# SPN1

# Technical Fact Sheet

Delta-T Devices

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# SPN1 Technical Fact Sheet


## Contents

## What does it measure?

The SPN1 Sunshine Pyranometer is one sensor with three output channels:-

1. Total (global) solar radiation
2. Diffuse radiation
3. Sunshine status.

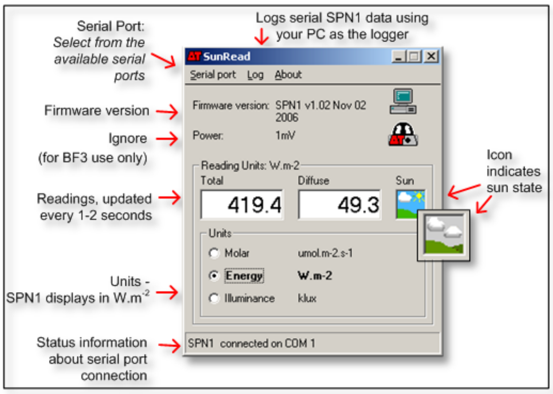



Figure 1 Showing how SPN1 real-time readings appear on a PC running the SunRead program

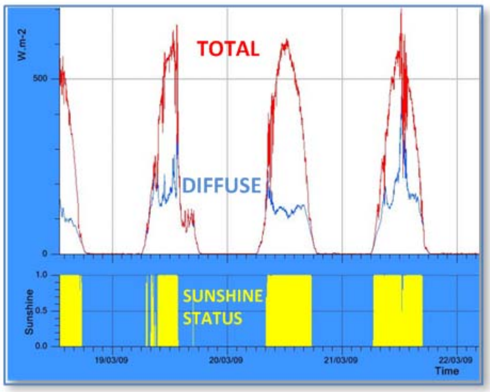



Figure 2 Graphical representation of the SPN1 readings logged over several days.
Upper chart: Total and Diffuse reading in $W/m^2$
Lower chart: Sunshine status record as sunshine hours

## What is Total or Global radiation?

This is the radiation received from the whole of the sky, including the direct light from the sun and diffuse scattered light from the rest of the sky, including clouds and aerosols. This is what a standard, horizontal solar pyranometer will see.

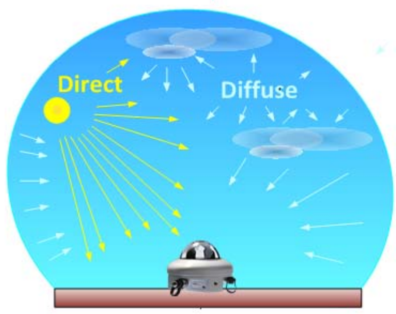



Figure 3 Diffuse and Direct radiation

## What is diffuse radiation?

Diffuse radiation is that which is received from the rest of the sky, excluding that received directly from the sun.

Diffuse radiation can be a valuable source of energy for photovoltaic devices.

Direct radiation can be predicted fairly well from satellite data, but it is a lot harder to model all the scattering processes in the atmosphere, and so it is best to measure the Diffuse radiation at a test site and over the time period of any photovoltaic trials.

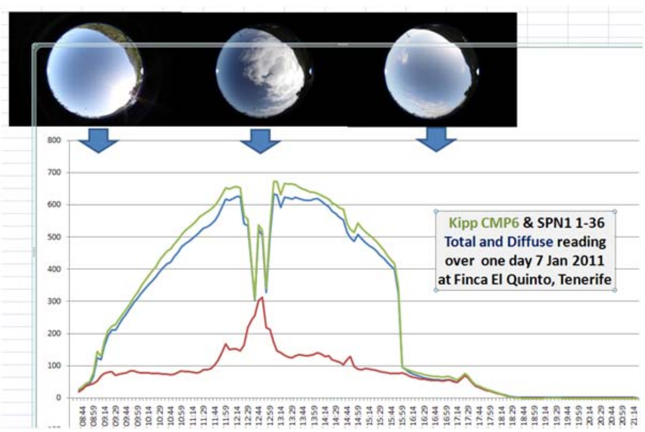



Figure 4: Total and Diffuse readings with corresponding sky photos taken with a fisheye lens, showing the effect of cloud at mid-day and of a mountain range at dawn and dusk. Data from Tenerife.

## What is sunshine status?

It tells you whether the sun was shining at a given point in time. This is roughly equivalent to when the sun is bright enough to cast a shadow. The reading is 1 or 0, that is, either ON or OFF.
More precisely:- the Sunshine status output indicates whether the energy in the direct beam exceeds the WMO standard threshold value of 120 $W.m^{-2}$, using an algorithm based on the Total radiation, and the ratio of Total to Diffuse radiation.

## Why is the SPN1 important?

It is used for

- Meteorological studies of Global, Direct and Diffuse solar radiation and sunshine duration measurements.
- Solar energy monitoring, and solar collector and solar photovoltaic research.
- Architecture and building design, illumination and heat balance studies of buildings and sports stadia.
- Automated solar thermal management of buildings.

## How does the SPN1 work?

It uses 7 sensors on a hexagonal grid covered by a perforated hemispherical dome, called a shadow mask. The shadow mask design is unique. Generated by computer, using a specially designed evolutionary algorithm, it ensures that:-

- at least one sensor is always exposed to the full solar beam
- at least one is completely shaded from the direct beam
- all sensors receive equal amounts of Diffuse light from the rest of the sky hemisphere.

## Advantages of the SPN1 design

The measurement of Direct and Diffuse solar radiation normally require two solar pyranometers plus a computer-controlled sun-tracking shade disk. The SPN1 can do this with no moving parts, and is consequently a lot cheaper and arguably more reliable. Being also much smaller, and lighter, and not needing to aligned North – it is easier to set up.
The response time is much faster - being less than 200 milliseconds, compared to up to 5 minutes for a standard thermopile solar pyranometer. In consequence, some customers have reported investigating the possibility of their use on moving cars, planes, and even buoys and boats. In such situations it is thought necessary to necessary to record the tilt and correct the data accordingly.

## What wavelengths are measured?

The SPN1 measures short wave radiation between 400nm and 2700nm in $W/m^2$.

## What units does it measure in?

Diffuse and Total solar radiation are both measured in Watts per square meter ($W/m^2$).
Sunshine status has no units. It is binary, one of two states, either there is sunshine, or there is not.
Sunshine hours are easily derived from sunshine status records once the logged data is saved to a spreadsheet.

## How do you get sunshine hours?

This is normally done by logging the sunshine status output data to a file, either on a data logger or directly onto a PC. The file is then imported into a spreadsheet. The sunshine hours is worked out by adding up the number of events with sun shining and dividing by the number of logging intervals in an hour.

Example
In one particular hour the sun came out 30 times. We were logging every minute, so there were 60 readings. During that hour, the amount of sunshine received was 30/60 = 0.5 sunshine hours.

## How do you obtain the Direct radiation?

The Direct beam component of solar radiation can be calculated from the Total minus the Diffuse component.

The Direct component is at a maximum when your detector is directly facing the sun. As you tilt the detector away from the sun it receives less energy. See also "What is Direct Normal Irradiance".

## How do you get kilowatt hours?

The SPN1 measures the *rate* at which radiation is received, in Watts per square metre ($W/m^2$). This is the energy received per second per square meter. With an SPN1 you would typically record this every minute or every five minutes using a PC or data logger. It is easy enough to turn this into kW hours once the data is imported into a spreadsheet. For instance if you measure $1000W/m^2$ continuously over a whole hour then after one hour you would have received 1 kW hour of energy.

## What is a cosine response and why should I care?

A perfect sensor would be perfectly black, absorbing all radiation on it, independent of its direction of tilt. One could imagine it might look like a black golf ball. In practice it is usually easier to design sensors (and some PV devices), with a flat detector surface. If this were perfectly black then its sensitivity to a direct beam of sunlight would vary as the cosine of the angle between the two.
The cosine response has become an industry standard against which the performance of solar sensors is commonly evaluated. The error in the cosine response of (horizontal) sensors tends to be worst when the sun is right on the horizon, which is unfortunate if you are particularly interested in the amount of radiation available at sunrise and sunset.

The SPN1 cosine error is less than 2% of the incoming radiation over 0 to 90 degrees.

## What are thermopiles?

Thermopile detectors are voltage-generating devices. The voltage is generated by the difference in temperature between two dissimilar metals, one in the sun and one in the dark. In many solar pyranometers these sensors are about the size of your fist.

SPN1 thermopile detectors are microscopic in comparison. They are hermetically sealed in a transistor-type package, purged with an inert gas, and heat-treated to ensure long-term stability.

These thermopile detectors act as a pure resistance and generate no 1/f or microphonic noise, only Johnson noise due to their resistance. They produce a linear output from $10^{-6}$ to 0.1 W/cm$^2$ of incident power. Designed with unique energy absorbing materials, they have an essentially flat spectral response over the spectral range of the SPN1, which is not limited at all by the thermopile design, but by other optical components specific to the SPN1 used to create a good cosine response.

## What is done to ensure the temperature coefficient is good enough?

Most thermopile pyranometers show a negative output during the night, due to radiative cooling of the earth into space. The construction of the SPN1 includes three separating elements between the atmosphere and the thermopiles, so this effect is minimal. The electronics within the SPN1 will only measure and output positive signals, so the output should never go below zero. In general, there will be a small positive output (<3W/m$^2$) in dark conditions, due to the effects of noise in the system.
The SPN1 is sensitive to fast changes in temperature, and these will create a positive error on cooling, or a negative error on warming. This may be visible if you move the sensor from a warm room into a cold atmosphere outside, until the sensor reaches ambient temperature.
The SPN1 temperature coefficient is ± 0.02% per °C (typically).

## Tilted SPN1: Why tilted?

Solar panel and photovoltaic researchers frequently mount their SPN1 in the same tilted plane as their solar panels so the SPN1 sees exactly what the panel sees, such as light reflected off the ground.

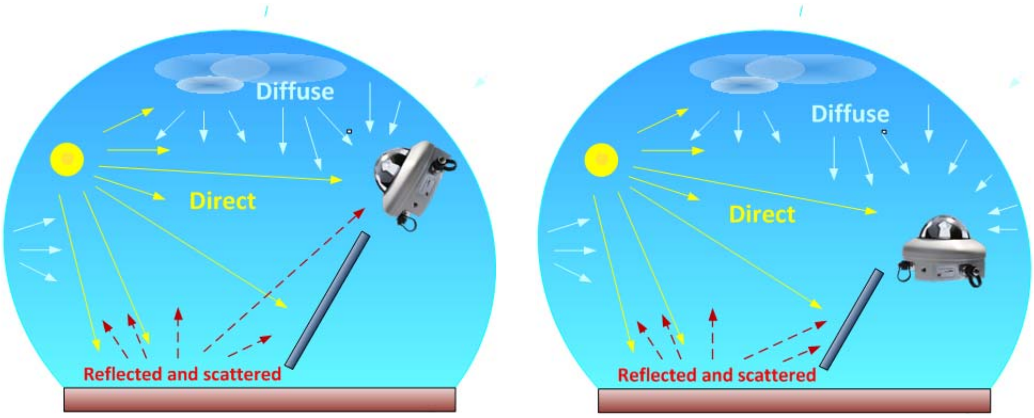



Figure 5: Schematic diagram illustrating the behaviour of a tilted and horizontal SPN1s. The SPN1 sees everything above its horizon. Tilting an SPN1 can be particularly useful for recording the same diffuse radiation as that received by a tilted photovoltaic panel (provided it does not see two suns – which may cause unreliable readings). A horizontal SPN1 can be useful for ease of calculating the DNI – Direct Normal Irradiance (if you don't have a sun tracking device).

## Tilted SPN1: What will it tell me?

A SPN1 tilted parallel to a solar panel will tell you exactly what the panel is seeing, including any solar radiation being reflected onto the panel from the ground.

Many solar panels do not track the sun; they are mounted at some fixed angle. In this case the calculation of the equivalent DNI (Direct Normal Incidence) radiation requires a computer.

## DNI: What is it?

Direct-Normal Irradiance (DNI) also called Direct-Normal Solar Irradiance (DNSI) is the energy in the solar spectrum incident in unit time at the Earth's surface on a unit area perpendicular to the direction to the Sun.

## DNI: Why needed?

This is an energy based method against which solar panels may be compared.

It is a common practice to compare solar panel efficiency to DNI. Maps of DNI are readily available and are often used to make a quick estimate the suitability of a particular site for solar power. One reason for this is that historical maps of DNI readings over several years are readily available in some countries (e.g. USA). In addition DNI maps at ground level can be calculated from satellite data with a suitable correction for travelling though the earth atmosphere.

The goal of accurately characterising the efficiency of a solar photovoltaic panel is of great interest to the solar photovoltaic industry. It is quite a complex subject - Wikipedia is a good place to start. Knowledge of the DNI at different sites is useful when making comparisons between field trials.

If a solar panel exactly tracks the sun (this requires two axes of movement) then it is common practice to compare its efficiency relative to Direct Normal Irradiance (DNI).

When comparing field trials from different locations the DN1 is not the whole story, because, of course, light does not just come directly from the sun but is scattered by the atmosphere and the ground. For tilted solar panels scatter from the ground can be a substantial additional source of solar power and the SPN1 is ideally placed to make these measurements.

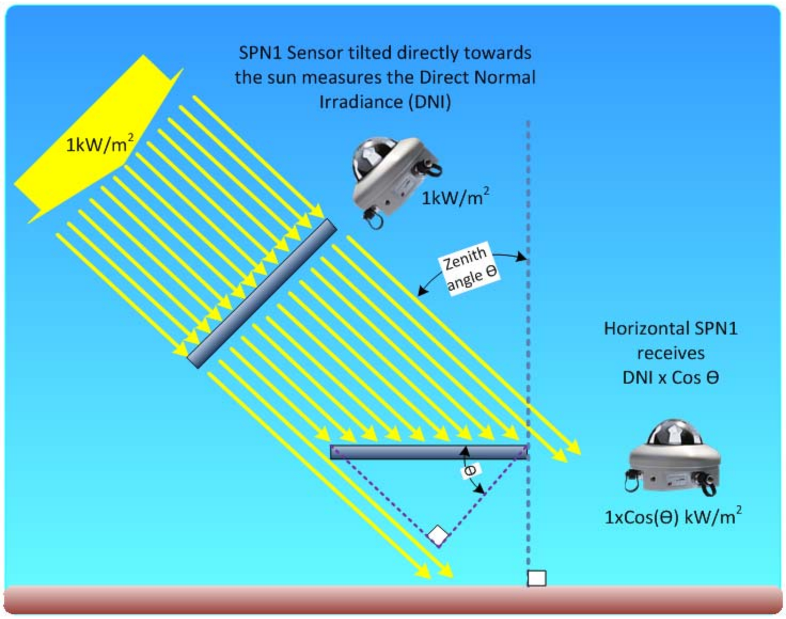
If you have an SPN1 attached to a 2 axis tracking system then the SPN1 Direct output gives you the DNI, but in addition the Diffuse output tells you the additional radiation being received, comprising both the light scattered from the sky and the clouds and from the ground.

## How do I calculate DNI if my SPN1 points directly at the sun?

The Direct Normal Irradiance is given by the equation:

DNI = Direct = Total(Global) –Diffuse.

## How do I calculate DNI if my SPN1 is horizontal?




DNI = (SPN1 Direct)/Cos Θ

Where:-

Θ = zenith angle
SPN1 Direct = SPN1 Total(Global) – SPN1 Diffuse.

We can provide an Excel spreadsheet add-in to calculate DNI from the output of a horizontally mounted SPN1.

The zenith angle is calculated for you by the add-in, or macro. In the spreadsheet function you need to enter the latitude and longitude, the local time, and the time difference relative to Greenwich Mean Time. It works out the zenith angle of the sun for that point in time.

## How do I calculate DNI if my SPN1 is tilted but not following the sun?

If your SPN1 is mounted parallel to your solar panel and the panel is tilted but not tracking the sun, then the maths is more complex. (It has a few more Sines and Cosines). We can provide an application note to tell your how to do the correction, but do not provide a computer program to do this.

Reference: **Use of BF3 Sunshine Sensor for Building Control** by John Wood 12/12/2002.
*(The BF3 was an earlier version of the BF5 Sunshine Sensor, which uses the same shadow mask technology).*

## Why do I get negative DNI values?

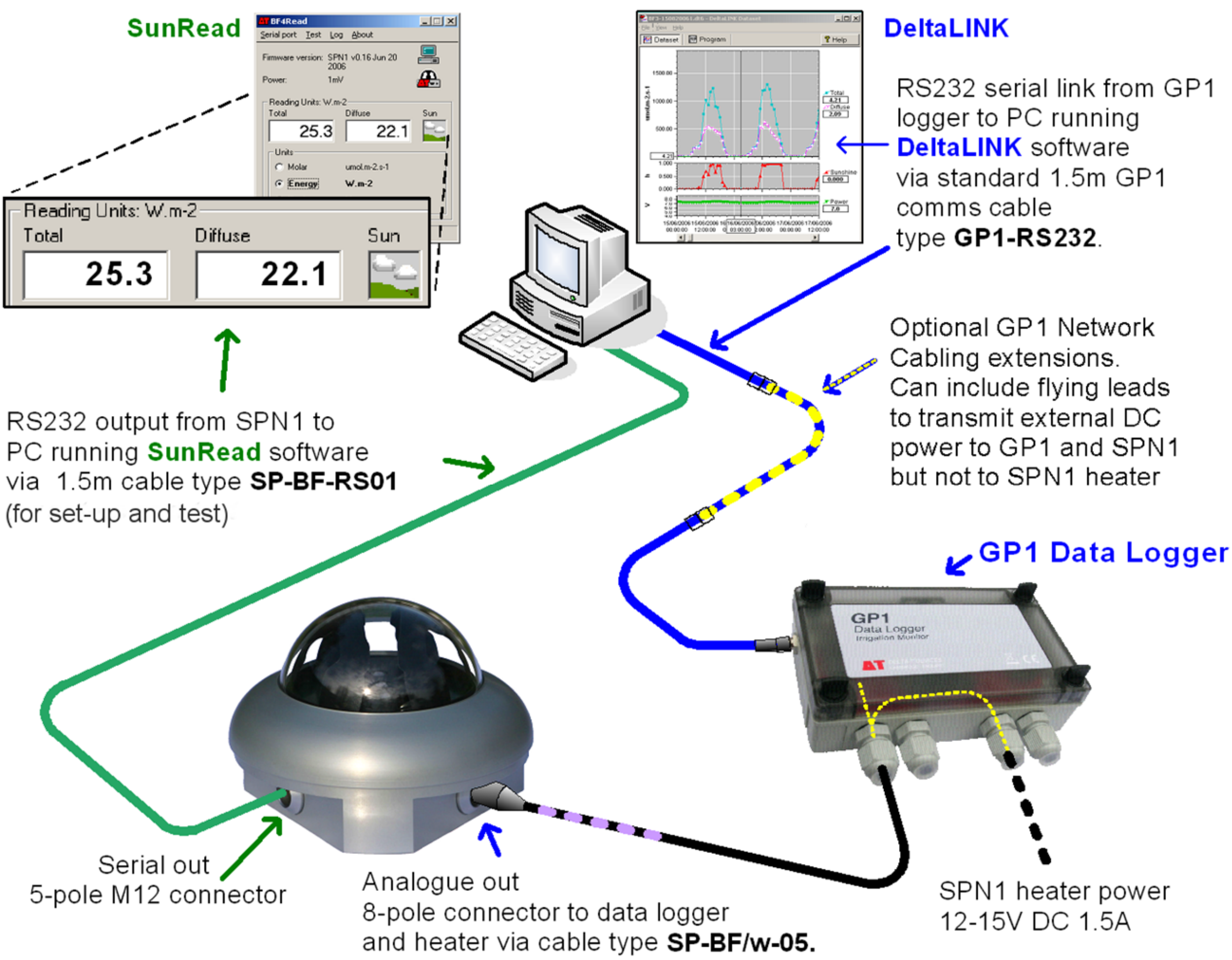
The SPN1 outputs always give the Global output greater than the Diffuse output, and so in the dark there will always be a small amount of noise on the outputs of a few W.m$^{-2}$ in the calculated Direct (horizontal) value. However, near sunset and sunrise, the solar zenith angle changes from <90° to >90°, which means the cosine of the zenith angle changes from a small positive value to a small negative value. When you calculate DNI = Direct / Cos(Zenith), the noise in the Direct value will give you a large positive and negative spike either side of sunset and sunrise.

The simplest way to avoid this is either to only calculate DNI when the Global radiation is greater than say 10W/m$^2$, or when the zenith angle is less than say 88°, and this will avoid all of these spikes around sunset.

To calculate the sums of your measurements in kWhr/(m$^2$.day), you just sum up all your readings for the day, and divide by the number of readings per hour, and divide again by 1000. So for example, where you log every 10 minutes (i.e. 6 readings per hour), just sum up all the values for the day (in W/m$^2$) and divide by 6000 to give kWhr/m$^2$.

## What does a complete SPN1 measurement system look like?

The readings from the SPN1 can be provided as an analogue signal, suitable for data loggers, or a digital, serial signal suitable for a computer or modem. The diagram below shows both options in use. The data ends up on your PC either way.  If you want real-time data suitable for say a building management system, then you would probably chose the serial output. If you are primarily recording data over a long period you might prefer to use the analogue output - connected to data logger – as these tend to be more reliable than a PC. We generally recommend you do not use both solutions simultaneously as some PCs can contribute a ground loop error to the analogue signal.



## SPN1 calibration

### Factory calibration

The SPN1 is calibrated at the factory against a transfer standard SPN1. Calibration is done before the shadow mask is fitted, so that all the thermopile sensors can be uniformly exposed. Units are calibrated in a 12 inch integrating sphere with a light source which approximately matches bright sunlight in intensity and spectral composition. The calibration factors required for each of the seven sensors are calculated and programmed into the SPN1. This matches the production unit to the reference, and spreads any cosine response variations evenly over the whole range of zenith angles.

The SPN1 is then checked against a second working standard.

After the shadow mask is fitted, the SPN1 reading is checked in the calibration lamp rig against a third working standard.

The working standards are routinely checked against two transfer standards which are themselves periodically recalibrated outside at Winster, UK, over a period of several weeks and a range of climatic conditions, against several higher standard references:-

- A primary standard SPN1
- A Kipp & Zonen CM21 pyranometer
- A tracking Kipp & Zonen CHP1 pyrheliometer
- A solar tracker and shading disk system using ventilated Kipp & Zonen CMP6 pyranometers

The CM21 and CHP1 are periodically recalibrated indoors at Kipp & Zonen against standards traceable to World Meteorology Organisation standards at Davos, Switzerland, see Figure 6.

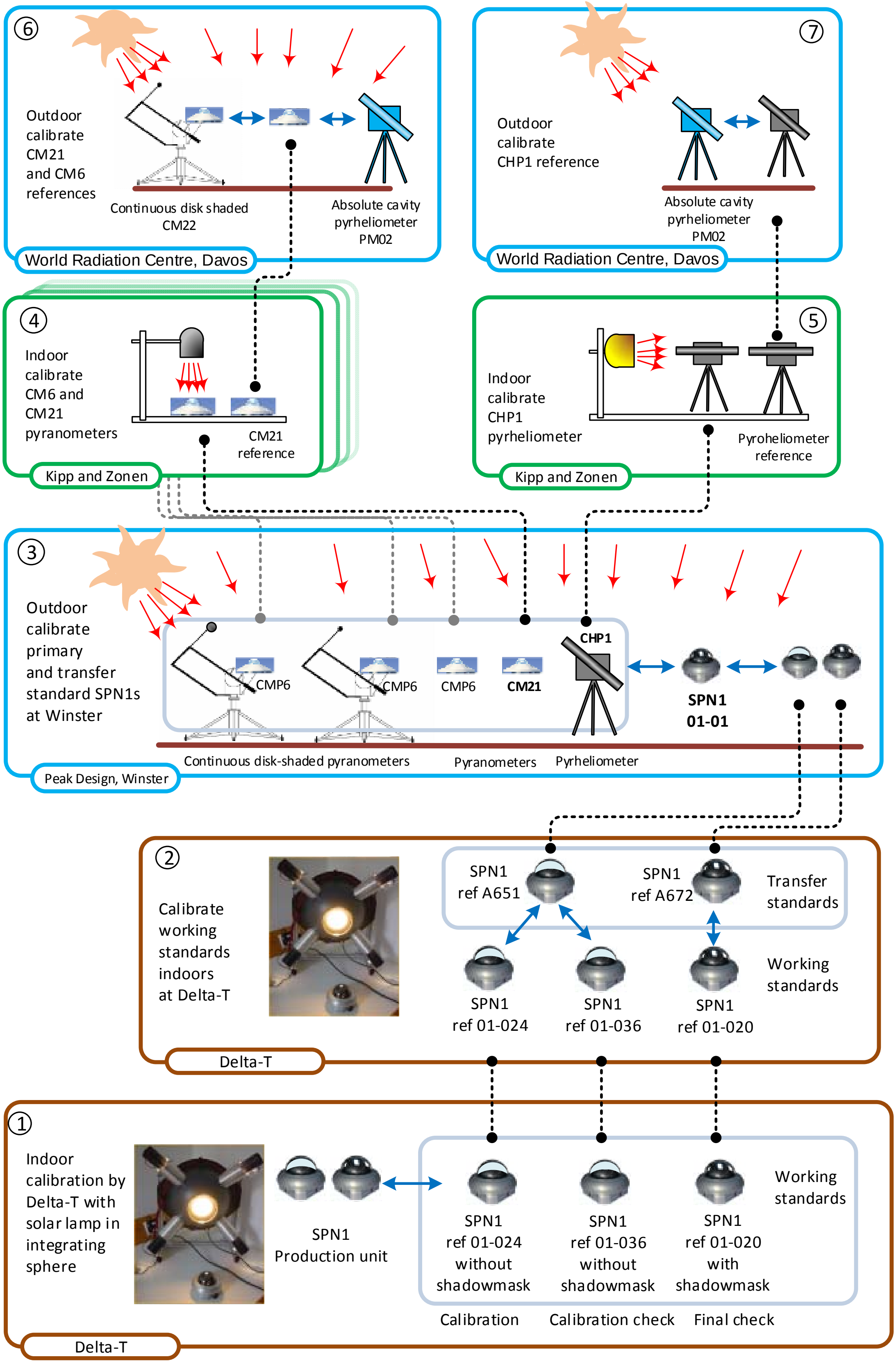



Figure 6 The SPN1 calibration chain

### Field re-calibration

It is possible, with care and attention to detail, for a user to recalibrate an SPN1 outdoors against a good quality solar pyranometer, given a suitable site with an adequate low horizon and a sun of sufficient intensity and which climbs high enough into the sky.

In the summer in the UK we routinely check laboratory calibrated batches of production unit SPN1s outdoors against one or more transfer standard SPN1s and one or more Kipp & Zonen CMP11 pyranometers - which are themselves periodically checked against a Kipp & Zonen CM21.

In our judgement the intensity and height of the winter sun in the UK (at 52 degrees North) is not suitable for calibration purposes - so we make occasional field trips to Tenerife in the Canary Isles where the winter sun exceeds 500 $W/m^2$.

At our test site in Tenerife the units under test are logged alongside one or more transfer standard SPN1 and Kipp & Zonen CMP6 pyranometers. They are all mounted horizontally using levelling mounts with bubble levels. The SPN1 heater power supply is provided by a high quality medical grade mains to DC power supply (with extra EMC protection supply and line-voltage stabilisation to minimise the effect of the local, poorly regulated, electrical mains noise and surges, and to minimise the possibility of earth-return current induced reading errors). Readings are taken every 5 seconds and averaged every 5 minutes for 10 to 15 days using a suitable battery powered data logger. The SPN1 and Kipp & Zonen glass domes are kept clean and free from raindrops as much as possible. Daily regressions of the SPN1 Total (Global) readings against the Kipp & Zonen readings are performed using a spreadsheet such as Microsoft Excel, from which the accuracy of the unit under test is determined.

### Why return to manufacturer for recalibration?

Our in-house recalibration procedure is described above under “Factory Calibration”. The procedure involves removing the shadow mask, which you should not try to do yourself, and recalibrating the gain amplifier of each of the seven individual thermopile sensors.
If you do a field calibration then you can only apply a single average correction to the whole unit and you will need to keep a record of this correction and apply it to each data set.

If you send the unit back to us then the recalibration information is actually applied and stored in the sensor.

## What quality standards apply?

The SPN1 matches or exceeds the ISO First Class standard and the WMO Good Quality standard for a solar pyranometer in all respects apart from the spectral response - which is accurate to ±10% over 0.4 to 2.7 µm.

## Comparison of SPN1 with WMO and ISO pyranometer standards

| | | ISO: Secondary Standard | ISO: First Class |  | |
|---|---|---|---|---|---|
| | | WMO: High Quality | WMO: Good Quality | SPN1 | Notes |
| **Response time** | ISO & WMO | < 15 s | < 30 s | 0.1 s | To 95% of final value (Actual response time is 100ms) |
| **Zero off-set** response: | ISO & WMO | 7 $W/m^2$ | 15 $W/m^2$ | <3 $W/m^2$ | To 200 $W/m^2$ net radiant loss to sky (ventilated) |
| **Zero off-set** response: | ISO & WMO | ±2 $W/m^2$ | ±4 $W/m^2$ | <3 $W/m^2$ | For 5°C/hr change in ambient temperature |
| **Resolution** | WMO | ±1 $W/m^2$ | ±5 $W/m^2$ | 0.6$W/m^2$ | Smallest detectable change |
| **Non-stability:** | ISO & WMO | ±0.8% | ±1.5% | <1.0% | Change in sensitivity per year |
| **Non-linearity:** | ISO & WMO | ±0.5% | ±1% | <1% | Deviation from sensitivity at 500 $W/m^2$ over 100 to 1000 $W/m^2$ range |
| **Directional response:** | ISO & WMO | ±10 $W/m^2$ | ±20 $W/m^2$ | ±20 $W/m^2$ | Error due to assuming that the normal incidence response at 1000 $W/m^2$ is valid for all directions |
| **Spectral selectivity** | ISO (0.35–1.5 µm)<br>WMO (0.30–3.0 µm) | ±3%<br>±2% | ±5%<br>±5% | ±10% (0.4-2.7 µm) | Deviation of the mathematical product of spectral absorptance and transmittance from the mean |
| **Temperature response:** | ISO & WMO | ±2% | ±4% | ±1% | Error due to 50°C ambient temperature change |
| **Tilt response:** | ISO & WMO | ±0.5% | ±2% | See note * | Deviation from horizontal responsivity due to tilt from horizontal to vertical at 1000 $W/m^2$ |
| **Achievable uncertainty:** | WMO hourly totals<br>WMO daily totals | 3%<br>2% | 8%<br>5% | 5% ±10$W/m^2$<br>5% | 95% confidence level |

* Believed to be <2%, not yet clearly measured.

# Notes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