ULTRAVIOLET RADIATION

Experiments and demonstrations

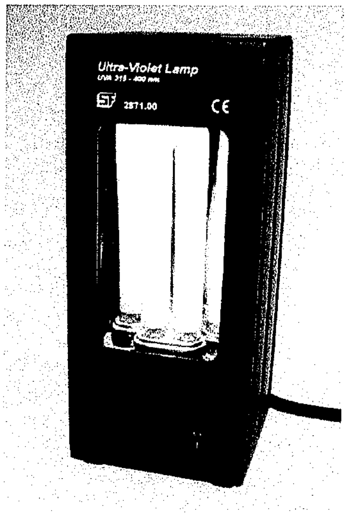
INTRODUCTION

The ultraviolet (UV) region of the spectrum is an important and interesting subject of study in secondary science education. Everyone is fascinated by demonstrations with UV light when surprising results are produced. The following experiments with UV radiation can be performed using detectors and materials available from *SolData Instruments* [1].

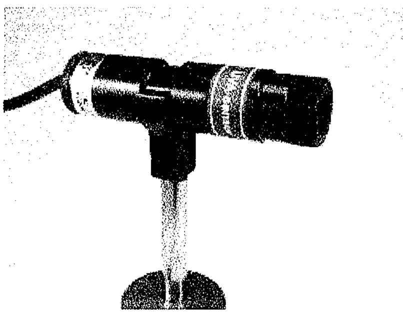
EQUIPMENT REQUIRED

With detectors, light sources and materials from *SolData* you can perform a wide range of demonstrations and experiments with UV:

UVA Light Source

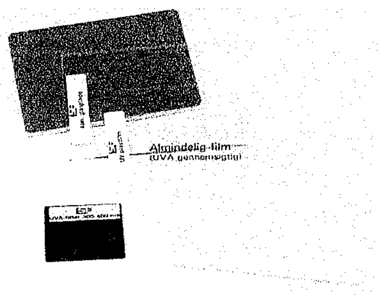


UVA Directional Detector



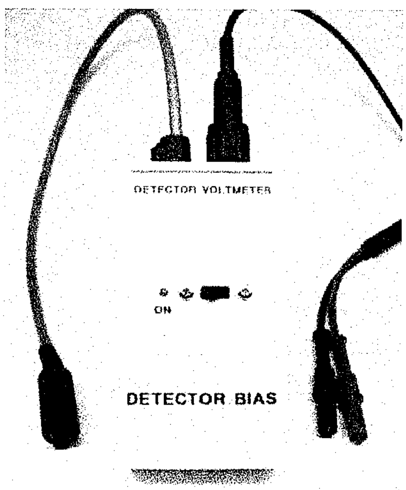
This narrow band detector is sensitive to UV radiation from 360-370 nanometers.

UVA Demo Set

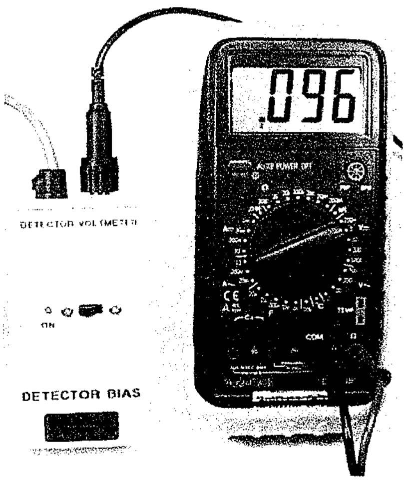


Glass plate, ordinary film, UV film, fluorescent and phosphorescent plates and a Schott UG1 UV filter.

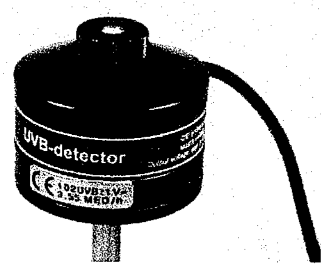
Detector Bias Box



Digital Voltmeter



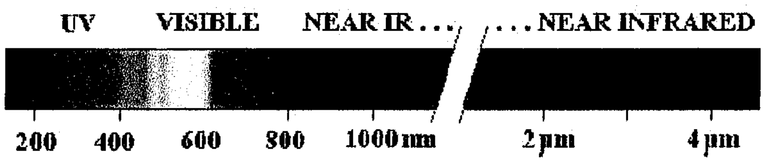
UVB Detector



The UVB detector sensitivity (CIE-87) corresponds to human skin and can be used to evaluate health risks.

WHAT IS ULTRAVIOLET LIGHT?

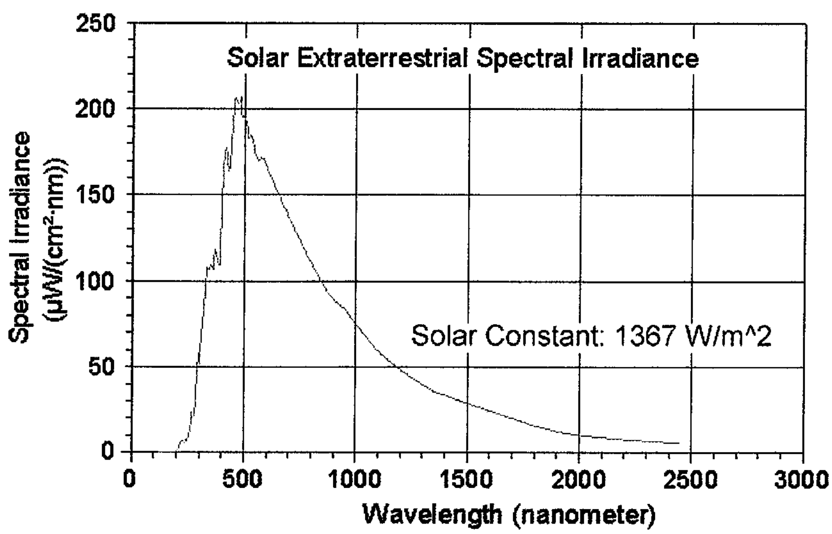
Before commencing with some demonstration experiments, we will briefly review the standard classifications of ultraviolet radiation.



The UV wavelengths (100-400 nanometers) are slightly shorter than wavelengths in the visible region (400-800 nm). The UV region is further divided into subregions as follows:

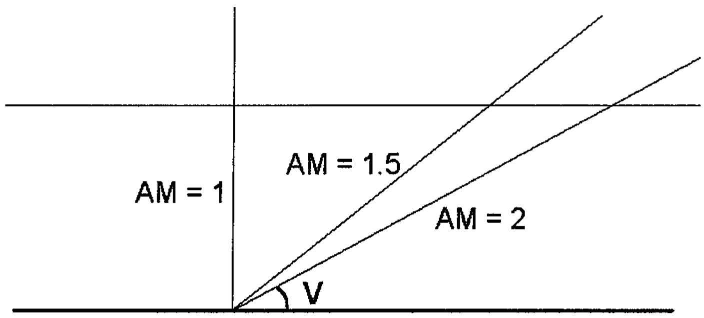
Region	Wavelengths	Comments
Vacuum UV	100 - 200 nm	Very hazardous. Solar vacuum ultraviolet (VUV) is stopped by the Earth's atmosphere. *photon energies: 12.4 - 6.2 eV*
UVC band	200 - 280 nm	Very hazardous. Oxygen and ozone strongly absorb UVC radiation. Fortunately, hardly any UVC normally reaches sea level. *photon energies: 6.2 - 4.4 eV*
UVB band	280 - 315 nm	Hazardous (burns, cancer, eye injury) due to ionization of molecules. Partly absorbed by the ozone layer. Significant at high solar elevation angles (around noon). *photon energies: 4.4 - 3.9 eV*
UVA band	315 - 400 nm	Slightly hazardous. Can cause bleaching of fabrics and fading of paints. Must be present to promote tanning and vitamin D. *photon energies: 3.9 - 3.1 eV*

The solar spectrum outside the Earth's atmosphere contains significant amounts of ultraviolet. Much of it is attenuated due to absorption by molecules or due to molecular scattering before the solar irradiance reaches the Earth's surface.



Wavelength:	310 nm	330 nm	340 nm	350 nm	365 nm	380 nm	405 nm
Air Mass 0:	68.9	105.9	107.4	109.3	113.2	112.0	164.4
Air Mass 1.5:	6.2	18.8	29.8	34.3	43.2	48.9	82.4

The table shows data (in µW per $cm^2 \cdot nm$) for ultraviolet measured outside the Earth's atmosphere (AM=0), and for radiation at sea level on a clear day with a solar elevation angle of about 42° (AM= 1.5). For solar elevation angles over about 25° the following approximation applies:



$$AM \approx 1/\sin(V)$$

If $V = 30°$, then the air mass (AM) through which the Sun's direct beam passes is: $AM \approx 1/\sin(V) = 1/0.5 = 2$. Notice from the table that for AM 1.5 the UV at 310 nm is scattered much more (less than 10% reaches the surface) compared with the UV at 405 nm (about 50% gets through). This is due to *Rayleigh scattering* of the radiation by air molecules.

Experiment 1: Absorption of UVA

Set up the UVA detector on a small tripod or other support as shown in the illustration. Connect the detector to the detector bias box, and plug the 4 mm safety jack leads into the digital voltmeter. Turn on the UVA lamp, and arrange the equipment as shown in the figure, so that the detector faces the UVA lamp. The output signal when the lamp warms up should be about 1 to 2 volts. Place various materials in front of the detector, and observe the attenuation. The *transmittivity* is the fraction of the light beam which passes through the material.

Material:	glass	plastic film	UV film	eyeglasses	plexiglass
U_M (volt)					
U_O (volt)					
$T = U_M/U_O$					

(U_O: *uattenuated beam signal;* U_M: *signal with material in the beam*)

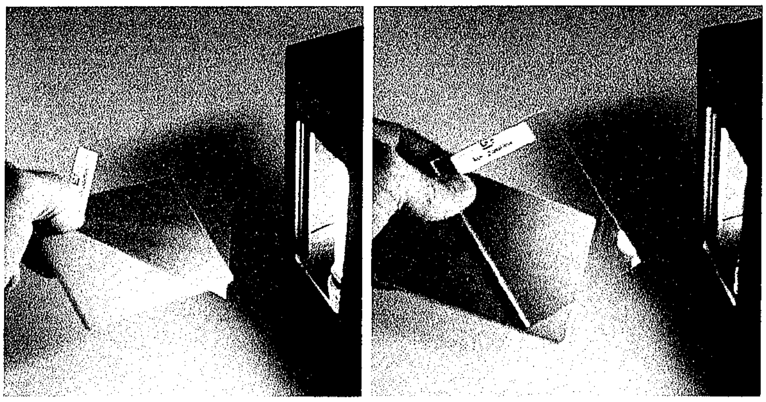
Fill in the table and find the transmittivities! Notice that ordinary glass does indeed transmit UVA at the detector wavelength (365 nm ± 5 nm). The transmittivity is about the same as it is for visible light. Later experiments will show that UVB on the other hand is highly attenuated by ordinary glass.

Experiment 2: UVA absorption in water

Arrange the light source and the detector so that the light passes vertically through a glass beaker. Let U_0 be the unattenuated signal. Now add water to the beaker and measure the transmittivity as a function of water depth. Draw a graph of the results showing transmittivity vs. water depth. At what depth is 50% of the beam absorbed? At what depth 75%?

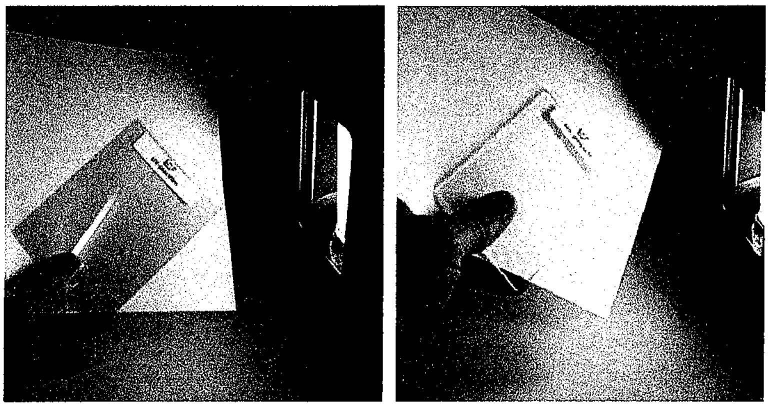
Experiment 3: Fluorescence

The UVA Demo Set contains many materials which can be used to show interesting properties of ultraviolet light. Turn on the UVA lamp so that it can illuminate the materials. The experiments should be performed in a darkened room. Place the fluorescent material in the beam. Note that when it is removed from the beam the fluorescent emission ceases at once.



At the left UV film shades the fluorescent plate. At the right glass shades it.

Place the fluorescent material in the UVA beam. Place the ordinary plastic film in the beam and note the effect. Try with glass. Try with the UV film. Try with the UG1 filter. The fluorescence is re-emission of visible light due to excitation by the UV radiation. If the materials used do absorb the UV, the fluorescent area covered by the item will appear dark.



At the left UV film shades bleached paper. At the right a glass plate. The UVA is stopped by the UV film but not by glass.

Ordinary bleached paper contains a fluorescent whitener. It will also react to the UV light and appear brighter. Try shading the paper with the UV film, and note the effect. Try with glass and ordinary film. Try with the UG1 Schott filter.

Experiment 4: Phosphorescence

Use the phosphorescent plate and repeat the demonstrations of Experiment 3. Note that phosphorescence also involves the excitation of the material by UV radiation and its subsequent re-emission of visible light. The re-emission in this case does not take place at once but after a time delay of seconds or minutes.

Experiment 5: Sun protection cream

Sun protection cream is rated with various sun protection factors. Sun protection "factor four" means that the user can tolerate UV exposure four times as long as without protection. Measure the mass of a glass plate on a sensitive balance. Place a drop of sun protection cream on the glass and spread it out evenly in a thin film. Weigh the glass again and find the mass per unit area of the film. Measure transmittivities with and without the film. What mass per unit area is required to give the UVA protection factor advertised for the product?

Experiment 6: UVA reflectivity

The UVA reflectivity of various materials can be studied by setting up a screen so that the detector does not view the UVA lamp directly but receives light reflected from various surfaces (at about a 45° angle). Use various types of paint, white paper, plant materials, snow, etc.

Experiment 7: UVA from various light sources

The response of the SolData UVA detector at a distance of 20 cm from the (warmed up) UVA lamp will be about 1.8 V. The UVA irradiance at this distance is about 10 $\mu W/(cm^2 \cdot nm)$ ("microwatts per square centimeter per nanometer"). The is no special name for this unit. It is the unit for *spectral irradiance*. The "per nanometer" in this expression means e.g. that for a bandwidth of just one nanometer the irradiance is 10 $\mu W/cm^2$, while for 5 nm it would be 50 $\mu W/cm^2$. Note that this same unit was used in the solar spectrum shown on page 2. The sensitivity of your instrument is provided on a label on the instrument housing.

The UVA detector measures the spectral irradiance in a single, narrow band of the UVA around 365 nanometers. The table at the top of page 3 shows that the solar spectral irradiance on a clear day when the solar elevation angle is about 42° (corresponding to 1.5 air masses) should be around 40 $\mu W/cm^2$. This high level may saturate the UVA detector. Its output signal can not exceed about 5 V.

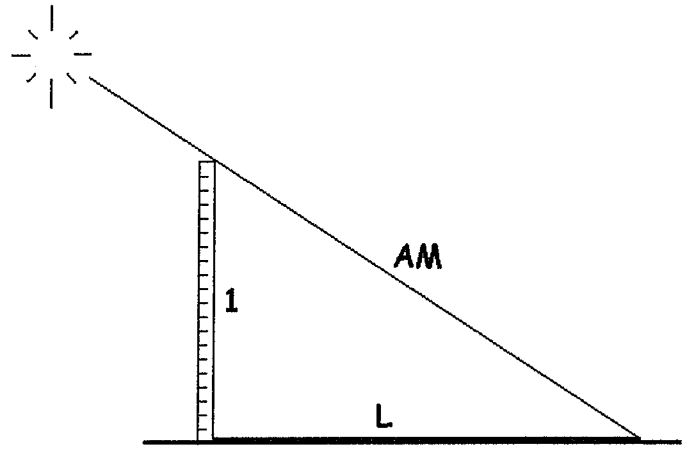
Try measuring the spectral irradiance near a halogen lamp. Try checking various types of sun lamps (solaria). There will be no detectable UVA emission from an ordinary tungsten incandescent light. However, you should be able to measure some UVA close to a fluorescent light.

Experiment 8: Solar UVA studies

One of the most interesting measurements which can be made with the UVA detector is to do a *Langley Plot* for 365 nm UV on a clear, sunny day. For this purpose you should use the collimator. It has a small aperture (about 4 mm in diameter) to reduce the strong signal from the direct rays of the Sun to a measurable level and to measure only the *direct* rays from the sun. The illustration at the right shows the UVA detector with the collimator in place.

The experiment requires a clear, sunny day. Mount the instrument on a tripod (use the adapter provided), and measure the direct solar irradiance every half hour or so throughout the morning until the sun reaches its maximum elevation angle. We are interested in the UVA irradiance (at 365 nm) versus the air mass through which the direct rays of the Sun pass.

You can find the elevation angle of the Sun in several ways. One way is to observe the shadow of a vertical meter stick on a flat surface. If you measure the length of the shadow to be *L* (use meters as the unit) then you can find the length of the hypotenuse of the right triangle. The length corresponds to the air mass value AM.



From *Pythagoras' theorem*:

$$1^2 + L^2 = AM^2 \Leftrightarrow AM = \sqrt{1^2 + L^2}$$

For example, if you measure a shadow length of 1.34 meters, then the air mass value $AM = 1.67$.

Furthermore, you can find the solar elevation angle V as follows: $\tan V = 1/L$, so $V = \tan^{-1}(1/L)$. On an ordinary pocket calculator you simply use the inverse tangent function. In the above example:

$$V = \tan^{-1}(1/1.34) = 36.7°$$

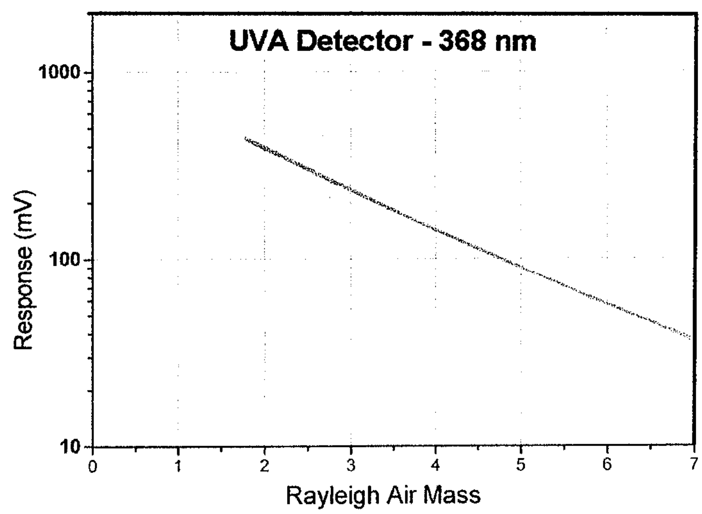
Another way of finding the solar elevation angle and the air mass is to refer to a nautical almanac. With knowledge of your latitude and longitude and the time of day, you can compute the solar elevation angle V. When you know the angle, you can use the same geometry to find the air mass value:

$$\sin V = 1/AM \iff AM = 1/\sin V$$

Checking using the same example : $AM = 1/\sin(36.7) = 1.67$.

NB: It should be mentioned that these simple techniques will not work for solar elevation angles smaller than about 25°. See for example [2] for a discussion of detailed methods which take into account the curvature of the Earth and refraction.

We assume that you have measured the air mass and the UVA direct irradiance at frequent intervals as the Sun climbs higher in the sky during the morning (or during a similar period after noon). You will have a table of UVA detector measurements (in volts) vs. air mass AM.



A graph of the UVA measurements vs. AM in a semilogarithmic coordinate system should yield a graph similar to the one shown in the figure. Such a graph is called a

Langley plot after the American solar physicist Samuel P. Langley. The graph in the illustration was in fact made from data acquired using a solar tracker to follow the sun continuously in northern Greenland with the sun above the horizon all day. The AM values are corrected for low elevation angles. The graph you draw will probably only have AM values from about 1 to 3 depending on your location and the time of year.

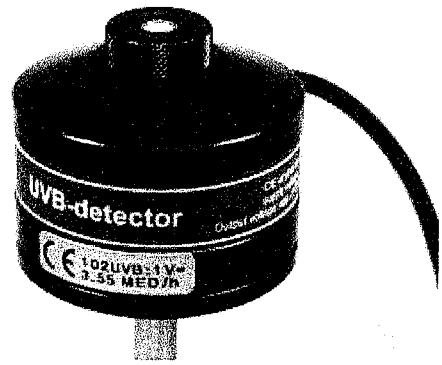
Be that as it may, you should draw the best straight line graph through your data. Extend the line so that it intercepts the ordinate (Y) axis corresponding to AM = 0. This value of the UVA detector signal corresponds to what you would expect to measure if the instrument were outside the Earth's atmosphere. Let us suppose that the value you read off your graph is 6.2 volts. Referring to the table on page 3, you can see that the expected air mass zero value of the solar spectral irradiance is 113.2 µW/(cm^2·nm). The response *R* of your instrument is thus:

$$R = \frac{113.2 \frac{\mu W}{cm^2 \cdot nm}}{6.2\ volt} = 18.25 \frac{\mu W}{cm^2 \cdot nm}\ per\ volt$$

In this experiment the Sun itself is used as a reference light source to find a dependable value for the response of your instrument. When you subsequently measure other, earthbound light sources, your instrument readings can be converted to true spectral irradiance values.

Experiment 9: UVB radiation

You may like to try measuring some UVB radiation, the most hazardous type of ultraviolet commonly encountered. To do so you will require the UVB detector shown in the accompanying figure. Note that the UVB instrument receives radiation from all directions above the instrument in contrast to the UVA detector which has highly directional response.



UVB sources are not commonly available in the laboratory. A high pressure mercury vapor lamp, a deuterium lamp or a carbon arc lamp are needed to yield measurable UVB. It will most often be preferable, when possible, to use the Sun itself as the UVB source.

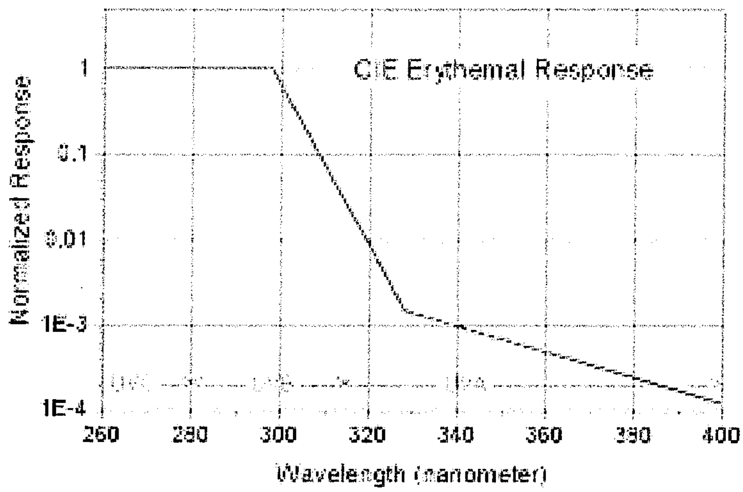
Set up the UVB detector on a tripod or other support. The thread in the bottom of the instrument is a 10 mm standard thread for laboratory rods. An adapter (supplied) can be screwed into this fitting to allow the detector to be mounted on the standard 1/4" thread used with photographic tripods. Your setup will be the same as shown on page 3 using the bias box and a standard digital voltmeter for readout, except that the detector will be the UVB detector instead of the UVA instrument.

Now you can try the same experiment with UVB as Experiment 1. Use the various transparent materials to examine their attenuation of UVB radiation. To do this experiment you will need constant sunshine for a few minutes. Note that ordinary glass does indeed strongly attenuate UVB radiation (while UVA did not). On a very bright, sunny day try measuring UVB in the shade. You will be surprised!

Experiment 10: UVB

It can be very instructive to measure the level of UVB radiation during the course of a day. This exercise is especially interesting in the summer months when UVB levels are high. Even better, take the instrument along to a region in the tropics where the solar elevation angle can be as high as 90°. You will then measure remarkably high UVB levels! At the location shown in the figure (near Cairns in Queensland, Australia) a UVB level of over 15 UVI was measured.

A brief note on *UVB units of measure* is in order. The UVB detector output signal U is proportional to the product of the CIE response $R(L)$ and the spectral irradiance $I(L)$ of the source being measured where L is the wavelength. $U = \int R(L) \cdot I(L)\, dL$ over the region of interest. Because UVB data is most often used to describe the biological effects of the radiation, the unit *MED per hour* is commonly used. A *dose* of one MED will cause a detectable reddening of the skin for an average person. This value corresponds to a total dose of 210 J/m^2.



A *dose rate* of 1 MED/hour corresponds to (210 J/m^2)/3600 s = 58.3 mW/m^2. The effective UV intensity (UVI) is defined so that 1 UVI = 25 mW/m^2 . Thus 1 MED/hour equals 2.33 UVI. SolData UVB detectors are calibrated so that ca. 6 UVI will yield an output of about 1 volt. Here is an example: You measure an output of 1.66 volts. This gives a dose rate of 10 UVI = (10/2.33) = 4.29 MED/h. In this case one MED would be received by an average person in 60/4.29 i.e. about 14 minutes.

See the SolData Instruments homepage for additional information: www.soldata.dk. Click on PRODUCTS then on LIGHT MEASUREMENT and UVB DETECTOR. There is also additional information on the UVA detector and other instruments at this URL.

LITERATURE

1) SolData Instruments homepage: www.soldata.dk. Our e-mail address is soldata@soldatanews.dk.
2) Frank Bason, *Aerosol optical depth measurements in the UV, visible and near IR at Thule Air Base, Greenland (76.5°N), during 1999*. Ph.D. dissertation, Aarhus University, Denmark, 1999.

D:\Documents\SolData\UV tekster\UV demoforsøg soldata.wpd