Ultraviolet-B Solar Radiation System for Measuring, Recording, Displaying and Warning of Dangerous Levels of Radiation at Recreation Grounds

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ABSTRACT

The article presents a system, including a multi-sensor instrument, for measuring, recording, processing and displaying the level of biologically active UV-B radiation. The multi-sensor instrument comprises of solar erythemal UV detectors distributed on a spherical (faceted) dome-like structure. Some of the detectors face upwards measuring the radiation emanating from the sky, while others face downwards, measuring radiation from reflected surfaces. The system displays UV-B radiation levels on billboards in real-time at recreation grounds, thereby warning of danger in instances of over-exposure to sun light. The displayed information includes the amount of sun exposure, in Minimum Erythema Dose, on different parts of the body in relation to the category of human outdoor activity, such as swimming, bathing, sport activity, and sitting in the sun (light) or in the shade. In addition, the system communicates and constantly updates the maximum recommended exposure time to sun light according to the different categories of outdoor activity, while displaying in colour-code, UV-B intensity and ultraviolet index (UVI). It was found that during
1. INTRODUCTION

Ultraviolet (UV) solar radiation, in particular (UVA and UVB), plays an important role in photochemistry and biology [1]. Consequently, several instruments and systems for different measurement purposes were developed [2-7]. Previous studies have shown that the increase in skin cancer cases, cellular DNA damage and other biological diseases, correlate to the increase of solar UV radiation in our environment [1,6,7]. The spectrum of ultraviolet solar radiation, broadly adopted as ranging between 10 nm to 400 nm, can be subdivided into a number of sub-ranges. The term UV-A denotes the wavelength range which extends from 320-400 nm, while the UV-B is in the range of 280-320 nm. UV-A and UV-B wavelengths are also called “Erythemal” UV irradiance. The UV-A accounts for 95 percent of the global UV radiation that reaches the earth’s surface at the equator. Concerning the erythemal UV irradiance, however, 17 percent is UV-A and 83 percent is UV-B [8]. Therefore, the UV-B irradiance is the main cause of erythema effect (redness of the skin). Roughly 0.3 percent of the total radiant energy reaching the earth’s surface is UV-B. UV-B photons are highly energetic, hence detrimental to the health of plants and animals. UV-B radiation can cause damage to the skin in the form of sunburn, premature skin aging, and eventually to skin cancer [1,6]. It can also cause damage to the protein inside the outer layer of the eye and thus promote the appearance of a cataract [7], impairing vision and may lead to blindness. The degree of erythema depends on the UV-B radiation level, skin sensitivity of the body (skin type), and length of exposure time. A unit for measuring UV-B radiation is the Minimum Erythema Dose (MED), defined as the minimum energy that causes the sunburn phenomenon. A person with fair skin who absorbs 1 MED is exposed to 21 milli-joules per square centimetre (or 1MED=0.0583 WHR/m²) of UV-B on the skin which results in a slight reddening of the skin. Another measure of UV-B radiation exposure is MED/HR (1MED/HR=58.3 mW / m²) defined as the intensity of the UV-B radiation (energy per unit time). The amount of biological active UV-B radiation reaching the Earth’s surface varies depending on the season, the time of day, the weather, and the amount of ozone in the atmosphere and altitude. Measurements show that biological active UV-B solar radiation can reach levels above 5 MED/HR during the summer months, and the erythema times for a person with skin type II can be lower than 20 minutes.

Common instruments for measuring UV-B may be divided into static and portable devices. They are known by different names such as Ultraviolet Pyranometers, UV Radiometers, UV-Biometers and Photodosimeters. Static instruments at meteorological stations are mounted on horizontal surfaces and therefore measure radiation on this plane only. Portable or personal instruments [9-14] measure the radiation coming from a direction where the instrument points. Both types of instruments, pointing to any desired direction in the sky, will be capable of measuring the radiation on one plane only at a given time. UV-B radiation incident on several inclined surfaces simultaneously may be measured by using a system comprising of several UV-B Pyranometers mounted at different azimuth and elevation angles. A system of this type would be both large and expensive. To date, no commercial instrument is available for measuring the angular distribution of the UV-B solar radiation in the sky; and no single commercial instrument is available that is capable of simultaneously measuring the UV-B radiation on several different inclined surfaces.

Meteorological stations are performing horizontal plane UV measurements and conveying information on the UV radiation hazards by displaying the UV index. However, a substantial amount of radiation falls on inclined surfaces due to the direct, diffuse and reflected UV
irradiances. For humans engaging in outdoor activities, for example, inclined surfaces include face, neck, limbs, shoulders, back, chest, etc. The study in [15] shows that irradiance measured on a horizontal surface is an inadequate indicator of the irradiance on vertical surfaces. Investigators have measured the UV-B direct beam radiation on a horizontal surface and on a surface normal to the sun for different solar zenith angles and on inclined surfaces [16,17]. The UV-B diffuse radiation under shaded areas (trees and shade structures) was also measured to see whether these shades provide adequate UV protection [18-20]. The solar erythema UV effect on human legs for standing and sitting postures was also studied in [21]. Polysulphone dosimeters were employed to monitor the erythema UV radiation on selected parts of a human model. Models were also developed to simulate human (different body parts) exposure to solar UV radiation [22-25]. These models predicted the UV exposure dose and its distribution across the body.

Multi-sensor instruments for measuring the global solar radiation of the visible or whole spectrum have been developed in the past for solar engineering applications, but are not commercially available. The instrument in reference [26] employs 24 sensors, the one in reference [27] employs 25 sensors, and the instrument in reference [28] contains 135 sensors. In all of these instruments, the sensors are distributed on a hemisphere.

A static UV-B multi-sensor instrument for simultaneous measurement of erythemally weighted irradiance on multiple-inclined surfaces was developed in [29]. This instrument uses a three-dimensional parametric solar irradiance model, which is based on an optimal fitting – mean square error wise – between the model’s output and the sensor’s readings. Upon obtaining the optimal parameters, an algorithm calculates the irradiance on any desired inclined surface.

In this article we describe an instrument for measuring, recording, displaying and warning of dangerous levels of UV-B radiation at recreation grounds. The instrument includes the developed multi-sensor instrument [29], comprising of solar erythemal UV detectors, an electronic circuit for data logging and processing, a display board and an electrical supply unit (see Fig. 1). The instrument is intended to be placed at recreation grounds, such as beaches, swimming pools, resort areas, playing fields, etc., and the warning of dangerous levels of UV-B radiation will be displayed on billboards. The displayed information includes the amount of sun exposure in MED on different parts of the human body according to the outdoor activity, warning about the maximum recommended exposure time to sun light with respect to the skin type of the person, and displaying in colour (blue, yellow or red) the UV-B intensity, in UV index (UVI), updated in real-time during the day. In principle, the instrument measures and displays biological active UV-B radiation on multiple-inclined and oriented surfaces.

Fig. 1. UV-B multi-sensor system

2. MATERIALS AND METHODS

2.1 Short Description of the Multi-sensor Instrument

Fig. 2 illustrates the UV-B multi-sensor instrument comprising of a faceted spherical-like body equipped with UV-B detectors, a mounting post and an electronic box. The unit comprises of an upper and lower dome including planes upon which UV-B detectors are attached. Seven detectors, 1 to 7, face the sky, to cover the space above the horizontal plane. Six detectors, 8-13, face downwards to cover the space below the horizontal plane for measuring ground reflection. The spectral response of the detectors corresponds approximately with the Erythema Action Spectrum (EAS).

The view angle of the detector is ±30° (shown by circles) and they are uniformly distributed, as shown in Fig. 3. The detectors’ view angles are also shown in Fig. 1 by the cones projecting from the detectors. Table 1 and Table 2 provide the azimuth and elevation angles of each detector. These angles describe the direction of the unit vector perpendicular to the detector plane. Azimuth 0° is due south; positive azimuth refers
to west; and negative azimuth refers to east. Elevation angle 0° corresponds to the unit vector pointing to the horizon, positive elevation angles correspond to detectors facing the sky, and negative elevation angles correspond to detectors facing the ground. The detectors were tested on an optical bench using a UV point source. They exhibited a high spectral responsive uniformity and light linearity. Linear regression was applied to obtain the coefficients relating the output voltage of the detectors to light intensity. These coefficients were used to calculate the UV-B irradiance on different target surfaces. The multi-sensor instrument was then calibrated outdoors against a Solar Light Co., Inc. reference instrument. The electronic box contains a voltage supply unit; a unit for signal amplification; a signal sampling and processing unit; and electronics for the display unit, see Appendix A. More details on the irradiance model and the multi-sensor instrument may be found in [29]. Fig. 4 shows, for example, the correlation between the UV-B irradiance model and the reference instrument irradiance, on a horizontal surface on 29 May.

| Detector | Elevation (deg.) | Azimuth (deg.) |
|----------|------------------|----------------|
| 1        | 90               | 0              |
| 2        | 45               | 0              |
| 3        | 45               | -60            |
| 4        | 45               | -120           |
| 5        | 45               | 180            |
| 6        | 45               | 120            |
| 7        | 45               | 60             |

Table 2. Distribution of detectors 8-13

| Detector | Elevation (deg.) | Azimuth (deg.) |
|----------|------------------|----------------|
| 8        | -30              | 60             |
| 9        | -30              | 0              |
| 10       | -30              | -60            |
| 11       | -30              | -120           |
| 12       | -30              | 180            |
| 13       | -30              | 120            |

In a characteristic daily activity at water resorts, the level of exposure is highly dependent on the type of activity, such as sun bathing, swimming, walking, ball playing, etc. We therefore divided the activities into several categories. Table 4 summarises four categories of human activity at a water resort.

| Skin type | 1 MED (J/m²) |
|-----------|--------------|
| I         | 210          |
| II        | 250          |
| III       | 350          |
| IV        | 450          |

2.2 Categories of Human Outdoor Activity

Humans undertake their daily outdoor activities in a number of different postures. Accordingly, different parts of the body are exposed to the solar radiation for different lengths of time. The main parts (surfaces) are (in ordinary activity) the top of the head, face, neck, limbs, shoulders, back and chest (for example, at the seaside). The inclination of the body surfaces towards the sun changes during the day and thus the absorbed biological active UV-B radiation will also change. The effect of UV-B radiation on the human body is an accumulative process. Therefore, it is important to determine the amount of absorbed UV-B energy on characteristic surfaces of the human body during a daily profile of activity. The MED (radiant energy per unit area in J/m²) is a measure that determines the level of UV-B that is dangerous to the body, where 1 MED indicates the onset of the erythema phenomena. For this reason, it is important to know the intensity and time dependence of UV-B radiation incident on surfaces as a function of both the angles to the horizontal and the azimuthal orientation. It also depends on the skin type of the person as shown in Table 3 [30].
Fig. 4. Correlation between the UV-B irradiance model and the irradiance of the reference instrument on a horizontal surface on 29 May

2.2.1 Category 1: Sun bathing/swimming

The activity of this group of people is sunbathing and/or swimming. In this category, they spend most of their time with their backs and/or chests exposed to the sun in a horizontal plane.

2.2.2 Category 2: Sport activity

The activity of this group of people is playing games, such as volleyball, and bat and ball where the body is mostly in a vertical position. The upper part of the body is usually mostly naked. While playing, they change their vertical position to north, south, east and west. The chest and the back are exposed equally to the sun in this activity.

2.2.3 Category 3: Sitting position in the sun

The activity of this group of people is to relax and read at the swimming pool or beach wearing a swimming suit. The person usually sits on a beach chair with his body facing towards the water. His body leans with an elevation angle of 60° with respect to the horizontal.

2.2.4 Category 4: Sitting position in shade

The activity and body position of this category is similar to category 3, but in the shade.

2.3 Characteristic Planes of the Human Body

The characteristic planes (other planes may also be important) of a person subjected to UV-B radiation in outdoor activity include face, nose, neck, top of the head, limbs, chest, back, shoulders, etc. (see Figs. 5 and 6).
Table 4. Categories of human activities at a water resort and the individual representative plane (Elevation and Azimuth)

| Representative plane | Characteristics | Activity          | Category |
|----------------------|-----------------|-------------------|----------|
| Elevation Azimuth    |                 |                   |          |
| 90°      N/A        | Most of time lying on belly or back; representative is the horizontal plane | Sun bathing, swimming | Category 1 |
| 0°          E N      | Most of time in vertical position in all orientations; representative is the vertical plane | Sport activity (volleyball, bat and ball, running, walking) | Category 2 |
| 60°  e.g. E or W   | Sitting most of time facing the water | Sitting in sun | Category 3 |
| 60°  e.g. W        | Sitting most of time facing the water under a shade | Sitting in shade | Category 4 |

Table 5. Characteristic activity of a person during a day at a water resort

| Activity       | Start hour | Stop hour | Arms/Legs Elev. | Arms/Legs Az. | Chest Elev. | Chest Az. | Top head Elev. | Top head Az. | Nape Elev. | Nape Az. | Nose Elev. | Nose Az. | Face Elev. | Face Az. |
|----------------|------------|-----------|-----------------|---------------|-------------|-----------|----------------|-------------|------------|----------|------------|----------|------------|---------|
| Walking        | 10:00      | 10:30     | 0 -90           | 90            | 0 -45       | 90        | 0 -30          | 90          | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90   |
| Sitting        | 10:30      | 11:00     | 90 -45          | 60 -45        | 30 -45      | 90        | NA -90         | 90          | 90 -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90  |
| Swim/Tan      | 11:00      | 11:30     | 90 -90          | NA -NA        | 70 -90      | 45        | NA -30         | 45          | NA -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90  |
| Walking/Play  | 11:30      | 12:00     | 0 -90           | 90            | 0 -45       | 90        | 0 -90          | 90          | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90   |
| Sitting        | 12:00      | 13:00     | 90 -45          | 60 -45        | 30 -45      | 90        | NA -90         | 90          | 90 -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90     | 90 -90  |
| Walking        | 13:00      | 14:00     | 0 -90           | 90            | 0 -45       | 90        | 0 -90          | 90          | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90      | 0 -90   |

NA – Not Relevant, Azimuth: 0° = South, 90° = West; Elevation 0° = Horizontal

* Swim Tan – The Elev. and Az of the back of the body = 0°

3. RESULTS

The irradiance on a desired target surface, defined by the azimuth and elevation angles, was calculated by the proposed multi-sensory irradiance model [29]. Target surfaces are listed in Tables 4 and 5 for human characteristic activities at a water resort. The figures and tables in Section 3 were based on measured and processed data. The purpose of the multi-sensor system (see Fig. 1, includes instrument, display and computer) is to warn about the danger of body over-exposure to the sun light at recreation grounds. These warnings may be characterized by the following information:

3.1 Warning of the amount of Sun Exposure Corresponding to the Category of Human Activity

Fig. 7 shows the amount of energy in MEDs that a person absorbed during the summer day 29/5/2014 on the beach in central Israel (latitude 32°N), whilst swimming, bathing, sports activity, sitting in the sun and shade, based on the categories listed in Table 4. Fig. 7 also shows the rate of change of the energy, in MED/HR (radiation intensity) and in UVI

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1 MED / HR = 58.3 \frac{mW}{m^2} \times 40 / 1000 = 2.33 UVI
\]

[8], absorbed in the body according to the
different categories. This information may be used for warning the community about the maximum recommended exposure time to absorb 1MED.

The results apply to a person with skin type III. One may observe that between 10:48 and 16:33 local time, a person may absorb more than 13 MEDs whilst sun bathing, i.e. 15 times more than recommended. An active person will absorb half that amount. It is important to emphasize that sitting in the shade for that period of time is equally as dangerous as it is for sports activity.

The daily biological active UV-B radiation during the summer months (June-August) between 10:30 and 16:00 local time according to the categories Tan/Swim, Sport, Sun sitting and Shade sitting, is given in Fig. 8. One may notice that the change in MED on consecutive days is quite small and therefore it is possible to convey information about the daily or weekly forecast of the UV-B radiation, similar to that as in Fig. 7.

A person who is aware of the danger of overexposure to the sun may consult Fig. 7 before going to the beach. One may determine the amount on MEDs absorbed when leaving the beach at a certain time based on the person’s skin type, the category of activity and the time of arrival at the beach. For example, if a person wishing to sun bathe arrives at 12:57 and leaves at 15:07 local time, he may experience 6 MEDs (13 MEDs minus 7 MEDs, see Fig. 6), see also examples in Appendix B.
3.2 Warning about the Maximum Recommended Exposure Time to Sun Light According to Different Categories of Outdoor Activity

As mentioned above, the people on the beach receive from the display of the UV-B system continuous (real-time) information on the UV-B radiation, informing them of the maximum recommended exposure time to the sun according to the person's skin type and the category of outdoor activity. This time corresponds to the absorption of 1MED (the onset of sunburn). In addition, the display is coloured (blue, yellow or red) representing ranges of UV-B intensities in UV index (UVI) that is updated in real-time during the day. The colour is identified from a distance informing and warning the public about the intensity of the sun light (with respect to UV-B radiation). The ranges of the UV-B intensities, represented in different colours, are shown in Fig. 9 (blue-low, yellow-moderate, red-high). Table 6 shows, for example, the maximum exposure time, in minutes, corresponding to the skin type and category of activity. The local time is also indicated. This table is updated in real-time. For example, a person with skin type III arriving at 11:03:40 local time for the purpose of sunbathing (category 1), the maximum recommended time to spend on the beach is 41 minutes, whereas a person with skin type II arriving at 12:50:19 local time, the maximum recommended time is 16 minutes (see Table 7).

3.3 Monitoring the amount of UV-B Absorbed Energy by the Different Parts of the Body According to a Characteristic Activity during the Day at a Water Resort

This application of the proposed UV-B multisensor system emphasizes the importance of monitoring the biological active UV-B radiation on different parts (planes) of the body during a characteristic activity day at a water resort.

Figs. 4 and 5 describe some characteristic planes of the human body (other planes may also be important). The direction of the planes with respect to the sun, at any given time, was used to determine the amount of UV-B absorbed radiation in a daily activity between the hours 10:00 to 14:00 local time. The characteristic activity consisted of standing (walking), sitting and/or swimming. The length of time of each activity was assumed, as shown in Table 5. The amount of UV-B radiation absorbed by the mentioned planes, for a person with skin type III, on the 22/7 for example, is shown in Fig.10 above. Not surprisingly, the vertex of the head and the nose received the largest level of the radiation.

![Fig. 9. Intensity of the UV-B radiation represented in colours](image)

Table 6. Maximum exposure time, in minutes, as a function of category and skin type for a person arriving at beach at 11:03:40 local time

| Local time 11:03:40 | Maximum Exposure Time [min.] | Skin type |
|---------------------|-------------------------------|-----------|
| Category 1 | Category 2 | Category 3 | Category 4 |
| 25 | 52 | 28 | 59 | Type I – Bright skin Never tan Always burn |
| 29 | 62 | 33 | 70 | Type II – Bright skin Sometimes tan Sometimes burn |
| 41 | 87 | 47 | 98 | Type III – Brown skin Sometimes tan Sometimes burn |
| 53 | 112 | 60 | 126 | Type IV – Dark skin Always tan Never burn |

Table is with no memory of previous sun exposure
Table 7. Maximum exposure time, in minutes, as a function of category and skin type for a person arriving at the beach at 12:50:19 local time

| Local time 12:50:19 | Maximum Exposure Time [min.] | Skin type |
|---------------------|-------------------------------|-----------|
| Category 1           | Category 2                    | Category 3| Category 4 |
| 14                  | 32                            | 15        | 43         |
| 16                  | 39                            | 18        | 52         |
| 23                  | 54                            | 25        | 72         |
| 30                  | 70                            | 33        | 93         |

Type I – Bright skin
Always burn
Type II – Bright skin
Sometimes tan
Type III – Brown skin
Sometimes burn
Type IV – Dark skin
Always tan

Table is with no memory of previous sun exposure

Fig. 10. UV-B radiation absorbed by different parts of the body in a daily activity at the beach

4. CONCLUSIONS

A system for measuring, recording, displaying and warning of dangerous levels of UV-B radiation is described. The system includes a multi-sensor comprising of solar erythemal UV detectors distributed on a spherical dome-like structure. Seven detectors face the sky for measuring the UV-B radiation emanating from the sky, and six detectors face downwards for measuring the reflected UV-B radiation from the ground or nearby objects. The measurements of the detectors are processed using a developed radiation function model, the results of which may be displayed on billboards placed at recreation grounds or at any outdoor activity site, warning of dangerous levels of UV-B radiation. The information is displayed in real-time. This includes the intensity of the UV-B radiation coded by colours, the maximum time recommended for taking part in a desired activity outdoors, corresponding to the person's skin type and the amount of UV-B radiation a person may absorb in the time period of that outdoor activity. The purpose of displaying dangerous levels of UV-B radiation in real-time at sites where outdoor activities take place is to create public awareness of the danger of over-exposure to sun light, to use protection means, and thereby, to reduce the morbidity related to solar rays. During the time period between 10:00 and 16:00, a person may absorb more than 15 MEDs in sun bathing, i.e., 15 times more than is recommended. A person engaged in sports activity will absorb half of this amount. Sitting in the shade for that period of time is equally as dangerous as it is for sports activity. Not surprisingly, the vertex of the head and the nose receive the largest amount of radiation. Erythema time for a person with skin type II may be exposed less than 15 minutes in the middle of the day in summer.

Static UV-B instruments at meteorological stations are mounted horizontally and therefore measure the radiation on horizontal planes only. Mobile instruments measure the radiation coming...
from a direction where the instrument points. To date, no single instrument for simultaneously measuring the biologically active UV-B radiation on multiple surfaces has been developed. This kind of instrument and system has been developed by the authors for the purpose to warn the community public of dangerous levels of UV-B radiation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX A

A schematic diagram of the system components for measuring and displaying the UV-B radiation is shown in Fig. A1.

![Schematic diagram of the UV-B system](image)

**Fig. A1. Schematic diagram of the UV-B system**

The data acquisition and processing include three units: voltage supply unit, amplification unit and a sampling unit.

The voltage supply unit is designed for \(\pm 9\) Volts to supply power to the various circuits. In the amplification unit, the detectors' currents are amplified and converted to millivolts levels (see Appendix B) by a transimpedance circuit. The sampling unit contains a multiple channel sampling card (National Instruments) accommodated by laptops. A dedicated software program was written using Labwindows/CVI (National Instruments) to sample the readings of the various channels and to process the data for display purposes.

APPENDIX B

Examples of measurements and processed data of UV-B solar radiation are shown in Tables B1-B3.

Table B1 describes the amount of radiant energy per unit area absorbed on a horizontal plane for different exposure times. For example, a person arriving at a recreation ground at 12:45 for the purpose of sun bathing and stays for 45 minutes will absorb 3MEDs. The absorbed radiant energy on an inclined plane of 60\(^\circ\) facing south is shown in Table B2. Table B3 shows a sample of measurements in volts of the 7 detectors (Det) on the upper-dome of the instrument and their conversion to radiant energy in \(mW / m^2\) at different times on 29/05/14. The table includes also the conversion of the three-dimensional (3D) parametric solar irradiance model values into volts and radiant energy.

**Table B1. Radiant energy per unit area absorbed on a horizontal plane for different exposure times**

| Onset time Exposure time, minutes | 16:45 | 15:45 | 14:45 | 13:45 | 12:45 | 11:45 | 10:45 |
|----------------------------------|-------|-------|-------|-------|-------|-------|-------|
| 0.33                             | 0.51  | 0.72  | 0.83  | 1.01  | 1.02  | 0.86  |
| 0.98                             | 1.39  | 1.61  | 2.03  | 2.05  | 1.78  |
| 1.39                             | 2.01  | 2.40  | 3.00  | 3.10  | 2.76  |
| 1.75                             | 2.67  | 3.19  | 3.67  | 4.21  | 3.77  |
| 4.33                             | 6.76  | 7.06  | 8.06  | 7.93  |
| 7.51                             | 9.63  | 11.26 | 11.84 | 180   |
| 11.38                            | 13.84 | 15.03 | 240   |
### Table B2. Radiant energy per unit area absorbed on an inclined plane 60° facing south, for different exposure times

| Exposure time, minutes | 16.45 | 14.45 | 13.45 | 12.45 | 11.45 | 10.45 |
|-----------------------|-------|-------|-------|-------|-------|-------|
| 0.31                  | 0.47  | 0.67  | 0.78  | 0.96  | 0.97  | 0.81  |
| 0.89                  | 1.29  | 1.62  | 1.92  | 1.94  | 1.67  | 1.30  |
| 1.27                  | 1.69  | 2.26  | 2.83  | 2.93  | 2.59  | 2.45  |
| 1.60                  | 2.38  | 2.99  | 3.65  | 3.97  | 3.54  | 3.20  |
| 3.98                  | 5.36  | 6.64  | 7.62  | 7.52  | 6.20  | 5.40  |
| 6.95                  | 9.01  | 10.61 | 11.17 | 11.00 | 11.00 | 10.60 |
| 10.61                 | 12.98 | 14.15 | 14.00 | 13.94 | 13.94 | 13.94 |

### Table B3. Sample measurements of detectors and UV-B irradiance model data

| Time  | UVB Radiation 3D Model [W/m²] | UVB Radiation 3D Model [W/m²] | Det[1] [W/m²] | Det[2] [W/m²] | Det[3] [W/m²] | Det[4] [W/m²] | Det[5] [W/m²] | Det[6] [W/m²] | Det[7] [W/m²] |
|-------|-----------------------------|-------------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 10:42:53 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 |
| 10:43:03 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 | 0.360 |
| 10:43:13 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:43:23 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:43:33 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:43:43 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:44:03 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:44:13 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:44:23 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:44:33 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:44:43 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 | 0.359 |
| 10:45:03 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:45:13 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:45:23 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:45:33 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:45:43 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:46:03 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:46:13 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:46:23 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:46:33 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:46:43 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:47:03 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:47:13 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:47:23 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:47:33 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:47:43 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |
| 10:48:03 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 | 0.361 |

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