing and skin cancer are discussed. With respect to the latter it is possible to distinguish between skin carcinoma and melanoma. Carcinomas are malignant tumours of epithelial cells. Melano-



<u>Figure 14</u> Minimal erythema-effective radiant exposure ('effectieve bestralingsdosis') necessary to induce erythema as a function of wavelength ('golflengte'). The data points are obtained by multiplying the values from Figure 12 with the spectral effectiveness function 'IEC84' shown in Figure 13.

mas are malignant tumours of pigment cells (melanocytes). Skin carcinomas are discussed in section 6.8 and melanomas of the skin in section 6.9.

Ageing of the skin is a natural phenomenon and is considered to be a degeneration of the skin. It is accelerated by exposure to UV radiation. This is demonstrated by people who are frequently exposed to the sun, e.g. farmers, road workers and seamen.

Ageing of the skin is associated with a decrease in elasticity, wrinkling and irregular pigmentation. Because of the protective effect of the skin pigment racial differences are observed. Light skinned people show the strongest ageing effects.

The increased ageing of the skin by UV irradiation has also been demonstrated with experimental animals. An action spectrum is not known.

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6.8 Skin carcinoma

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6.8.1 Types and incidence

The most frequently occurring types of skin carcinoma are the basal cell carcinoma and the squamous cell carcinoma. The former type is induced in the basal cell layer of the epidermis (see Figure 7). The tumour grows rather slowly and the risk of metastases is slight. The squamous cell carcinoma originates from differentiated keratinocytes and usually grows faster than the basal cell carcinoma. The risk of metastases cannot be overlooked.

The incidence of skin carcinoma in the Netherlands is estimated to be 400 to 500 per million inhabitants per year (data from the South Eastern provinces for the years 1976-1980; SO81). Specific studies in the United States of America and elsewhere have shown that the registration of skin carcinoma is less than complete. The true incidence in the Netherlands may be higher. Incidence rises strongly with age.

Skin carcinoma mortality is probably of the order of magnitude of 1% of the incidence. According to data of the

Netherlands Central Bureau of Statistics (CB85) the mortality rate has decreased since 1950 from about 10 per 1 000 000 per year to 6 per 1 000 000 per year. This decrease becomes even more important if corrections are made for changes in age distribution in the Dutch population during the last 35 years. This is associated with the strong increase in the skin carcinoma mortality with age from 1 per 10 million per year for young adults to 1 per 10 000 per year at the age of 85 (data for 1970-1979). The decrease in skin carcinoma mortality may be due to treatment of the cancer at an earlier stage.

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6.8.2 Association with UV radiation

Epidemiological studies point to UV radiation as a causative factor in skin carcinoma induction. More than 80% of the basal cell carcinomas and squamous cell carcinomas occur on those parts of the body that are regularly exposed to sunlight. The degree of exposure to radiation from the sun, age and the skin colour are found to be influential. Outdoor workers have a higher skin cancer incidence than indoor workers. Persons with type I and type II skin are found to be especially susceptible to skin cancer when living in sunny regions. Pigmented Caucasians and negroids have a much lower skin cancer incidence (Pa78, WH79).

The association between exposure to UV radiation and the incidence of skin carcinoma has been confirmed in studies with experimental animals (cf. Gru82). The next section discusses the spectral effectiveness (action spectrum).

Present knowledge does not indicate the existence of a threshold of the cumulated radiant exposure or the average daily exposure below which cancer induction is absent. There is always some risk of malignant tumours being induced. The magnitude of the risk depends on the UV exposure dose.

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6.8.3 Mechanism, action spectrum and dose-effect relationship

Individuals suffering from the heriditary disease Xeroderma pigmentosum are liable to get skin cancer at a young age after a slight exposure to radiation from the sun. Further research shows that these patients have defects in the DNA repair mechanisms. This suggests a mechanism for skin cancer induction in which UV induced damage of the cellular DNA plays a role.

Other studies point to UV induced changes in the immune system as factors in UV carcinogenesis. These effects are discussed further in appendix A.

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Action spectrum

Studies with mice show that exposure to UVB radiation is much more effective in inducing skin carcinoma than UVA radiation (factors of 1000 are found, We83). Another Dutch study found that UVA radiation is mutagenic in human skin cells, be it much less than UVB radiation (Si84). In the UVC spectral region the carcinogenic effect is probably somewhat less than in the UVB.

The few data available about the carcinogenesis action spectrum are presented in Figure 15. The figure also shows the erythema action spectrum (see Figure 13). It appears from the figure that the erythema action spectrum gives a not unreasonable picture of the spectral effectiveness of skin cancer induction.*

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Dose-effect relationship.

Slaper and Van der Leun (Sl85) have discussed at length the dose-effect relationship for the induction of skin carcinoma. Both experiments with animal studies and epidemio-

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* Cole (Co86) has recently published an action spectrum for UV carcinogenesis, computed from a variety of data on carcinoma induction in mice with UV radiation of differing spectral composition. It is quite comparable with the human erythema action spectrum like the 'IEC84' curve in Figure 13. However, the action spectrum of Cole stops at 330 nm; above this wavelength only an upper limit for the carcinogenic effectiveness was calculated. Given the increasing importance of the UVA component in the spectrum of artificial UV sources, the committee prefers to use the 'IEC84' action spectrum that is defined in the whole relevant wavelength region of interest.

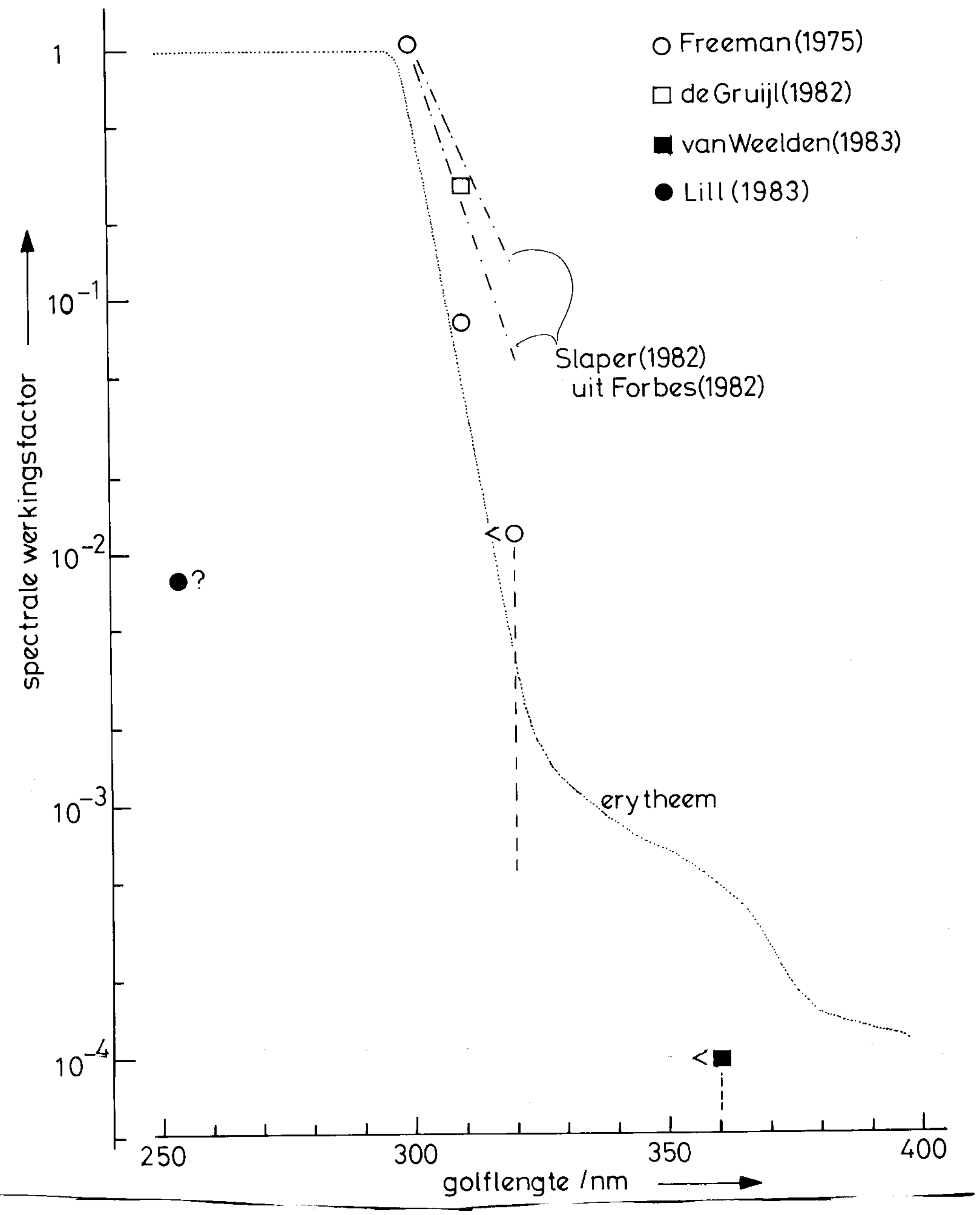

Figure 15 Spectral effectiveness ('spectrale werkingsfactor') for skin carcinoma induction as a function of wavelength ('golflengte') based on experiments with mice. The 'dot-line' curves have been computed by Slaper from experiments of Forbes. The symbol '<' at the data points of Freeman and Van Weelden indicates that tumours have been found, but that the spectral effectiveness is less than the value represented by the data point. Lill used a different strain of mice and a question mark has therefore been put at his data point. References: Fr78, Fo82, Gru82, Li83, We83; the calculations of Slaper (1982) have been reported in Sl85. The dotted curve is the erythema action spectrum currently being discussed in the IEC (cf. Figure 13).

logical data were taken into account. The results clearly indicate a stochastic effect; the probability of skin carcinoma induction is a function of the UV radiant exposure and of the time period since the irradiation.

From experiments with mice the relationship between the median tumour induction time, t_m, and the daily radiant exposure, h, is found to be:

$$t_m = k_1 h^{-0.6},$$

in which k_1 is a constant. This expression shows that the appearance of a tumor does not depend on the accumulated dose (h x t) but on the product $h^{0.6}$ x t; t is the time since the beginning of the daily irradiations.

The median induction time t_m is quite useful in describing the results of animal studies. For risk evaluation with humans the incidence rate is a more appropriate measure. It follows from both mice (laboratory studies) and human data (epidemiological research) that the number of tumours in a population can be described by:

$$I_{cum} = k_2 h^c t^d ,$$

in which t is the time period from the beginning of the irradiations (with humans the age). The parameter c describes the dependence of the incidence on the radiation dose and the parameter d the age dependence; k_2 is a constant. With humans the exponent c has a value of about 2 for basal cell carcinoma and of about 3 for squamous cell carcinoma (with mice the latter value is somewhat larger); the human values for the exponent d are 5 and 6 for basal cell and squamous cell carcinoma respectively.

These values lead to a quadratic dependence of the basal cell carcinoma incidence with radiation dose that is regularly received; for squamous cell carcinoma a cubic dose dependence of the incidence is obtained (S186).

The sensitivity of the skin for carcinoma induction differs from one part of the body to another. Differences in skin thickness, determined both by heriditary and environmental (UV radiation) factors, play a role. The skin carcinoma risk is greatest for the head, neck and hands as these parts are most exposed to radiation from the sun. These parts are also most at risk from additional exposure to artificial UV sources. Frequent significant exposure of other parts of the body, such as the trunk, is required before there is any significant skin cancer risk here. The relatively large surface are of the trunk is also a factor to be considered in this respect.

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6.9 Melanoma

The incidence of tumours of the pigment cells, melanomas, is much less than that of skin carcinomas. The tumours are more agressive, however, and are apt to metastasize. The incidence in the Netherlands appears to be 35 per million inhabitants per year (SO81). The Netherlands Central Bureau of Statistics has reported a mortality rate of 16 per million per year. It has been found in the United States of America that with an earlier diagnosis leading to an earlier treatment, the mortality rate might decrease.

The melanoma mortality in the Netherlands has increased from 19 deaths in 1950 to 284 in 1984; the average increase was 7 per year. Only 20% of this increase can be explained from changes in age distribution of the Dutch population (CB85). The increase in melanoma mortality is also found in other countries (St84). An increase in sunlight exposure is often put forward to explain this phenomenon. The melanoma mortality rate increases with age, as is the case with skin carcinoma. In the age group of 15-19 years the mortality rate is of the order of magnitude of 1 per million per year and increases to 1 per 10 000 per year at age 85 (data averaged over the years 1970-1979).

The causal link between melanoma and UV radiation (e.g. from the sun) is much less clear than in the case of skin carcinoma. Exposure to radiation from the sun probably plays a role together with other, as yet unknown, factors. One type of melanoma, the lentigo maligna, occurs frequently on those parts of the body that are most exposed to sunlight (Ho84b). The other types of melanoma are found on parts of the body that have an irregular irradiation history (trunk with males, legs with females).

Several studies show that people from the higher socio-economic groups with sedentary jobs are more susceptible to melanoma induction than others. This observation led to the hypothesis that an irregular irradiation with high peak exposures, leading to sunburn, plays a role (Ko84). The suggestion that UV radiation emitted by fluorescent lighting tubes would cause induction of melanoma (Be82) has not been confirmed by specific studies (Ri83).

The relation between the induction of melanoma and UV radiation is not at all clear. An action spectrum is not known and the association between the UV radiant exposure and the effect appears irregular. It is therefore impossible to take the possible risk of melanoma induction into account in the development of standards for exposure to UV radiation sources. The question of the association between UV radiation and melanoma is of importance however, given the increasing melanoma incidence in industrialized countries.

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7 EFFECTS OF UV RADIATION ON THE EYES

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7.1 Introduction

UV radiation may interact with the eyes as well as the skin. UVC and UVB radiation is mainly absorbed by the outer cell layers of the eye (cornea), but UV radiation of longer wavelengths penetrates deeper into the eye and may even reach the retina.

The eye sockets protect the eyes from exposure to radiation from the high sun (or artificial sources positioned at some height) (Ur69). Further protection is offered by reactions to (visible) light, such as the blinking reflex, puckering and the pupil reflex. With age the UV radiation yellows the lens of the eye and this effect protects the retina from irradiation (Gr72). The latter type of protection is absent with people from whom the lens has been removed.

Since the 1978 report of the Health Council (Gr78) little fresh data on the harmful interaction of UV radiation with the eye have become available. This implies that with respect to exposure limits and action spectra, the present report cannot come to conclusions that are different from or more sound than the earlier one.

Many UV sources also emit (visible) light that, reaches the retina as a matter of course. More data have recently become available concerning a possible harmful interaction between the shorter (visible) light waves and the retina. The information is however not sufficient to serve as a basis for exposure standards (La78, Ma85).

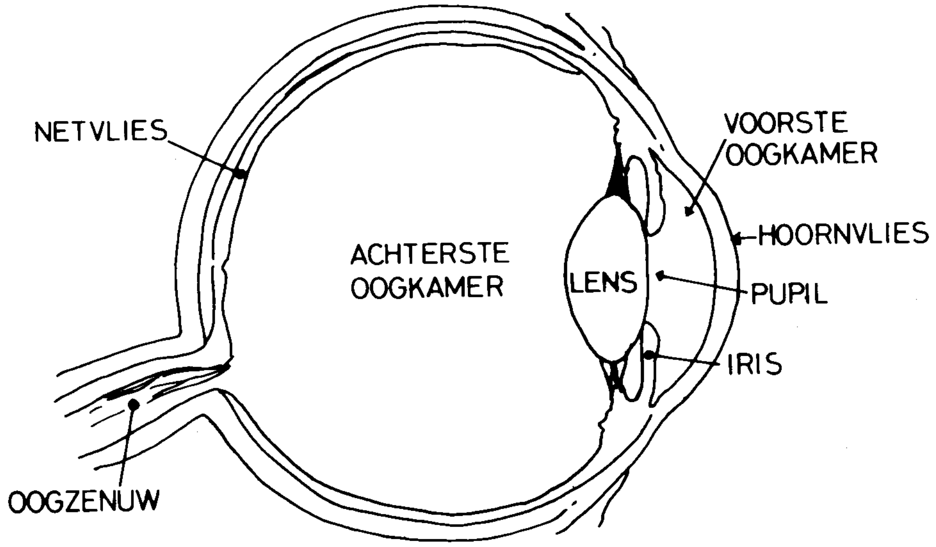

Figure 16 Structure of the left eye, viewed from above. The diagram shows the optic nerve ('oogzenuw'), the retina ('netvlies'), the posterior chamber of the eye ('achterste oogkamer'), the lens, the iris, the pupil, the anterior chamber of the eye ('voorste oogkamer') and the cornea ('hoornvlies').

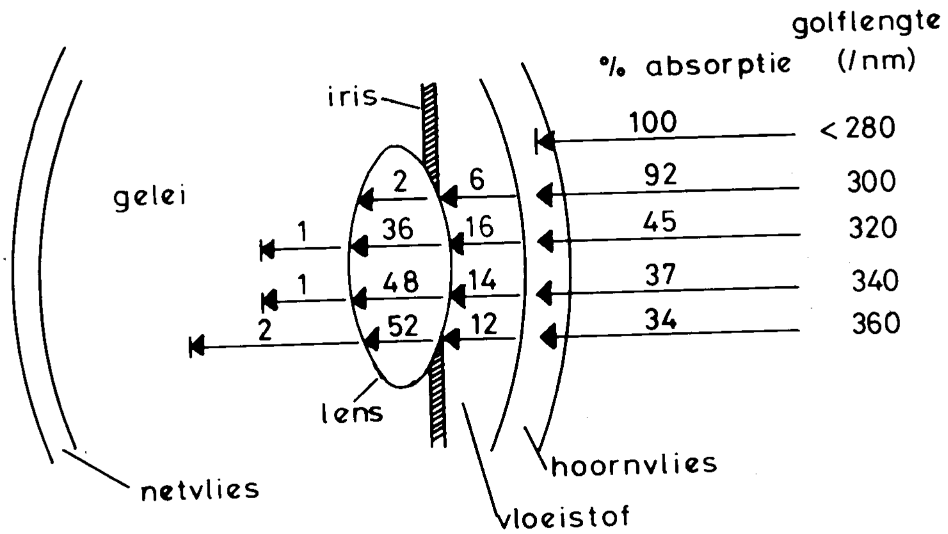

Figure 17 Penetration of UV radiation into the eye for different wavelengths ('golflengten'). The data ('% absorptie') give the fraction (%) of the radiation energy that is absorbed in the path indicated by the arrow. The diagram shows the retina ('netvlies'), the vitreous body ('gelei'), the lens, the iris, the aqueous humour ('vloeistof') and the cornea ('hoornvlies'). (Adapted from S180).

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7.2 Structure of the eye and optical properties*

The structure of the eye is shown in the diagram in Figure 16. The way in which UV radiation affects the eye depends on the penetration of the radiation into the eye. The absorption of the radiation as a function of the wavelength is shown in Figure 17. UVC radiation is nearly fully absorbed by the cornea. A small part of the UVB radiation reaches the lens and is absorbed there. UVA radiation is transmitted by the cornea for more than 50%; an important fraction penetrates into the lens.

The degree of absorption of the radiation by the lens depends on the age. Interaction of the radiation with the lens tissue generates pigment (yellowing of the lens), which leads to an increased absorption (Gr72). The adult lens does not therefore transmit UVA radiation. In children a fraction of the radiation reaches the retina. This is also the case with people who have the lens removed, or replaced by an artificial lens of a more transparent material.

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7.3 Keratitis and conjunctivitis

Absorption of UV radiation by the eye may induce inflammation of the cornea and conjunctiva (keratitis and conjunctivitis respectively). This painful effect is popularly known as snow-blindness or welder's eye, as reflection of radiation from the sun by snow or exposure to radiation from a welding arc may lead to exposures exceeding the threshold for the inflammation.

After the exposure there is a latent period of 6 of 12 hours. This period decreases with increasing radiant exposure values. The resulting inflammation is very painful and is accompanied by tears and uncontrolled blinking. These symptoms last from 6 to 24 hours after exposure; after 48 hours visibility usually is back to normal again.

If radiant exposure values are appreciably higher

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* Summary of the original Dutch version of the report

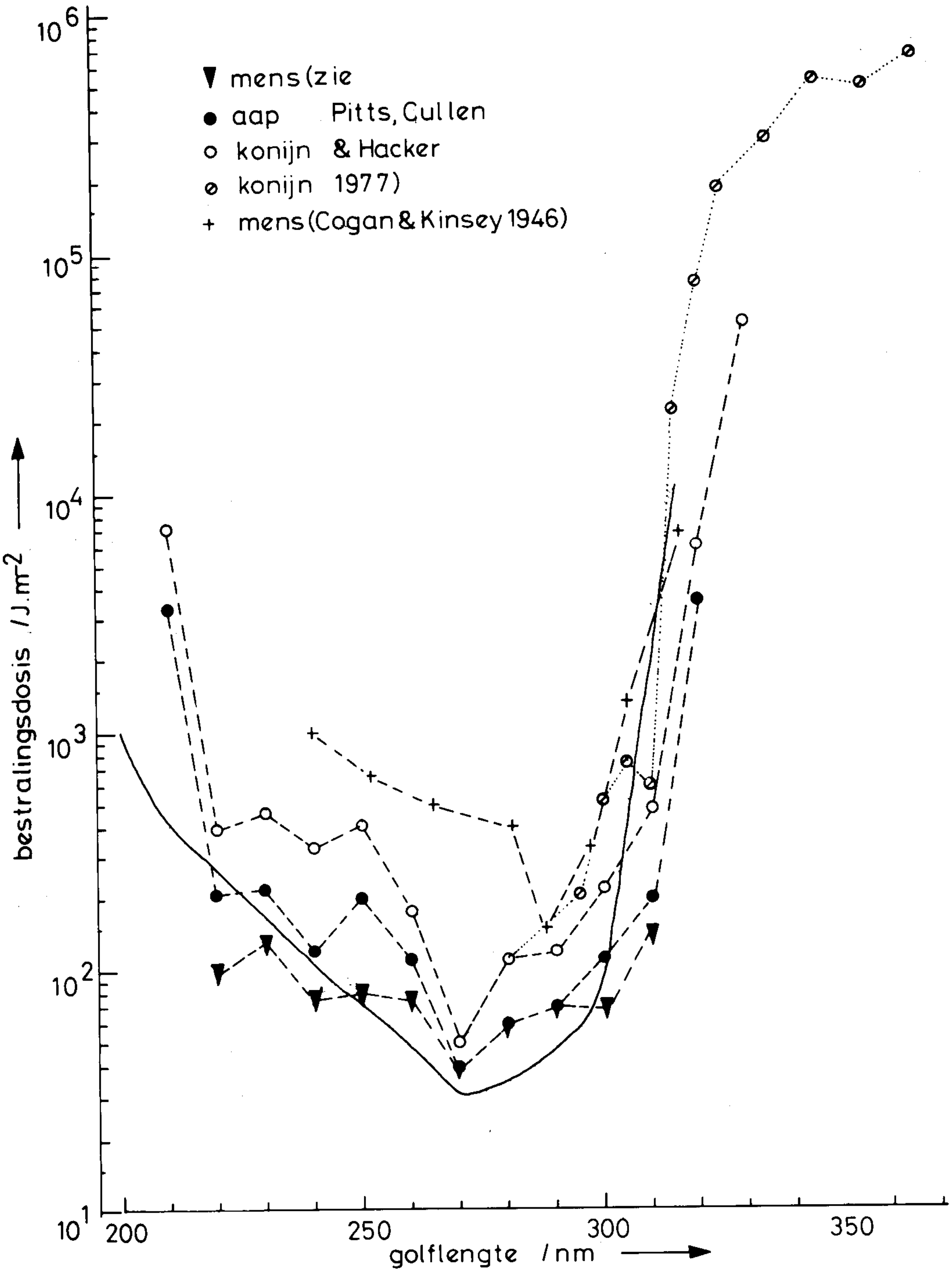

Figure 18 Threshold values of the radiant exposure ('bestralingsdosis') for keratitis as a function of the wavelength ('golflengte'). References: Pi77, Co46. The triangles pertain to human ('mens') data, closed circles - monkey ('aap'), open circles - rabbit ('konijn'), plus symbols - humans ('mens'). The full curve gives the exposure limit proposed by the ACGIH (see IN85).

than the inflammation threshold, the deeper cell layers of the cornea will be damaged. This may permanently affect the eyesight. Tissue transplantation may be necessary to restore the transparency of the cornea.

Experimental values of the radiant exposure threshold for keratitis are presented in Figure 18. The results obtained from studies with humans by Pitts (Pi77) and by Cogan and Kinsey (Co46) differ mainly in the values of the threshold dose; the wavelength dependence of both sets of data is quite similar. This difference in magnitude is possibly due to different experimental definitions of the threshold radiant exposure (Pi69).

Steck argued (St86b) that if the values of Pitts were correct, even a short exposure to radiation from the sun would lead to keratitis, and this does not occur in practice. On the other hand the results of Cogan and Kinsey (Co46) may be criticized for the large bandwidths that were used, especially in the critical wavelength region of 300 to 320 nm. This diminishes the reliability of their spectral radiant exposure thresholds.

The data presented in this chapter are to be used for preventing or limiting the harmful effects of UV radiation on the eyes. It seems prudent therefore to use the human data of Pitts as a basis. Above 300 nm a somewhat steeper wavelength dependence of the radiant exposure threshold can be assumed, as the problem of finite bandwidth also plays a role in the work of Pitts.

This approach is equivalent to taking the spectral effectiveness for keratitis and for erythema induction as equal (cf. Gr78). The threshold limit values for unintended exposure to UV radiation proposed by the American Conference of Governmental Industrial Hygienists (ACGIH, see IN85 and Chapter 8), that are also given in Figure 18, fit this approach quite well. With this threshold curve exposure to radiation from the sun (sun angle of 60°, horizontal direction of view, squinting) a few hours exposure should not lead to keratitis. This confutes the objections of Steck (St86b).

....

No threshold values for the spectral radiant exposure have been published for conjunctivitis (St86a). The arguments for deriving a separate threshold curve for conjunctivitis from the erythema sensitivity are not very convincing (St86a, He42). However, by applying the keratitis threshold values the conjunctivitis risk will also be adequately restricted.

....

7.4 Lens opacities

Interaction of UV radiation with the lens of the eye produces a yellow colouring (Gr72, Le80). This effect reduces the transmission of UVA radiation by the lens and so protects the retina from radiation damage (Vo84).

The colouring of the lens may however develop into opacities, the so-called brown cataract. This phenomenon may be due to metabolic disturbances or to interaction with UV radiation. The latter mechanism is supported by epidemiological studies that show an association between the prevalence of this type of cataract and the exposure to radiation from the sun (for a review: Zi83). Given the transmission properties of the eye (see Figure 17) the (long wavelength) UVA radiation would be responsible for inducing the cataract. It is not possible to derive a quantitative dose-effect relationship from the present data.

The results from studies with experimental animals (Pi77) only allow the conclusion that below the keratitis and conjunctivitis thresholds acute harmful effects of the radiation on the lens present no real risk.

Quantitative data for chronic UV irradiation effects are lacking. The Health Council report from 1978 (Gr78) mentioned only one study (Zi74). Mice were exposed continuously to UV radiation with a wavelength of 365 nm and an irradiance of 4 W/m^2. After a period of 35 weeks lens opacities occured. From that study the Health Council proposed in case of chronic exposure (longer than 10 years) to artificial sources an irradiance exposure limit of 0.4 W/m^2. This value would make any increase in the natural risk of cataract incidence negligible. In Chapter 15 of the present report a value of 1

W/m^2 is proposed instead.

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7.5 Damage of the retina

Very long wavelength UV radiation -in sofar as it reaches the retina-, and in particular short wavelength (visible) light will permanently damage the retina in the event of prolonged exposure from high intensity sources. Both thermal and photochemical effects may occur. The former need no further discussion here, as the risk from the light sources discussed in the present report can be regarded as negligible.

The photochemical effects are associated with the production of phototoxic compounds (like oxygen radicals). With high radiation intensities the removal rate of these compounds is insufficient to prevent damage of the retina tissue. The full mechanism and the relationship between effect and the radiant exposure or the irradiance is very uncertain at present (La78, Ma85).

In protecting the eyes against UV radiation the effects discussed in this paragraph should be taken into account. This may necessitate special requirements for the absorptive properties of 'UV glasses' in the visible spectral region.

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7.6 Other eye diseases

Apart from keratitis, conjunctivitis and cataract there are other eye diseases that may be due to UV irradiation. With populations in northern regions, but also elsewhere, degeneration of the cornea has been observed. Such effects might be caused from chronic exposure to reflected UV radiation (from snow, sand) (Fo72, Fo73).

The incidence of the eye disease pterygium, in which a morbid growth of the conjunctiva covers the cornea and may lead to blindness, is higher in tropical regions than elsewhere. This points to UV radiation as a causative factor (Du65, Mo84). An increased incidence of the disease with welders was reported (Ka84), but this result differs from those of other studies (Em81).

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A recent report focused on the prevalence of melanoma in the eye (Tu85). Exposure to sunlight was mentioned as a possible risk factor. Further research is needed to confirm this hypothesis.

Given the limited amount of data and given the fact that these diseases are not considered to be a health problem in the Netherlands at present, these phenomena will not be taken into account for the purpose of deriving exposure standards.

....

7.7 Special exposure situations

It was mentioned above that people who have their lens removed, usually because of a cataract, run a risk of damage to the retina from UV irradiation. Protection of the eye by UV absorbing lenses is required. Special yellow inplant lenses are now available (We83).

Another group of persons with an increased risk of damage to the eye are psoriasis patients that are treated with psoralens and UVA radiation. Animal experiments have shown that at relatively large radiant exposure values opacities in the cornea and the lens occur. Human studies suggest similar effects (Br85).

8 ACTION SPECTRA AND THRESHOLD DOSES

In Chapters 6 and 7 the effects of UV radiation on the skin and the eyes were discussed, and the knowledge currently available regarding the action spectra and threshold doses was presented. In this chapter the committee draws conclusions from the scientific data. These conclusions will be used as the basis for deriving standards for exposure to UV radiation.

Intentional exposure to UV radiation concerns irradiation of the skin. In those situations it is possible, at least in theory, to protect the eyes against radiation damage. The guidelines for intentional exposure, to be provided by the committee, will refer to the erythema action spectrum that is being discussed by the IEC (see Figure 13). On the basis of what little information is available the committee proposes to use this action spectrum in connection with the risk of skin cancer induction.

Figure 13 shows that the 'IEC'-action spectrum does not differ appreciably from the erythema action spectrum discussed by the CIE. The committee however sees no need to fit a curve of a prescribed form to the experimental data as is done in the CIE proposals. It does not make the evaluation of the emission spectra of radiation sources much simpler.

Quantitative data about erythema induction below 250 nm are lacking. There are some indications that threshold doses are higher than in the UVB spectral region. As most radiation sources used for intentional exposures emit hardly any radiation with wavelengths smaller than 250 nm, the committee feels justified in setting the action spectrum equal to 1 in that spectral region.

The committee also prefers a MED value of 200 J/m^2 instead of the 100 J/m^2 proposed within the CIE. This can be justified by the fact that the MED is a reference value for the whole population. The reference value should relate to persons with a 'normal' white skin (type II/III) and to the parts of the skin that are most exposed to radiation from the sun (head, neck, hands). Most data presented in Figure 12 are from studies of the induction of erythema in the skin of the trunk, which will occur at lower radiant exposure values.

In case of unintentional exposure to UV radiation both the irradiation of the skin and of the eyes has to be taken into account. It was indicated in Chapter 7 that one threshold curve can be used for erythema and for keratitis and conjunctivitis. This curve is considered to be a starting point for exposure standards.

In the UVA spectral region induction of erythema determines the threshold dose. The committee proposes to extrapolate the threshold curve mentioned to wavelengths larges than 310 nm by using the erythema action spectrum. The committee does not deem it necessary to modify the threshold curve in view of a possible risk of cataract induction for (chronic) exposure to UVA radiation.

By taking the reciprocal of the threshold dose spectrum an action spectrum type of function is obtained that will be denoted by 'skin/eye action spectrum'. This function is normalized to 1 at 270 nm. It can serve to compute skin/eye-effective radiant exposures. The threshold value of the skin/-eye-effective radiant exposure is 30 J/m^2. The utilisation of an action spectrum presupposes the additivity of the effects caused by radiation of different wavelengths. The committee is of the opinion that using the skin/eye action spectrum for protection purposes takes the UV radiation risk adequately into account.

The report of the Health Council about micrometer radiation (Gr78) proposed for wavelengths smaller than 270 nm a constant threshold dose of 30 J/m^2, similar to recent proposals for laser exposure limits (IN85a, see also IN85b). However, the threshold dose curve proposed for unintentional exposure fits the experimental data quite well. The committee sees therefore no need for lower values in the UVC spectral region. It should further be noted that the constant laser threshold was probably proposed in order not to complicate the laser standards any further (Sc84).

The Health Council report from 1978 (Gr78) saw no need to take the risk of cataract induction into account for exposure to artificial UV sources during periods shorter than 10 years. There is no new scientific information that impels us to change that point of view. In this respect the proposals of the committee deviate from international recommendations (IN85a).

In Table 4 the action spectrum for intentional exposure is given. The table also presents the radiant exposure, that is equivalent to an erythema-effective radiant exposure of 200 J/m^2 as a function of wavelength. Table 5 presents similar data for unintentional exposure. The radiant exposure column gives values that are equivalent to a skin/eye-effective radiant exposure of 30 J/m^2.

Table 4 Action spectrum to be used with intentional exposure (erythema action spectrum) and radiant exposure equivalent to an erythema-effective radiant exposure of 200 J/m^2 (1 MED).

wavelength (nm)	action spectrum	radiant exposure equivalent to 1 MED (J/m^2)
≦ 297	1,000	200
298	0,975	205
299	0,887	225
300	0,730	274
301	0,565	354
302	0,437	458
303	0,337	593
304	0,260	769
305	0,200	$100x10^1$
306	0,154	130 "
307	0,118	169 "
308	$0,911x10^{-1}$	220 "
309	0,701 "	285 "
310	$0,540x10^{-1}$	$370x10^1$
311	0,417 "	480 "
312	0,323 "	619 "
313	0,250 "	800 "
314	0,194 "	$103x10^2$
315	0,150 "	133 "
316	0,115 "	174 "
317	$0,881x10^2$	227 "
318	0,672 "	298 "
319	0,515 "	388 "
320	$0,400x10^{-2}$	$500x10^2$
321	0,318 "	629 "
322	0,262 "	763 "
323	0,221 "	905 "
324	0,192 "	$104x10^3$
325	0,171 "	117 "
326	0,155 "	129 "
327	0,143 "	140 "
328	0,134 "	149 "
329	0,127 "	157 "

(table 4 continued)

330	$0,121x10^{-2}$	$165x10^{3}$
331	0,117 "	171 "
332	0,112 "	179 "
333	0,108 "	185 "
334	0,104 "	192 "
335	$0,997x10^{-3}$	201 "
336	0,958 "	209 "
337	0,923 "	217 "
338	0,891 "	224 "
339	0,862 "	232 "
340	$0,835x10^{-3}$	$240x10^{3}$
341	0,810 "	247 "
342	0,786 "	254 "
343	0,765 "	261 "
344	0,744 "	269 "
345	0,725 "	276 "
346	0,707 "	283 "
347	0,689 "	290 "
348	0,672 "	298 "
349	0,655 "	305 "
350	$0,639x10^{-3}$	$313x10^{3}$
351	0,623 "	321 "
352	0,607 "	329 "
353	0,591 "	338 "
354	0,575 "	348 "
355	0,558 "	358 "
356	0,542 "	369 "
357	0,525 "	381 "
358	0,508 "	394 "
359	0,490 "	408 "
360	$0,473x10^{-3}$	$423x10^{3}$
361	0,455 "	440 "
362	0,436 "	459 "
363	0,417 "	480 "
364	0,398 "	503 "
365	0,379 "	528 "
366	0,358 "	559 "
367	0,335 "	597 "
368	0,312 "	641 "
369	0,288 "	694 "

(table 4 continued)

370	$0{,}265x10^{-3}$	$755x10^{3}$
371	0,243 "	823 "
372	0,223 "	897 "
373	0,205 "	976 "
374	0,189 "	$106x10^{4}$
375	0,175 "	114 "
376	0,164 "	122 "
377	0,154 "	130 "
378	0,147 "	136 "
379	0,142 "	141 "
380	$0{,}139x10^{-3}$	$144x10^{4}$
381	0,137 "	146 "
382	0,135 "	148 "
383	0,134 "	149 "
384	0,132 "	152 "
385	0,130 "	154 "
386	0,128 "	156 "
387	0,127 "	157 "
388	0,125 "	160 "
389	0,124 "	161 "
390	$0{,}122x10^{-3}$	$164x10^{4}$
391	0,121 "	165 "
392	0,119 "	168 "
393	0,118 "	169 "
394	0,116 "	172 "
395	0,115 "	174 "
396	0,113 "	177 "
397	0,112 "	179 "
398	0,110 "	182 "
399	0,109 "	183 "
400	$0{,}108x10^{-3}$	$185x10^{4}$

Table 5 Action spectrum to be used with unintentional exposure (skin/eye action spectrum) and radiant exposure values equivalent to a skin/eye-effective radiant exposure of 30 J/m^2 (threshold values).

wavelength (nm)	action spectrum	threshold value radiant exposure (J/m^2)
180	0,03	1 000
190	0,03	1 000
200	0,03	1 000
205	0,051	590
210	0,075	400
215	0,095	320
220	0,12	250
225	0,15	200
230	0,19	160
235	0,24	130
240	0,30	100
245	0,36	83
250	0,43	70
254	0,50	60
255	0,52	58
260	0,65	46
265	0,81	37
270	1,0	30
275	0,96	31
280	0,88	34
285	0,77	39
290	0,64	47
295	0,54	56
297	0,46	65
300	0,30	100
303	0,12	250
305	$0,69 \times 10^{-1}$	500
308	$0,26 \times 10^{-1}$	1200
310	$0,15 \times 10^{-1}$	2000
313	$0,69 \times 10^{-2}$	4300
315	$0,42 \times 10^{-2}$	7200
320	$0,11 \times 10^{-2}$	$2,7 \times 10^4$
325	$0,48 \times 10^{-3}$	$6,3 \times 10^4$
330	$0,34 \times 10^{-3}$	$8,9 \times 10^4$
335	$0,28 \times 10^{-3}$	$1,1 \times 10^5$
340	$0,23 \times 10^{-3}$	$1,3 \times 10^5$
345	$0,20 \times 10^{-3}$	$1,5 \times 10^5$

(table 5 continued)

350	$0,18x10^{-3}$	$1,7x10^{5}$
355	$0,16x10^{-3}$	$1,9x10^{5}$
360	$0,13x10^{-3}$	$2,3x10^{5}$
365	$0,11x10^{-3}$	$2,9x10^{5}$
370	$0,74x10^{-4}$	$4,1x10^{5}$
375	$0,49x10^{-4}$	$6,2x10^{5}$
380	$0,39x10^{-4}$	$7,8x10^{5}$
385	$0,36x10^{-4}$	$8,3x10^{5}$
390	$0,34x10^{-4}$	$8,9x10^{5}$
395	$0,32x10^{-4}$	$9,4x10^{5}$
400	$0,30x10^{-4}$	$1,0x10^{6}$

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9 EXPOSURE TO RADIATION FROM THE SUN

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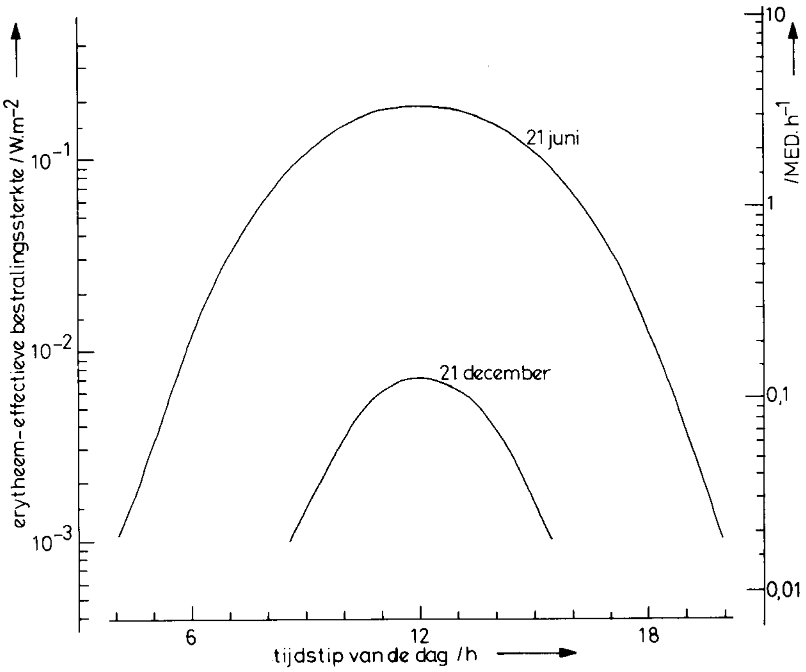
Exposure to (UV) radiation from the sun is to a certain extent unavoidable. The degree of exposure will depend on the lifestyle and behaviour. An upper limit of the radiant exposure from the sun at a certain place is given by the integral of the irradiance from the sun at that place. The irradiance will vary with the time of the day, with the weather and with the composition of the atmosphere. Figure 19 shows the variation of the erythema-effective irradiance on a clear mid-summer and mid-winter day in the Netherlands. There were no clouds and in the computation the thickness of the ozone layer was taken to be 6 g/m^2 (which is equivalent to a thickness of 3 mm at standard temperature and pressure) (Gr80).

The maximal daily erythema-effective radiant exposure at our latitudes is about 20 MED (4 kJ/m^2). The corresponding annual value in the Netherlands is about 1650 MED (330 kJ/m^2) (S185). This value has been corrected for attenuation by the clouds.

The actual amount people are exposed to will be below this value. This is due to several factors, such as the time of the day and the time spent outdoors. Furthermore, not every part of the skin is exposed to the same degree; it depends on the clothes that are worn. The impact of some of these factors will be characteristic for a certain group of the population, such as farmers and road workers who have outdoor occupations. In many instances, however, these factors differ greatly from one person to another and will give rise to large differences in radiant exposure values. In the last decade habits have changed in our society, leading to an increased exposure to UV



<u>Figure 19</u> Computed erythema-effective irradiance ('erytheem-effectieve bestralingssterkte') as a function of the time of the day ('tijd van de dag') at 52.5° North on 21 June and on 21 December. Clouds are absent and the thickness of the ozone layer is 6 g/m^2. (Computation according to Gr80).

radiation from the sun. We need only think of the increased leisure time, the fashionableness of 'sun holidays' and the wearing use of clothes that leave more parts of the body uncovered.

From the limited data available the annual erythema-effective radiant exposure (for the head and the hands) in the Netherlands can be calculated to be about 300 MED (60 kJ/m^2) for people with outdoor occupations and 100 MED (20 kJ/m^2) for indoor workers (S185). These values are averages around which a large variation occurs. 'Sun holidays' of 3 weeks duration in the South of France or in Spain are accompanied by an erythema-effective radiant exposure of 60 to 75 MED (12-15 kJ/m^2). Beach-lovers in those regions receive during the same period radiant exposures of 100 to 150 MED (24-30 kJ/m^2).

These data on exposure to radiation from the sun will be used in the following chapters as a reference in the derivation of standards for exposure to artificial UV radiation.

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PART 3 INTENTIONAL EXPOSURE TO UV RADIATION OF THE GENERAL PUBLIC

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10 USE OF UV RADIATION SOURCES BY THE GENERAL PUBLIC

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10.1 Definitions and intended effects

This chapter and the three following ones are about the use of UV radiation sources, such as sunlamps, suncouches and solaria by the general public. The focus is on intentional exposures to UV radiation, either in the private home or in commercial establishments. The exposures discussed here are not accompanied by medical advice.

The main aims for of the irradiation are improvement in general health and skin tanning. Sometimes however people expose themselves with both aims in mind. Irradiation for health purposes is often performed to compensate for a lack of exposure to the sun. As has been indicated in section 6.3 there are only vague associations between (UV-)exposure to the sun and positive health effects. The production of vitamin D in the skin by UV radiation is an exception.

In the Western industrialized societies a tanned skin is often viewed as a symbol of vitality and social status. This is probably the reason behind the skin tanning motive. Another reason for tanning may be to obtain some protection against the sun. It has been explained in section 6.4 that protection against UV radiation from the sun is primarily provided by the skin thickening reaction and only to a lesser extent by the (delayed) pigmentation of the skin. The direct pigmentation induced by UVA radiation, seems to have no protective effect at all.

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10.2 Surveys

The appreciation of the effects of the sun on the body and the pleasure of sunbathing will probably influence the use of UV sources by the public. This is confirmed by the investigations of Greiter (Gr82). Polls in several countries showed that roughly 40% of the population believe that sunbathing promotes health. One third of the respondents stated that, although possibly harmful, sunbathing is nevertheless pleasant.

At the suggestion of the committee the Dutch Consumer Safety Institute ('Stichting Consument en Veiligheid') investigated the use of UV equipment by the general public (Be86)*. It was found that in 221 of the 1507 households contacted, one or more people (346 all together) had used an UV lamp for personal irradiation in the period December 1983 till November 1984. By extrapolation this result implies that in the Netherlands about 1 million people (7% of the population) in 0.7 million households (13%) were irradiated in that period.

About three quarters (72%) of the respondents who expose themselves to UV radiation do so only to get a tanned skin. Another 9% mentioned general health improvement apart from skin tanning. For 18% health purposes were the only reason for the radiation exposure. About half of the latter group (10%) irradiated themselves because of skin diseases. This group is outside the scope of the present discussion as these irradiations can be classified as medical treatments. It can be concluded that in Netherlands skin tanning is the primary motive for using artificially generated UV radiation by the general public.

The survey also asked as to where the irradiation was performed. More than half (58%) of the respondents had themselves irradiated in a private home. Of those who used the facilities of a commercial establishment, more than 90% mentioned skin tanning as the reason for exposure.

Several other results of this survey will be presented below.

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* This study has been commissioned by the Ministry of Housing, Physical Planning and the Environment and has been supervised by the committee.

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10.3 Equipment used

In the past the sunlamp was commonly used for irradiation at home. This UV source has a relatively important UVB component (see Chapter 5). In the Netherlands this type of source is still used in about one quarter of all cases, mainly for irradiation at home. Improvement in health was mentioned by more then half of the users as the only or second reason for using this type of equipment (Be86). Nearly all of the people who treat themselves for skin diseases use a sunlamp.

In the recent past a variety of equipment with a relatively important UVA component has appeared on the market. If the manufacturer emphasizes health effects to be obtained with the irradiation (Wo--) the remaining UVB component is usually larger than when skin tanning is stressed in the sales promotion (Ph--). Very often the appliances are fitted with fluorescent lamps. In high intensity equipment, e.g. face tanning appliances or equipment for room irradiation high pressure mercury halide lamps are used in combination with a filter. This 'quick-tanning' equipment is mainly found in commercial establishments.

The face tanning appliance and the sun lamp are equipment for partial body irradiation. One can further distinguish:

- the suncouch, where the user rests on a transparent acrylic surface, below which the UV (fluorescent) lamps are positioned;
- the suncanopy which usually exposes from above;
- smaller equipment in the form of table top equipment of appliances on a stand.

A suncouch and a suncanopy are sometimes combined into one appliance which enables irradiation of the body from all sides. The suncouch and the suncanopy are the type of equipment most frequently used, especially for skin tanning purposes (Be86). In commercial establishments sources with high pressure mercury halide burners in combination with a filter are found under the name of solariums or suncanopies (Co86).

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10.4 Estimate of the irradiation period

The Dutch survey (Be86) tried to find out how many times the equipment was used and for how long. It appeared that on the average people expose themselves 25 to 30 times per year. There are however differences with respect to the type of equipment. The suncouch is used 30% less and the suncanopy and the smaller UVA equipment 50% more than the average over all types of equipment. The use of the sunlamp compares well with the overall average. These differences will probably depend on the comfort of a certain appliance for the user.

Deviation from the average values is however considerable. More than 25 irradiations with a suncouch occur; the maximal found was 72 times per year. A little under a quarter of the suncanopy users irradiate themselves more than 50 irradiations per year. In a few cases the number of times a year approached 170. The use of the sunlamp for skin tanning was limited in most cases to less than 30 irradiations per year, with one exception of 120 irradiations. In case of the treatment of skin diseases with the sunlamp the number of irradiations per year is considerably higher; the average lies between 40 and 50.

From the number of irradiations the annual exposure time may be derived. The so-called UVA equipment is used between 20 to 30 minutes per irradiation. This implies that suncouches are used about 350 minutes per year and UVA canopies and the smaller UVA equipment about three times as long. A sunlamp is used for much shorter times. Many operating instructions indicate only 2 minutes per irradiation. With less intense sources the period of use per irradiation may increase up to 10 minutes. Depending on the intensity of the source a sunlamp is used between 50 and 150 minutes per year.

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10.5 Estimate of the radiant exposure

A straightforward estimation of the radiant exposure from the data obtained in the Dutch survey is not possible. The irradiance at the position of the user and the radiation spectrum are not well known. An attempt has been made using information supplied by manufacturers to gain some idea about the erythema-effective radiant exposure. UVA equipment delivers about 0.8 MED (160 J/m^2) per irradiation, and sunlamps something like 2 MED (400 J/m^2). On average the annual erythema-effective radiant exposure from UVA canopies and face tanning equipment is estimated to be somewhat less than 30 MED (6 kJ/m^2). For sunlamps used for tanning one derives 55 MED (11 kJ/m^2) per year.

These estimates indicate that people receive from UV appliances for skin tanning on the average an erythema-effective radiant exposure between 20 and 60 MED (4 to 12 kJ/m^2) per year. In nearly all cases the individual annual radiant exposure will not exceed 100 MED (20 kJ/m^2) per year.

It should be stressed that these are only rough estimates. Further studies are necessary to obtain more reliable data.

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10.6 Acute radiation effects

The annual radiation exposure will give an indication of the chronic risk (skin cancer) posed by irradiation. Apart from that the risk associated with the use of the UV sources will be determined by the occurrence of acute effects.

According to the Dutch survey (Be86) about 85% of the people who exposed themselves in 1984 claimed to have experienced no problems from the irradiation. Of those who did, about one fifth needed treatment in a hospital or from a general practitioner. The number of persons with problems is too small to allow further statistical analysis. Symptoms mentioned were an itchy, painful or dried skin and erythema. Painful eyes were also mentioned. Most problems are caused by the suncanopy and the sunlamp.

11 REGULATIONS IN OTHER COUNTRIES

11.1 Summary

In some countries regulations have been laid down to govern the construction and the use of UV sources for irradiation. The legal force of the regulations differs from country to country. In some countries legal requirements for the construction and properties of the appliances have been laid down, elsewhere official standards have been issued or recommendations relating to the proper use of the equipment have been formulated. The various regulations are listed in Table 6. This list is probably not complete, but it is thought to give a representative overview of the type of regulations to be encountered in (Western) industrialized countries.

The Swedish legislation is very strict. In order to own and operate an UV source a licence is required, unless the type of appliance in question has been certified. None of the other countries has a licensing system.

11.2 Irradiance

Some regulations put restrictions on the total and on the spectral irradiance. Table 7 presents an overview. This table shows that the regulations differ significantly. At the short-wavelength side of the spectrum these differences are not so important in practice, given the absorption of the radiation in the air. In order to avoid the need for very costly equipment for testing the UV appliances, the newer USA regulations have specified the lower boundary of the UV spectral region as 200 nm instead of 180 nm as in the older regulations.

Table 6 Overview of official regulations in other countries governing the use of UV appliances for skin tanning.

country	year	spectral region	type of regulation
USA	1980	180-320 nm	legal product requirements
Canada	1980	180-320 nm	legal product requirements
Sweden	1982	200-400 nm	licence and legal product requirements
UK	1982	100-400 nm	recommendations for construction, maintenance, and application of UV appliances in commercial establishments; the recommendations suggest a way of complying with general legal obligations
BRD	1982	200-400 nm	measurement and classification of UV appliances; draft German industrial standard (DIN)
Australia	1983	100-400 nm	maintenance and operation of UV appliances in commercial establishments; Australian standard (a standard with product requirements is in preparation)
USA	1985	200-400 nm	legal product requirements (modification of the 1980 regulations)

Table 7 Overview of the requirements on the irradiance at the position of the irradiated person in the official regulations.

USA	The total irradiance in the 180-260 nm spectral region should not exceed 0.3% of the total irradiance in the 260-320 nm spectral region. The 1985 regulations change the former spectral region to 200-260 nm.
Canada	Similar to the USA.
Sweden	The spectral irradiance is multiplied by a prescribed action spectrum. The total effective irradiance in the 200-280 nm spectral region should not exceed 0.002 W/m^2, and in the 280-315 nm spectral region 0.05 W/m^2. The (unweighted) irradiance in the 315-400 nm spectral region should be larger than 20 W/m^2 but not exceed 200 W/m^2.
Australia	The spectral irradiance should be measured with a prescribed measuring instrument. The total irradiance measured in the 100-280 nm spectral region should not exceed 0.01% of the measured total irradiance in the 100-400 nm region. In the 280-300 nm this fraction is 0.1% and in the 300-315 nm spectral region 1%. The total spectra irradiance in the 100-400 nm spectral region should not exceed 200 W/m^2.

The Swedish and Australian regulations limit the total UV irradiance to 200 W/m^2, at least in practice. In Sweden the regulations specify an accurate determination of the spectral irradiance followed by weighting in the UVC and UVB spectral region with a prescribed action spectrum. In Australia the characteristics of the measuring instrument and the measuring procedure are given in the standard. This difference in approach is probably due to the fact that in Sweden type approval is based on measurements by a national standards institute, whereas the Australian standard pertains to on the spot measurements by the operator of the establishment.

The German standard gives a procedure for evaluating the properties of UV appliances by determining an erythema-effective and a pigmentation-effective irradiance. The action spectra are given in the standard. The pigmentation action spectrum is for immediate pigmentation. The erythema-effectiveness of radiation with wavelengths above 325 nm is supposed to be nil; the same holds for the pigmentation-effectiveness of radiation with wavelengths below 300 nm. The classification is derived from this evaluation.

Commenting on the German standard, the committee is of the opinion that using an action spectrum for immediate pigmentation leads erronneously to the promotion of appliances that emit UVA radiation and almost nothing else as rather effective for tanning.

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11.3 Switching off

Most regulations limit the irradiation time. In practice this restriction can be complied with using an automatic timer. Safety considerations suggest an emergency switch, with which the irradiation can be interrupted at any time. This switch should be within hand reach of the irradiated person. Table 8 lists the requirements of the different regulations.

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11.4 Eye protection

Several regulations require the use of eye protectors (glasses, etc.) These eye protectors should transmit sufficient visible light to enable the reading of labels and other signs. See Table 9 in section 13.5.

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11.5 Information

The regulations also list the information to be provided to the user. The German standard is an exception in this respect, as it only concerns the technical properties of the equipment. The user is to be informed through labels attached to the equipment and through an instruction manual. In Australia a contract between the operator of the establishment and the client is required; the contract is a means of confirming that the client has been informed about the risks of the irradiation.

The information for the user should indicate:

- that UV radiation is being used;
- eye damage;
- erythema (sunburn);
- ageing of the skin and skin cancer;
- the influence of the skin type on the effects from the irradiation;
- the effects of drugs;
- the effects of cosmetics;
- to consult a physician in case of problems.

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11.6 The irradiation course

The Australian standard also regulates the irradiation course (in commercial establishments). The total radiant exposure during the first irradiation of a course should be limited to 50 kJ/m^2, and the exposure of any following irradiation to 200 kJ/m^2. The radiant exposure should be determined from a measurement of the spectral radiant exposure using a measuring instrument with prescribed properties. The time interval between two successive irradiations should be at least 48 hours.

Table 8 Requirements with respect to switches in the UV appliances.

regulation	timer obligatory	upper time limit	emergency switch obligatory
USA (1980)	yes	10 min	no
Canada (1980)	yes	10 min	no
Sweden (1982)	yes	30 min	no
UK (1982)	yes	- *	yes
Australia	yes	30 min	yes
USA (1985)	yes	- *	yes

* Upper limit to be determined by the manufacturer depending on the properties of the equipment.

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11.7 References

USA (1980)
21 CFR, part 1040.20, Sunlamp products and ultraviolet lamps intended for use in sunlamp products (May 7, 1980)

Canada (1980)
P.C. 1980-1652, part XI, Sunlamps (June 19, 1980)

Sweden (1982)
SSI FS 1982: 1, The regulations of the Swedish National Institute of Radiation Protection concerning sunlamps (February 1982)

UK (1982)
Guidance note GS 18 from the Health and Safety Executive, Commercial ultra-violet tanning equipment (December 1982)

BRD (1982)
Entwurf DIN 5050, Nichttherapeutische UV-Bestrahlungsgeräte für den menschlichen Körper; Messung, Kennzeichnung, Typeneinteilung (November 1982)

Australia (1985)
Australian Standard 2635-1983, The installation, maintenance and operation of solaria for cosmetic purposes (1983)

USA (1985)
21 CFR part 1040.20, Sunlamp products; performance standard: final roule, 50 Federal Register 36548-36552 (September 6, 1985)

12 PRINCIPLES FOR GUIDELINES

12.1 Effects to be considered

Intentional exposure of the skin to artificial ultraviolet (UV) radiation for non-medical purposes occurs in both private homes and commercial establishments. In the Netherlands the primary reason for such irradiation is to tan the skin. Fortunately, it is relatively easy to protect the eyes from the harmful effects of UV radiation. In discussing the necessity and nature of measures to limit exposure to UV radiation, attention can therefore be focused on the effects it has on the skin.

Some instances of intentional exposure to UV radiation have resulted in undesired (acute) side-effects (see section 10.6). As far as is known these side-effects did not permanently damage the health of the individuals involved. Chronic skin disorders resulting from exposure to artificial UV radiation, such as ageing of the skin and skin cancer, have been demonstrated in experimental animals (see section 6.8), but not in humans. However, the possibility of chronic damage to health, and of skin cancer in particular, should be taken into consideration.

On the other hand a certain exposure to UV radiation is benificial. Irradiation of the skin plays a role in the production of vitamin D in the human body (section 6.3). A lack of UV radiation may be detrimental to the body as well. The committee sees no reason to make a distinction between 'natural' UV radiation (from the sun) and artificial UV radiation in this respect. UVB radiation in particular is effective in producing vitamin D.

Acute effects occur if the radiant exposure exceeds a certain threshold level, which varies from individual to individual. This threshold may be altered by the use of certain drugs and cosmetics. No threshold dose has been proved to exist with respect to the risk of skin cancer induction and it is therefore prudent to assume that any exposure entails some risk. The risk increases with increasing radiant exposure.

As general principles for guidelines the committee proposes:

- preventing acute, undesirable effects;
- limiting the risk of chronic effects.

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12.2 Balancing disadvantages and benefits

The reason behind skin tanning probably has to do with feelings of well-being. Irradiation may also contribute to the production of vitamin D and its health purpose can be rationalized thus. Another aim of using UV appliances may be to increase the adaptation of the skin to UV radiation. In considering the use of a UV source, these benefits most be weighed against the possible harmful effects. If the irradiation is performed in such a way that acute effects are avoided, these harmful effects primarily concern the possible induction of and death from skin cancer. Likewise, the authorities will have to balance public health costs and benefits in deciding on regulating the use by the general public the regulation of UV radiation for skin tanning and general health improvement.

For the individual it will be practically impossible to weigh rationally the benefits of skin tanning against the harm of skin cancer. In addition the authorities will encounter difficulties in deciding on regulations. To achieve the desired effects an erythema-effective radiant exposure of several tens MED (several kJ/m^2) per year are required (see Chapter 6, Chapter 10 and section 12.4 below). This value is smaller than the difference between outdoor and indoor workers as regards radiant exposure from the sun (see Chapter 9).

It is not for a committee of the Health Council to

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conclude on the desirability or acceptibility of UV radiation for skin tanning. In what follows standards are proposed on the assumption that irradiation is deemed acceptable.

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12.3 Necessity and nature of the guidelines

The incidence of skin cancer, or in any case of skin carcinoma, depends on the accumulated radiant exposure (see section 6.8). In principle any further exposure increases the risk. There is thus every reason to restrict the radiation exposure without preventing the results that people wish to achieve.

Two different types of measures may be envisaged. Firstly, requirements could be laid down for the construction of UV appliances, and secondly, guidelines for the information and instruction of the user (and the operator of the equipment) could be proposed. The latter are of particular importance as exposure is generally unsupervised. The user can expose himself of herself repeatedly to the UV radiation.

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12.4 The necessary radiant exposure for vitamin D production

It was estimated in section 6.3.1 that an erythema-effective radiant exposure of about 60 MED (12 kJ/m^2) per year on the head and hands of Caucasians would be sufficient to produce the required amount of vitamin D. This estimate is derived from exposure to the sun, i.e. a radiation source with an important UVB component. Exposure to the sun in the case of some people is relatively infrequent, e.g. indoor workers with only a few recreational activities in the open air. It is quite plausible that these people would benefit from an additional exposure to artificial UV radiation of some tens MED (5 to 10 kJ/m^2). The radiation source should in that case contain a non-negligible UVB component.

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12.5 Limiting exposure to radiation

The committee has based its recommendations on the exposure to UV radiation from the sun. In this way the skin cancer risk is implicitly taken into account. It has been estimated in Chapter 9 that in the Netherlands people with indoor occupations receive an erythema-effective radiant exposure of 100 MED (20 kJ/m^2) per annum and those working continuously out of doors one of about 300 MED (60 kJ/m^2). The difference in skin cancer risk associated with this difference in exposure to radiation from the sun generally has no influence on the choice of occupation (cases of hyper-sensitivity excepted). Indeed, exposure to radiation from the sun has sofar not given rise to specific health and safety regulations.

From these considerations the committee proposes an erythema-effective radiant exposure of 100 MED (20 kJ/m^2) per annum as a primary limit and a basis for guidelines. This value is smaller than the difference in radiant exposure between outdoor and indoor workers, and enables the desired results of the irradiation to be achieved.

Slaper en Van der Leun have computed the skin cancer risk associated with a certain additional radiant exposure following the procedure presented in a recent paper (S186). If indoor workers exposed themselves regularly and over many years to an additional annual radiant exposure of a hundred MED, the risk of skin cancer induction among these people would increase by a factor of 4. Taking into account the results from the survey presented in Chapter 10, the committee is of the opinion that this situation is very unlikely to occur.

A more realistic estimate of the skin cancer risk associated with the use of UV appliances by the general public has been obtained. This was done by taking 1 million Dutch people between 15 and 55 years of age, the number of people thought to be exposed year after year to an erythema-effective radiant exposure of 30 MED (6 kJ/m^2). The composition of the group may change over the years. Such an exposure would contribute an extra 5 to 6% to the skin cancer incidence among the Dutch population. It was assumed that the proportion of indoor and outdoor workers was the same in the exposed group as in the whole population. It will be more reasonable to assume, however, that the people who expose themselves to artificial UV sources are mainly indoor workers. In that case the additional skin cancer incidence in the Dutch population decreases to about 2%. This is equivalent to 150 new cases of skin cancer per year. With the former assumption the extra number of skin cancers induced per year would be about 350. The calculated number of skin cancer deaths will increase by a few per year. It should be stressed that these calculations apply only to the risk of skin carcinoma; a quantitative statement with respect to changes in the induction of melanoma is not possible.

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13 GUIDELINES

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13.1 Introduction

In this chapter the committee presents its recommendations for the safe use of UV appliances by the general public. The recommendations pertain only to those aspects that are directly related to exposure to UV radiation. Other safety aspects, such as those relating to electricity, are dealt with in the Dutch standards NEN 6101 and NEN 6127 and the amendment to the corresponding IEC standards made by the International Electrotechnical Committee.

The expression 'UV lamp' as used below denotes the radiation source in the UV appliance. The word 'course' means a series of irradiations given at certain intervals. The user is the person who exposes himself or herself to the radiation.

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13.2 Course

Recommendation: The instructions for an irradiation course and for the number of courses per year provided by the manufacturer (or by the operator of a commercial establishment) should be based on a limitation of the annual erythema-effective radiant exposure to 100 MED (20 kJ/m^2).

Some flexibility is required given the differences between UV appliances (especially with regard to effective irradiance) and the different types of courses. It is therefore neither possible nor desirable to elaborate on the primary norm and formulate strict rules.

In general the instructions for a course take the form of a schedule of exposure times. In proposing exposure times the decrease of the irradiance due to ageing of the UV lamps has to be taken into account. The distance between the UV source and the user is also of importance. With some UV appliances this distance does not depend on the construction of the equipment, and clear instructions are therefore required.

Recommendation: The erythema-effective radiant exposure of the first irradiation of a course should be restricted to 0.5 MED (100 kJ/m^2).

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Recommendation: The erythema-effective radiant exposure of an irradiation of a course should not exceed a value 1.5 times the one immediately preceding.

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Recommendation: Between the first and second irradiation of a course a time interval of at least two full days should be observed. The interval between all further successive irradiations should be at least 24 hours.

The effect of these recommendations is that an enhanced sensitivity to UV radiation which might lead to undesirable side-effects or complaints will be detected at the lowest possible radiation dose. The third recommendation serves the same purpose. At the radiant exposure proposed as a maximum for the first irradiation some people may already experience acute effects, such as erythema.

An increase in radiation dose may be necessary because of radiation spectrum dependent adaptive changes in the skin (thickening, tanning). This increase is not always necessary, however, to the same extent. With sources containing a negligible UVB component it may even be dispensed with. The recommended limitation of this increase prevents the occurrence of side-effects.

A time interval of one day may not always be sufficient to avoid acute reactions between UV radiation and photoactive compounds in the skin. If such reactions are observed the course should be interrupted at once.

Recommendation: No person should irradiate himself or herself when using photo-active medicines. If in doubt medical advice should be sought.

Many medicines, both for external and internal use, contain photo-active compounds that may enhance sensitivity to UV radiation. Some examples are listed in Appendix C.*

Recommendation: Make-up should be removed from the skin at least 3 hours before the irradiation.

Many cosmetics contain photo-active compounds. The 3 hour period stems from the fact that cosmetics can penetrate the skin and thus are not easily removed simply by washing. The most practical advice is to refrain from using cosmetics during the period of the day preceding the irradiation.

Recommendation: The use of sunscreens during the irradiation is not recommended.

Sunscreens attenuate UV radiation, though the extent of attenuation is dependent on the wavelength. As the instructions for courses are based on untreated skin, they are not applicable when sunscreens are used. Furthermore, some sunscreens contain photo-active compounds that may cause complaints after exposure to artificial UV radiation.

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13.3 Special situations

Recommendation: People with sensitive skin (type I) should be alert for undesired skin reactions to the irradiation.

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* Omitted in the English version of the report.

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In such cases erythema may occur at an erythema-effective radiant exposure as low as 0.5 MED (100 J/m^2). Decreasing the radiant exposure of the first irradiation to 0.25 MED (50 J/m^2) is recommended in this instance. People with type I skin will probably not achieve the desired tanning effect.

Recommendation: The unweighted irradiance should be restricted to 1 kW/m^2.

Irradiance levels of the order of 1 kW/m^2 or more may lead to thermal effects (burns) of the skin. The irradiance refers to the total irradiance of all electromagnetic radiation emitted by the UV lamp.

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13.4 Provisions

Recommendation: UV appliances should have a timing mechanism to set the prescribed irradiation times. When the irradiation time set has elapsed the timing mechanism should automatically switch off the appliance.

The automatic switching action would prevent greater radiant exposures than intended, e.g. when a person falls asleep during the irradiation. A timer is not always feasible for UV lamps for room irradiation. The committee deems such situations acceptable only if persons entering the irradiation area receive clear instructions about the exposure time to be taken into account.

Recommendation: If the user cannot easily remove himself or herself from the UV source, the UV appliance should have an emergency switch within reach of the user so that it can be switched off.

An example of such an appliance is the combination of a suncouch and a suncanopy.

Table 9 Spectral transmission of eye protectors.

wavelength (λ) (nm)	maximum transmission
$240 \leq \lambda \leq 320$	0,1%
$320 < \lambda \leq 400$	1%
$400 < \lambda \leq 500$*	5%

* A recommendation for this wavelength region has been given, as there are indications that looking for a long time into a very bright blue light source may cause eye damage.

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Recommendation: If the erythema-effective irradiance depends on a filter placed between the UV lamp and the user, the appliance should be inoperable if the filter is not in place.

This recommendation is applicable in the case of appliances with high pressure mercury lamps in which a filter attenuates the irradiance in the UVB part of the spectrum (see Figure 5).

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13.5 Eyes

Recommendation: Eye protectors such as glasses or goggles should be supplied with every UV appliance. The operator of a commercial establishment should make such protectors available to the users. The transmission requirements for such eye protectors are given in Table 9.

With the radiant exposures allowed by the recommendations from section 13.2, eye damage cannot be ruled out. For this reason the committee recommends the provision of eye protectors. It cannot be taken for granted that all sunglasses will satisfy the transmission requirements. The committee is of the opinion that the use of eye protectors should not be obligatory. Some users will prefer to close their eyes during the irradiation. This also provides adequate protection for the eyes.

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13.6 Labelling

Recommendation: Each UV appliance should carry a label placed where users will easily see it. The label should inform the user about the emission of UV radiation, about the potential risks of the exposure to that radiation and about the need to follow the instructions in the manual.

The message on the label should be short and clear: a pictogram and a few keywords should be sufficient. There may however be some situations, e.g. in the case of room irradiation, in which the label should contain more detailed instructions, as users will most probably not study an instruction manual.

<u>Recommendation:</u> Instructions to the effect that the UV lamp should be replaced only by a lamp of the same type should be attached near the lamp fitting.

The erythema-effective irradiance greatly depends on the lamp type. As several different types of lamps can be used in the same fitting it would be easy to fit a lamp of a different type. This could have important consequences for the user, as regards both the desired and the undesirable effects of the irradiation. Fitting a lamp of a different type should be conditional on explicit instructions of the manufacturer, who should provide the owner of the appliance with a revised instruction manual.

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13.7 <u>Information and instruction</u>

<u>Recommendation:</u> Sales brochures and other advertising material should mention the risks of exposure to UV radiation. They should contain no pictures suggesting that irradiation may take place without protecting the eyes.

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<u>Recommendation:</u> A manual should be supplied with each appliance explaining how the appliance operates, giving instructions for the irrradiation course and informing the user about the potential risks of exposure to UV radiation

The safe use of UV appliances for non-medical purposes depends on the user being properly instructed. Written information available before the purchase of the appliance as well as in the form of an instruction manual is therefore essential. The operator of a commercial establishment must provide oral information and instruction, and provide each user with a simple leaflet giving basic information about exposure to UV radiation and instructions for the course.

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13.8 Accuracy and uncertainties

The interaction between UV radiation and the skin is not clear in every respect. Some uncertainty still exists. Furthermore, there will be differences in effect from one person to another.

Several recommendations relate to the exposure time. An accuracy of 10% in setting the exposure time is deemed sufficient by the committee. Variations in production batches, ageing of the lamps and dirty equipment will influence the irradiance of the UV lamps. The committee is of the opinion that the recommended radiant exposures should not be exceeded by more than 20%.

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PART 4 UNINTENTIONAL EXPOSURE TO UV RADIATION

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14 Nature of the exposure

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15 Limits for unintentional exposure

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16 Restricting the exposure

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14 NATURE OF THE EXPOSURE

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In Chapter 3 a distinction was made between intentional and unintentional exposure to UV radiation. The former was discussed in part 3 of this report. This chapter and the two which follow deal with the unintentional exposure.

Table 1 (Chapter 3) presented an overview of situations in which people might become unintentionally exposed. The table shows that unintentional exposure affects not only people at work but also the public at large. In some situations artificial UV radiation is used specifically to achieve a certain effect. In other situations the generation of UV radiation is an (unintended) side-effect. An example of the former is the use of UV radiation for sterilization. The radiation emitted by the welding arc is an unintended (and unwanted) side-effect. These differences, however, will not affect the exposure standards.

It is as also possible to classify exposure situations with respect to the radiation source, e.g. the sun or an artificial source. Exposure can take place at different locations. e.g. at work or in public places. An example of the latter is the use of 'black-light' lamps in theatres and lightshows, and the application of a UV lamp for cleaning the fish-tank water in the living room.

In evaluating the harmful effects and the associated risks from exposure to UV radiation it may be necessary to consider other effects, apart from direct interaction of the radiation with the skin and the eyes. In the printing industry for example, workers may be exposed to both UV radiation and photo-active chemicals. The combined exposure may induce specific effects, in addition to the effects induced by each of the agents separately. With arc welding the photochemical reaction products in the welding fumes contribute considerable to the occupational risk. The standards proposed in this report do not take these effects into account.

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15 LIMITS FOR UNINTENTIONAL EXPOSURE

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15.1 Principles

With unintentional exposure to a (potentially) harmful agent like UV radiation the risk associated with the exposure has to be weighed against the benefit of the application or activity that causes the exposure. Such an analysis is outside the scope of this report (cf. section 12.2).

If exposure to UV radiation cannot be avoided, but is considered, at least in principle, to be justified, the exposure should be limited as far as reasonably achievable. In the first place an attempt should be made to avoid exposure by shielding the radiation source. If that is not possible measures to restrict the exposure time and to increase the distance to the radiation source can be considered. If a further reduction in exposure is necessary protective clothing and eye protectors may have to be used. This approach is not different from that taken in other fields occupational and environmental health and safety and need not be explained further here.

In considering the necessity of protective measures, it should be borne in mind that UV radiation also has a positive health effect, i.e. the production of vitamin D in the skin (see section 6.3). The (unavoidable) daily radiant exposure from the sun may be used as a point of reference.

To prevent unacceptable health risks to the individual, individual exposure limits are of importance. As skin cancer induction by UV radiation has no threshold dose (see section 6.8), these exposure limits cannot be interpreted as boundaries below which no effect will occur.

The exposure limits recommended below by the committee are based on two principles. First, that harmful effects for which there is a threshold dose must be avoided. Furthermore, the risk of chronic effects for which there is no threshold dose, is to be restricted to a reasonable value.

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15.2 Acute effects

The most important acute effects are erythema of the skin and keratitis and conjunctivitis of the eyes. Chapter 8 defined the skin/eye action spectrum. Limiting the skin/eye-effective radiant exposure to 30 J/m^2 will avoid these acute effects, even with relatively sensitive people. Figure 20 shows the radiant exposure corresponding to this limit as a function of the wavelength (cf. column 3 in Table 5). The limit for the skin/eye-effective radiant exposure should be applied to the exposure over one (working) day. The committee is of the opinion that this limit may be used both for occupational exposure and for exposure of members of the public.

Some people are hyper-sensitive with respect to UV radiation (photodermatoses). Even an exposure to radiation from the sun causes pathological skin reactions with these people. This hyper-sensitivity may be induced by photo-active compounds in, for example, cosmetics and drugs. Photo-toxic effects have also been observed. It is impossible to take such effects into account in defining exposure limits. People who have had a lens of the eye removed, should use eye protection even with exposures below the limits (cf. section 7.7).

The exposure limits recommended by the Health Council of the Netherlands in 1978 (Gr78) and recent proposals by the International Radiation Protection Association (IN85a)* are also shown in the figure. In the wavelength region above 300 nm the differences between the older Health Council curve and

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* The same exposure limits have already been published some time ago by the American Conference of Governmental Industrial Hygienists (ACGIH) in the list of Threshold Limit Values, recommended by this organisation.

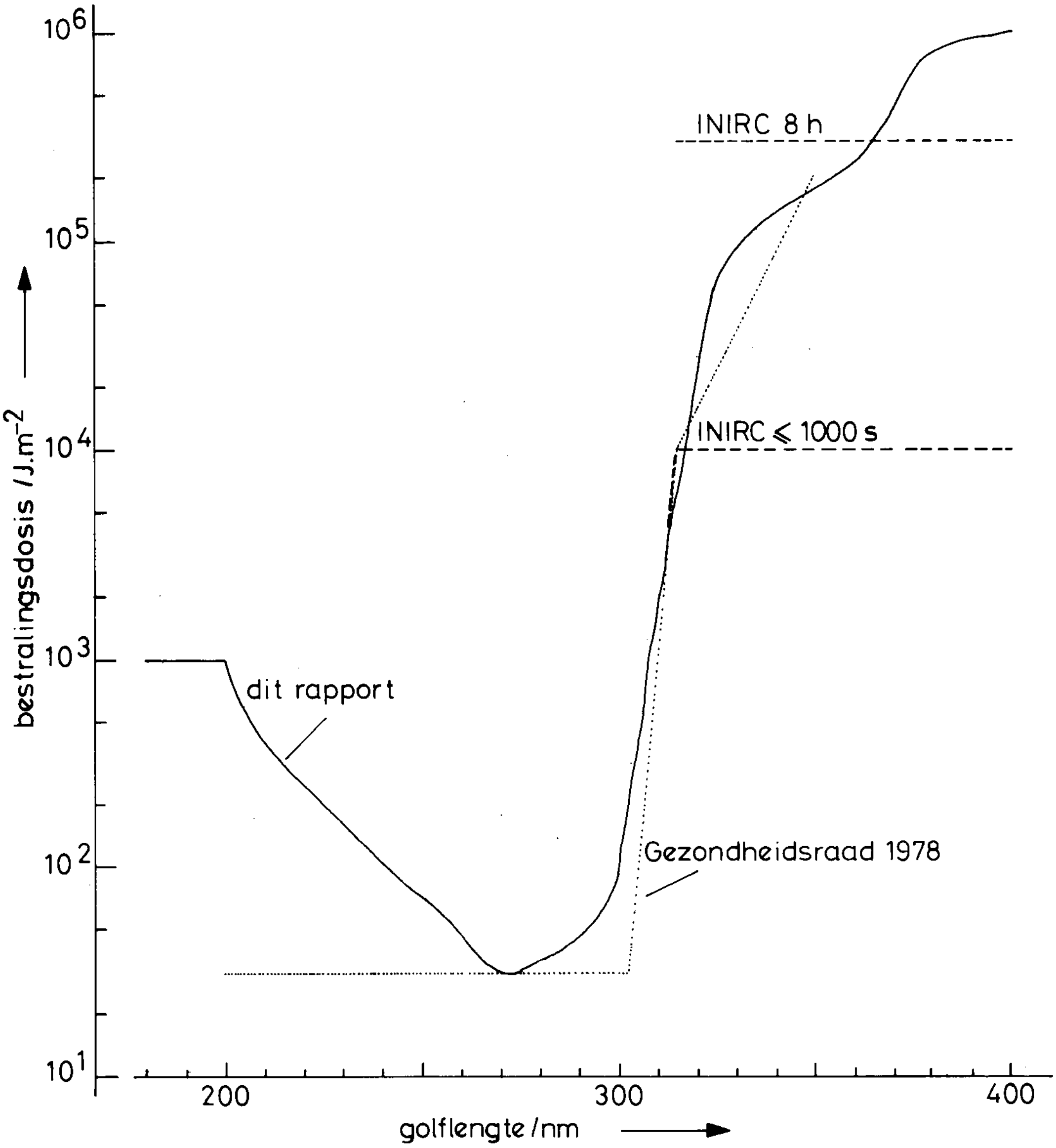

Figure 20 Exposure limit recommended by the committee for unintentional exposure to UV radiation (skin/eye, Table 5; 'dit rapport' = this report), together with the earlier recommendation of the Health Council (Gr78) and international recommendations (INIRC = International Non-Ionizing Radiation Committee of the International Radiation Protection Association: IN85a). The figure gives the radiant exposure ('bestralingsdosis') as a function of the wavelength ('golflengte').

the new one are the result of new data on erythema induction by UVA radiation. In the wavelength region below 300 nm in 1978 a constant value of 30 J/m^2 was proposed. A similar recommendation is found in standards for exposure to sources of coherent radiation (lasers) (IN85b). The reason behind recommending a constant value below 300 nm is probably to prevent further complication of the laser exposure limit (Sc84). The exposure limit for the UVC and UVB region recommended in the present report (Table 5 and Figure 20) are widely accepted at present and are scientifically well founded. The committee therefore sees no need to retain the older recommendation.

The differences between the exposure limits for the UVA-spectral region proposed in this report and international recommendations (IN85a) are discussed in the next section.

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15.3 Cataract

It was explained in section 7.4 that exposing the eyes to UVA radiation may contribute to the risk of cataract formation. If the exposure limits proposed above are applied, the committee takes the view that this risk is only of importance if there is chronic irradiation of the eyes. Such may be the case in some occupations or with patients that are treated with UV radiation. In the latter case however measures to protect the eyes are normally part of the treatment.

In some occupations the exposure to UV radiation has a non-incidental character and may be prolonged for years at a stretch. In those situations further protection of the eyes against the UVA irradiation becomes necessary to restrict the exposure of the lens of the eye.

The committee recommends the use of a reference value for the UVA irradiance of 1 W/m^2 in case of chronic exposures. This value is somewhat higher than the 0,4 W/m^2 proposed in the earlier report (Gr78). This is because it appeared that with 'normal' illumination the irradiance sometimes exceeded the latter value. There are furthermore hardly any data from which an irradiance limit can be derived. A further consideration is that the irradiance in the lens is usually lower than the one at the position of the eye. This difference becomes large if the radiation has a more diffuse character.

It should be stressed that the committee recommends a reference value for chronic UVA exposure. Exceeding this value incidentally need not lead to harmful effects in the eye.

The proposed reference value can be compared with the exposure to radiation from the sun, which is also chronic in character. One obtains from section 5.3 that the irradiance from the sun does not exceed 50 W/m^2. The value applies for a clear mid-summer day at noon in the Netherlands. About half of the irradiance is due to direct radiation and the other half to scattered radiation. Assuming that only scattered radiation is incident on the eye, only a small percentage of the available irradiance reaches the lens of the eye, i.e. 1 to 2 W/m^2. This is the situation at noon on a clear day in summer. The irradiance averaged over many years will be lower by more than one order of magnitude.

The IRPA and the ACGIH (IN85a) have recommended that the irradiance in the UVA spectral region be limited to 10 W/m^2. The committee prefers the reference value of 1 W/m^2 in the case of chronic exposure.

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15.4 Skin cancer

This section deals first with the skin cancer risk associated with the exposure limit for acute effects. The initial problem encountered is, that the exposure limit is based on the skin/eye action spectrum instead of the erythema action spectrum, which can be used to evaluate the skin cancer risk (cf. section 6.8 and Chapter 8). In general the erythema-effective irradiance of a polychromatic UV source will not exceed twice the skin/eye-effective irradiance. In exceptional cases the difference may become as large as 5. A skin/eye-effective radiant exposure of 30 J/m^2 (the exposure limit) is therefore roughly equivalent to an erythema-effective radiant exposure of 0.3 MED (60 J/m^2); in exceptional cases the erythemaeffective radiant exposure corresponding to the exposure limit will be 0.7 MED (150 J/m^2). Applying the exposure limit based on acute effects will give in practice and on average an extra erythema-effective radiant exposure that is considerably smaller than 1 MED (200 J/m^2); a value of 0.1 MED (20 J/m^2) is a reasonable estimate.

The difference in erythema-effective radiant exposure between an outdoor and an indoor worker is about 1 MED (200 J/m^2) per working day (see Chapter 9). Van der Leun and Slaper calculated that such a difference in radiant exposure corresponds to an increase in skin cancer risk by a factor of about 5 (calculation method is described in S186). If an indoor worker is exposed daily over a 40 year period to an extra erythema-effective radiant exposure of 0.1 MED (20 J/m^2), this will increase the skin cancer risk by about 25%.

The risk of skin cancer induction in the case of chronic exposure to UV radiation around the exposure limit for acute effects appears to be much less than the extra risk caused by working permanently out of doors. From this the committee concludes that a separate exposure limit for chronic irradiation is not necessary.

It was concluded in the earlier report of the Health Council (Gr78) that an erythema-effective radiant exposure of less than 0.15 MED was unconditionally acceptable and a radiant exposure between 0.15 MED and 0.45 MED conditionally acceptable. That older recommendation does not differ appreciably from the present one, especially if one takes into account that exposure limit has a much stricter meaning than acceptable level*.

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15.5 Conclusions

Unintentional exposure to artificially generated UV radiation should be restricted as much as is reasonably achie-

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* The Health Council report of 1978 (Gr78) concluded that the standard for chronic exposure was much more restrictive than that for acute exposures. This conclusion was however based on the erronous presumption that an erythema-effective radiant exposure of 1 MED was equivalent to a skin/eye-effective radiant exposure of 30 J/m^2.

vable. If the exposure is of the same order of magnitude as the unavoidable exposure from the sun further protective measures need not to be taken. This is acceptable in view of the positive effect of UV radiation on the organism through irradiation of the skin (production of vitamin D).

Exposure to artificial UV radiation of an individual should in any case be limited to a skin/eye-effective radiant exposure of 30 J/m^2 per day. This value can be used both for occupational exposure and for irradiation of members of the general public. In the case of chronic occupational exposure a further restriction of the exposure of the eye in the 315 - 400 nm (UVA) spectral region is in order. The committee recommends in this case a reference value of the UVA irradiance of 1 W/m^2.

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16 LIMITING THE EXPOSURE

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16.1 Introduction

In this chapter the committee suggests ways for limiting the exposure to UV radiation. A detailed treatment of the possible protective measures in however outside the scope of the present report. Although the emphasis is upon artificial UV radiation, some attention will also be given to exposure to radiation from the sun.

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16.2 Exposure at the workplace

One way to reduce the number of exposed persons is to separate the workplace where the UV sources are applied from other workplaces and places that are open to the public. This enables one to confine attention to the people that work with or in the immediate neighbourhood of the radiation sources. In the case of temporary activities the separation may be non-permanent in nature. An example is the use of welding curtains with occasional welding activities.

To avoid unnecessary exposure to UV radiation signs should indicate the use of UV sources in a room. These signs should mention 'UV radiation' and indicate the nature of the radiation source.

Workers that are occupationally exposed to UV radiation should receive information about the effects of UVB radiation on the skin and the eyes. The possible interaction between UV radiation and certain chemicals and their possible toxic effects should be included in this information.

In the case shielding of the radiation sources and measures with respect to exposure time and distance to the radiation source are insufficient to reduce the exposure level below the exposure limits, and the use of protective clothing and eye protectors are required. Not all clothing materials however are effective in protecting the skin from UV radiation. Table 9 presents some examples.

It is sufficient to refer to the Dutch standards on eye-protectors (NE81a, NE81b). For protecting the eyes special UV glasses should be used; it cannot be taken for granted that each type of sun glasses will offer sufficient protection against UV radiation.

If it is not possible to protect the skin with clothing, sunscreens may be used (An79, Ro83). The protection factor of a sunscreen is the factor by which the minimal erythema dose has to be multiplied if the sunscreen is used. This quantity is defined for the radiation spectrum of the sun. With other source spectra the protection factor will be different and in general smaller if the spectrum is shifted to the longer wavelengths. A test on a possible allergy for the sunscreen is in order (Th84). Products that contain photoactive compounds should not be used.

Practical data and recommendations to limit the exposure to UV radiation can be found in a German publication (Sc84). It should be noted that the exposure standard and action spectra in that report differ from those recommended here.

In evaluating the exposure to UV radiation the radiation emitted by sources for illumination has to be taken into account. In general these sources contribute negligibly to the total radiant exposure (Sl85). In case of fluorescent lighting, however, the UV irradiance will depend on the phosphors and types of glass used; in some instances the contribution to the radiant exposure may become important (Je81).

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16.3 Exposure in public places

In places open to the public some people will be present carrying out their work. Having accepted the principle that it should be possible to work in those places without special personal protection, the occupational exposure will

Table 9 Protection factors of different tissues for UV radiation (Sc81). The protection factor is the ratio of the irradiance that impinges on the tissue and the transmitted irradiance.

material	protectionfactor* UVA	UVB
denim, dark blue	1700*	
cotton bathing towel	110	>1300
white cotton gloves	82	216
tightly woven white cotton	33	86
white cotton and synthetic material	8	43
loosely woven cotton and synthetic material	3,5	13
plastic gloves	1,2	2
nylon stockings	1,2	1,6

* Determined with a mercury-halide source.
** Unlike the other values, determined by averaging the measurement results at 313 nm, 365 nm and 436 nm (Be80).

determine the protective measures to be taken. These measures involve the construction of the radiation sources and the equipment that contains the UV lamps and the way in which the radiation sources are positioned. A special sign at the entrance is not deemed necessary.

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16.4 UV lamps

In Chapter 13 it was pointed out that a new evaluation of the exposure to UV radiation is required if UV lamps are replaced by another type. This recommedation is also applicable in the case of unintentional exposure. Putting a label at the lamp holder indicating the type of UV lamp is recommended.

Affixing a label in a clearly visible position on the UV equipment is also recommended. The label proposed in section 16.2 can be used here. If exposure to photo-active chemicals is possible, this should be mentioned on the label as well.

It has been reported in the literature that 'normal' light sources were inadvertently replaced by UV sources, thus causing acute eye and skin damage (Ro79). Such problems should be avoided by organisational measures and appropriate labelling of the containers of the UV lamps.

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16.5 Exposure to UV radiation from the sun

Outdoor workers are occupationally exposed to UV radiation from the sun. This exposure involves the same risks as exposure to artificial UV radiation. In many instances the radiant exposure will be even larger. It is however difficult to regulate exposure from the sun. Information about the risks of the exposure and about possible protective measures is therefore of prime importance. In this respect it should be emphasized that sun glasses do not always offer adequate eye protection (Ge81).

Special information to the general public about unintentional exposure from the sun is deemed unnecessary. Such information is only necessary in case of intentional exposure, such as that associated with 'sun holidays'.

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PART 5 CONCLUSION

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17 CONCLUSION AND RECOMMENDATIONS

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This chapter summarizes the most important conclusions and recommendations. Recommendations for further research are presented in the next chapter.

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Social and scientific developments

In 1978 the Health Council of the Netherlands prepared a report on unintentional exposure to UV radiation. Social and scientific developments since that time justify a revision and extension of that report. The most important social development is the increasing use of UV appliances by the general public for skin tanning. The scientific progress made relates to the association between UV radiation and skin cancer (Chapter 3).

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Effects of UV radiation on the skin

Interaction of UV radiation with the skin contributes to the production of vitamin D in the body. Other positive health effects of UV radiation reported in the literature are not backed by scientific proof. After exceeding an individually determined threshold dose UV radiation causes erythema of the skin. Exposure to UV radiation accelerates the skin-ageing process and increases the risk of skin carcinoma induction. An association between UV radiation (radiation from the sun) and the occurrence of melanoma (Chapter 6) is suspected.

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Effects of UV radiation on the eyes

Exposure the eyes to UV radiation causes keratitis and conjuntivitis after a threshold dose is exceeded. An association between UV exposure and the occurrence of cataract is suspected, but the nature of a possible dose-effect relationship is unclear. There are indications that high intensity sources of UVA radiation (or short wavelength visible light) cause photochemical damage in the retina (Chapter 7).

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<u>Action spectrum for intentional exposure</u>

Standards for intentional exposure to UV radiation (non-medical applications like skin tanning) should be based on skin effects. It is possible, at least in principle, to protect the eyes adequately against the radiation. The effectivity of the irradiation can best be described by an erythema-effective radiant exposure. The action spectrum to be used is based on proposals from international commissions. The erythema-effective radiant exposure can be expressed in terms of a reference value of the minimal erythema dose for lightly pigmented Caucasian skin not recently exposed. This reference value, called MED, is equal to an erythema-effective radiant exposure of 200 J/m^2 (Chapter 8).

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<u>Action spectrum for unintentional exposure</u>

Standards for unintentional exposure to UV radiation should take into account both effects on the skin and on the eyes. The effectivity of the irradiation can best be described with a skin/eye-effective radiant exposure. The action spectrum proposed is derived, as far as UVB and UVC radiation is concerned, from international recommendations. It is primarily based on the occurrence of keratitis and conjunctivitis. In the UVA spectral region the action spectrum is derived from the erythema action spectrum mentioned above.

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<u>Intentional exposure for skin tanning</u>

It is estimated that the average erythema-effective radiant exposure of Dutch people who irradiate themselves for skin tanning purposes is some tens MED (5 till 10 kJ/m^2) per annum. This is less than the difference in average annual radiant exposure between someone who works permanently outdoors and an indoor worker. The radiant exposure during a three-week 'sun holiday' is several times larger than the annual value estimated for artificial skin tanning (Chapter 9, Chapter 10).

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Standards for intentional exposure to UV radiation

The committee recommends that guidelines for UV irradiation (non-medical applications) be based on a radiant exposure of not more than 100 MED (20 kJ/m^2) per year. In programming a course the manufacturers of UV appliances should also take the recommendations concerning successive irradiations into account. The instruction manual of an UV appliance should mention the risks of UV exposure and suggest ways to restrict these risks. The construction of the appliances can contribute to restricting the risks associated with the irradiation (Chapter 12, Chapter 13).

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Standards for unintentional exposure to UV radiation

Unintentional exposure to UV radiation should be limited to a skin/eye-effective radiant exposure of 30 J/m^2 per day to avoid acute effects. Prolonged exposure up to this limit will increase the skin cancer risk by some 25%. This is considerably less than the difference in skin cancer risk between the outdoor and indoor worker (risk to the former is estimated to be 5 times the risk to the latter). The usual health and safety efforts may reduce the risk associated with the exposure. In some occupations one should pay attention to the concurrent exposure to UV radiation and photo-active chemicals (Chapter 15, Chapter 16). If prolonged exposure to UV radiation (say more than ten years) is unavoidable it is wise to restrict the (average) UVA irradiance to a value of 1 W/m^2.

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18 RECOMMENDATIONS FOR FURTHER RESEARCH

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It follows from the discussion of the UV effects on the skin and the eyes in Chapter 6 and Chapter 7 that not all details of the interaction mechanism are clear. Such knowledge, however, would improve the soundness of the basis for the exposure standards and could even lead to modifications of the present recommendations. It may also become possible to take into account effects not considered hitherto that up until now are left out of consideration. The following areas of research are therefore recommended by the committee.

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<u>Mechanism of skin cancer induction</u>

Several details of the skin cancer mechanism have been elucidated in recent years. It has become clear that DNA damage in the skin cells and DNA repair mechanism are of significance. Effects on the immune system also play a role. The relationship between these factors and the exact nature of the skin cancer induction process is still to a large extent unknown. A sound basis for the dose-effect relationship is therefore lacking.

Chapter 6 mentions that an association between UV radiation and melanoma is suspected. Until now no scientific basis for this association has been found. The mechanism of melanoma induction should be studied in connection with the research as the sun carcinoma mechanism. Given the aggressive nature of this type of cancer and its increasing incidence this research should have a high priority. The committee realizes however that the study of the mechanism of melanoma induction will prove quite difficult.

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The skin cancer action spectrum

Experimental data on the skin cancer action spectrum and the interaction of different wavelengths are scarce. Further research in this field is recommended. In addition to skin cancer, the skin ageing effect should be studied. Differentiation with respect to skin type will be necessary.

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Light damage in the retina

Prolonged interaction of UV radiation and (visible) light (wavelength region 380-500 nm) at sufficiently high irradiances can induce irreversible damage in the retina. Such damage is assumed to be caused by photochemical interactions in the retina and insufficient possibilities for repair processes to function. The mechanism of this harmful interaction is unknown however. As high intensity light sources are fairly common, further study of these effects is in order.

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Exposure to UV radiation

Exposure to UV radiation is generally calculated from theoretical or experimental data about the irradiance of a source and estimated exposure times. As risk factors are based on epidemiological research measuring the exposure directly is desirable. Dosimeters with a response simulating the relevant action spectrum are needed for these measurements. Better and more widely applicable dosimeters should be developed, for the purpose of measuring actual exposure. In this respect biological dosimetry may hold some promise. An example is the determination of radiation induced changes in the skin cells.

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Sunscreens

So-called sunscreens are usually only tested for their effectiveness in preventing erythema. However, that the erythema protection factor also holds good for protection against skin cancer is not self-evident. Further research in this field is recommended. Such studies should also focus on the possible phototoxic effects of certain compounds in the sunscreen.

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20 GLOSSARY OF TERMS

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In this chapter some of the terms used in the report are defined. As the purpose of the chapter was to be of help to readers not familiar with the subject, it has not been reproduced in the English version.

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APPENDICES

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A Mechanism of skin carcinoma induction by UV radiation

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B Medical applications of UV radiation

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C General information about the effects of ultraviolet radiation

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A MECHANISM OF SKIN CARCINOMA INDUCTION BY UV RADIATION

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A.1 Introduction

It was stated in section 6.8 that damage to DNA in the skin cells and the insufficient or partial repair of this damage might play a role in the induction of skin carcinoma. It was also mentioned that changes in the immune system caused by the UV radiation play a part in UV-carcinogenesis. This appendix presents some further details.

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A.2 Effects of UV radiation on the DNA*

It is to be expected that the action spectrum of the interaction between UV radiation and DNA resembles the DNA absorption spectrum. The absorption maximum of DNA is around 260 nm. The absorption spectrum has indeed been found to represent the effectiveness of the induction of DNA dimers rather well. The effectiveness in the UVC spectral region is larger than in the UVB by about a factor of 1000 ; UVA radiation is, again by a factor of 1000, less effective. Also UVC radiation is most effective in inducing single strand breaks. The effectiveness is however a factor of 1000 less than in the case of dimers. This difference is reduced to a factor of 10 in the UVA spectral region.

Given the role of repair mechanisms and the protective effects induced by the irradiation (skin thickening and skin tanning), the action spectrum of skin cancer induction will differ from the DNA absorption spectrum.

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* Summary of the original Dutch version of the report.

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A.3 Immunological effects of UV radiation*

From the study of the effects of UV radiation on murine skin it is concluded that UVB radiation:

- induces skin tumours;
- induces antigens in skin cells and also in tumour cells;
- suppresses the rejection of tumours with UVB induced antigens.

These results were obtained in experiments with mice. It is reasonable to assume that similar mechanisms apply to skin tumour induction in men.

The extent to which these observations are also relevant with regard to effects of UVA radiation is unknown. There are some indications that the avoidance of tumour rejection does not play a role with UVA induced tumours.

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A.4 Literature

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* Summary of the original Dutch version of the report.

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B MEDICAL APPLICATIONS OF UV RADIATION

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This appendix reviews the medical applications of UV radiation both for therapy and for diagnosis of skin diseases. As the purpose of the chapter was to be of help to readers not familiar with the subject, it has not been reproduced in the English version.

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C GENERAL INFORMATION ABOUT THE EFFECTS OF ULTRAVIOLET RADIATION

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This appendix describes the effects of exposure to UV radiation in a less technical way. It is intended for use in informing the general public in the Netherlands about the benefits and risks of UV irradiation. Translation into English was deemed unnecessary.