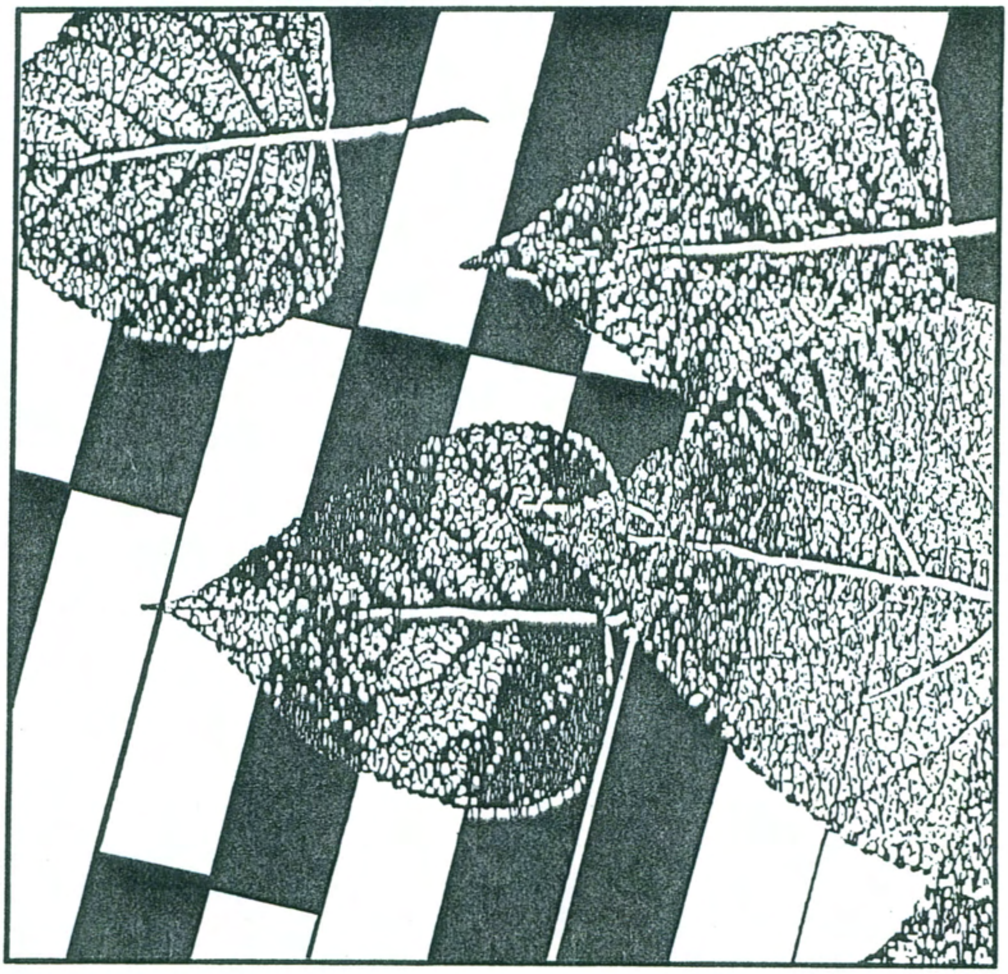
DELTA-T DEVICES

INSTRUMENTS FOR ENVIRONMENTAL AND INDUSTRIAL MEASUREMENT

Co-operatively owned and managed

Tube Solarimeter



User Manual

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TUBE SOLARIMETER
USER MANUAL

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Using this manual

This manual provides all the information necessary to correctly install, operate and maintain Tube Solarimeter types TSL and TSM. It should be read in conjunction with the Applications Note "Using Tube Solarimeters to Measure Radiation Intercepted by Crop Canopies and to Analyse Stand Growth" by J.L. Monteith, which provides additional detail on the installation and use of tube solarimeters.

Acknowledgements:

Developed in collaboration with **J.L. Monteith** formerly Professor of Environmental Physics at Nottingham University, England.

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1. Introduction

1.1 Function

Tube Solarimeters are designed to measure average irradiance (in kW m^{-2}) in situations where the distribution of radiant energy is not uniform. e.g. amongst foliage, in glasshouses etc. Their tubular construction provides the necessary spatial averaging, while minimising disturbance to the foliage of plants.

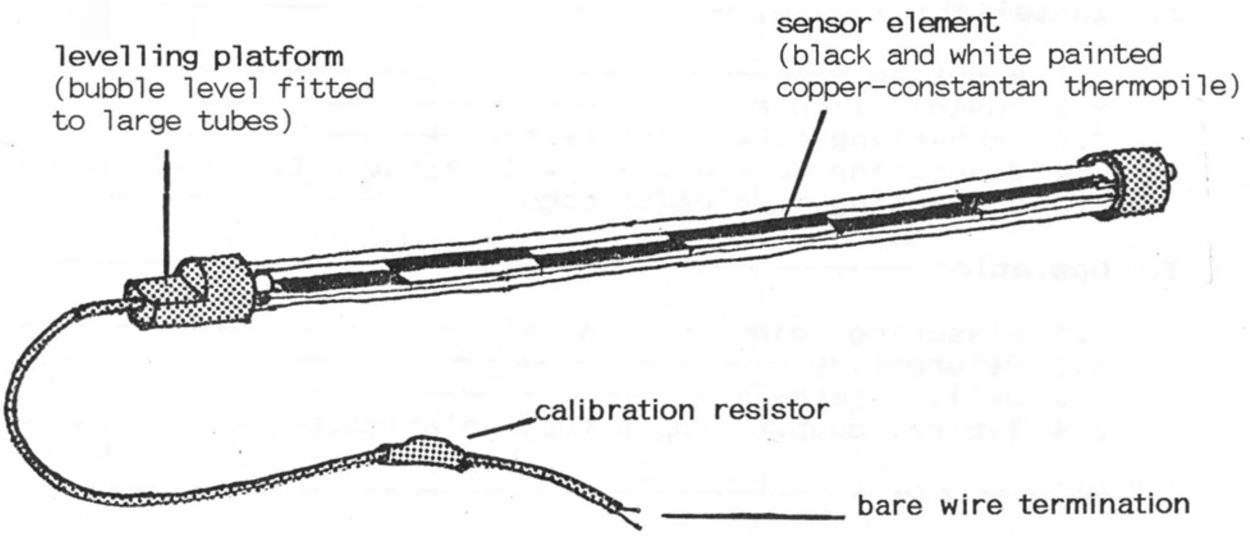

Fig 1. A Tube Solarimeter (diagrammatic)

1.2 Specification

Thermopile: Copper-constantan.
Tube: Pyrex borosilicate glass

	TSL	TSM
Overall Length	970mm	380mm
Tube Diameter	26mm	11mm
Element Size	858 x 22mm	320 x 8mm
No. of Junction Pairs	60	400
Typical Internal Resistance, ...	≈25 Ohms	≈70 Ohms
Approx. Response Time for 63% change	40 s	5 s
Approx. Response Time for 99% change	3 min	30 s

	TSL and TSM
Sensitivity (Diffuse Light)	15 mV/kW m^{-2}
Spectral Range (50% points).............	0.4 – 2.2 µm
Absolute Accuracy	±10% (solar spectrum,sun angle >30°relative to tube axis)
Operating temperature range.............	−30 to +60 °C.

1.3 Calibration

Tube Solarimeters are calibrated against a reference tube which is in turn calibrated outdoors regularly against a Kipp Solarimeter. The absolute accuracy of a tube solarimeter is limited mainly by the non-ideal spectral response (see fig 2.) and the directional sensitivity (see fig 3.). For interception studies (see Applications Note TSL-AN-4), when the output of the tubes are compared against each other, the relative errors will generally be less than ± 5%, significantly less than the typical sampling errors involved in such experiments.

1.4 Spectral response

The following graph shows the spectral response of tube solarimeters.

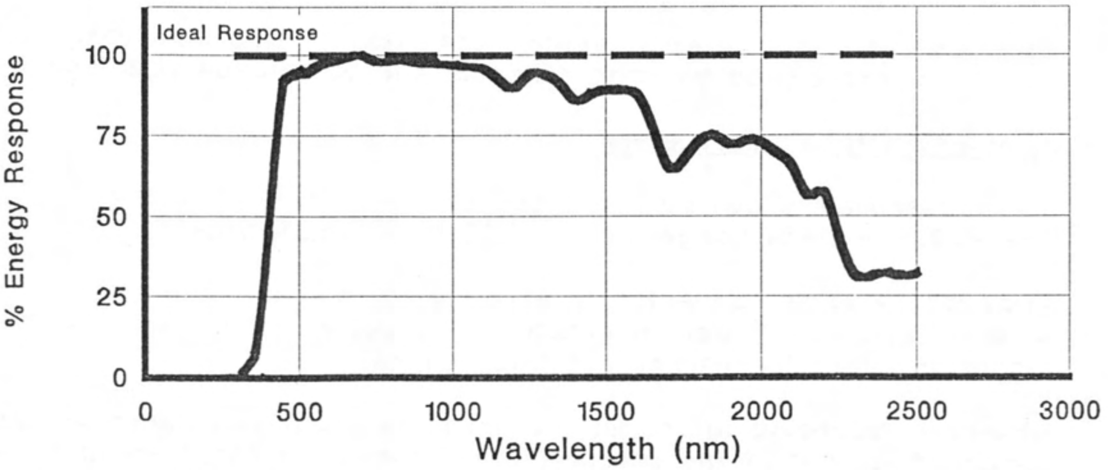

Fig 2. Spectral response of a Tube Solarimeter

1.5 Directional sensitivity

Tube solarimeters have a directional variation in sensitivity, due to their asymmetric shape. They have a slightly higher sensitivity when the solar beam is at right angles to the axis of the tube, and a lower sensitivity at glancing angles. For sun angles greater than 30° (relative to the tube axis) this variation in sensitivity is less than ± 3% (see ref 1). Errors due to directional sensitivity are minimised by orienting the tubes North-South if possible, and by making comparative measurements with parallel tubes.

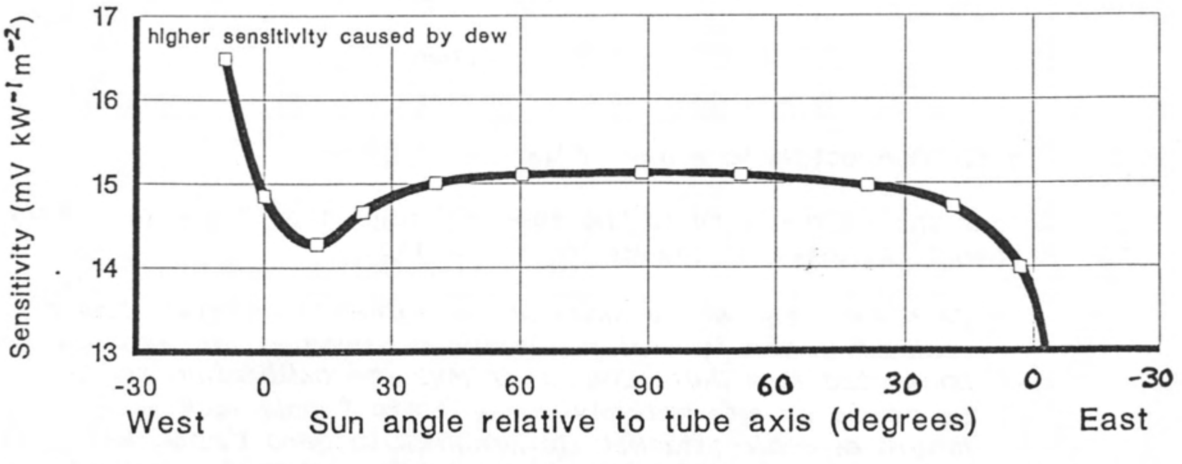

Fig 3. Typical variation in sensitivity of a Tube Solarimeter due to sun angle (long axis of Solarimeter mounted East - West)

2. Installation

2.1 Mounting

Tubes should be mounted horizontally (a levelling platform at one end facilitates this) and parallel to each other using the clips provided. An application note quantifying the errors caused by non-horizontal alignment can be obtained from Delta-T, (Applications note 1, Webb, 1986a).

2.2 Installation and Alignment

See chapter 4. of the Applications Note "Using Tube Solarimeters to measure radiation intercepted by crop canopies and to analyse stand growth".

2.3 Connecting tube solarimeters

Tube solarimeters can be connected to any Delta-T recording instruments, the MV2, the Delta Logger or the MVI (now discontinued).

They may also be connected to a voltmeter, for an instantaneous reading of solar irradiance, though in practice it is better to use an integrator or logger in order to average out fluctuations.

Whatever recording instrument is used, its input impedance should be large compared to that of the sensor (100 K ohms or greater would be suitable).

2.3.1 Jack plugs. Some customers, still using our earlier Millivolt Integrator Type MVI may need to attach a 3.5mm jack plug as follows:

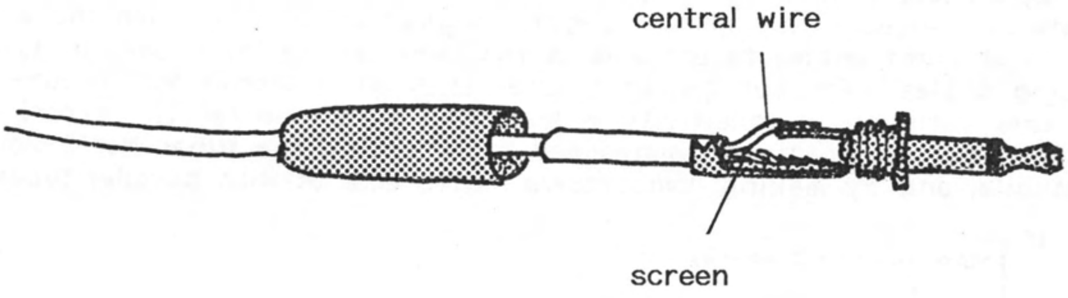

Fig 5. Connection to a Jack Plug.

Solder the central wire to the shorter, inner tag of the jack plug. The screen is soldered to the longer, outer tag.

> *CAUTION: Earlier versions of our Tube Solarimeters had a calibration resistor in the jack plug. If one of these earlier sensors is to be connected to a Delta Logger or MV2 the calibration resistor can either be moved or alternatively use a 3.5mm female jack socket with a short length of cable attached, terminating in bare tinned-wire ends. This option is easier, but is less desirable in that the jack plug and socket arrangement is not hermetically sealed.*

2.4 Connecting to a Microvolt Integrator type MV2

Follow this procedure to connect a tube solarimeter to an MV2 :

1. Open the MV2 case by loosening the four corner screws. Loosen the MV2 cable gland nut and insert the end of the cable.

2. Pass the cable through the cable gland and connect the central wire to the screw terminal marked "**VOLTAGE +**" and the screen to "**COMMON –**". Hook the cable under the white cable retainer clip tighten the cable gland and replace the lid. The MV2 is waterproof. The sensor cable is led through a waterproof cable gland to a screw terminal inside the housing of the MV2.

3. Set the mode switch to a convenient setting, this is a compromise between sensitivity and the maximum count the integrator can register. Mode 6 is recommended for daily integrals (see also the MV2 user manual section 2.5).

4. Ensure fresh batteries and silicon gel are installed.

5. Check the system is working properly by pressing the reset button next to the mode switch. This temporarily selects the most sensitive mode 4. The count rate is highest on mode 4, so this is a useful way of checking the counter and sensor are functioning.

   On releasing the reset button the mode returns to the value set by the mode switch, and the display resets to zero.

6. Reseal the case.

7. "Start" the integrator by resetting it to zero with the external magnet switch reset at the appropriate time. This could be at any time - a lot of people start at 9am.

8. Return at the same time each day, note the reading and reset the MV2.

   Longer or shorter integration periods may be used at the discretion of the user. It may be desirable to choose another mode switch setting, see section 2.5 of the MV2 user manual.

9. Convert the display counts to kJm^{-2}. In mode 6, 1 count = 0.666 kJm^{-2}. In other modes the conversion factor is calculated as follows:

$$1 \text{ count} = \frac{\text{sensitivity}}{0.015 \text{ V/kWm}^{-2}} = \frac{\text{sensitivity (in V sec)}}{0.015} \text{ kJm}^{-2},$$

   where the sensitivity is obtained from Table 1, in section 2.5 of the MV2 user manual.

2.5 Connecting to a Delta Logger

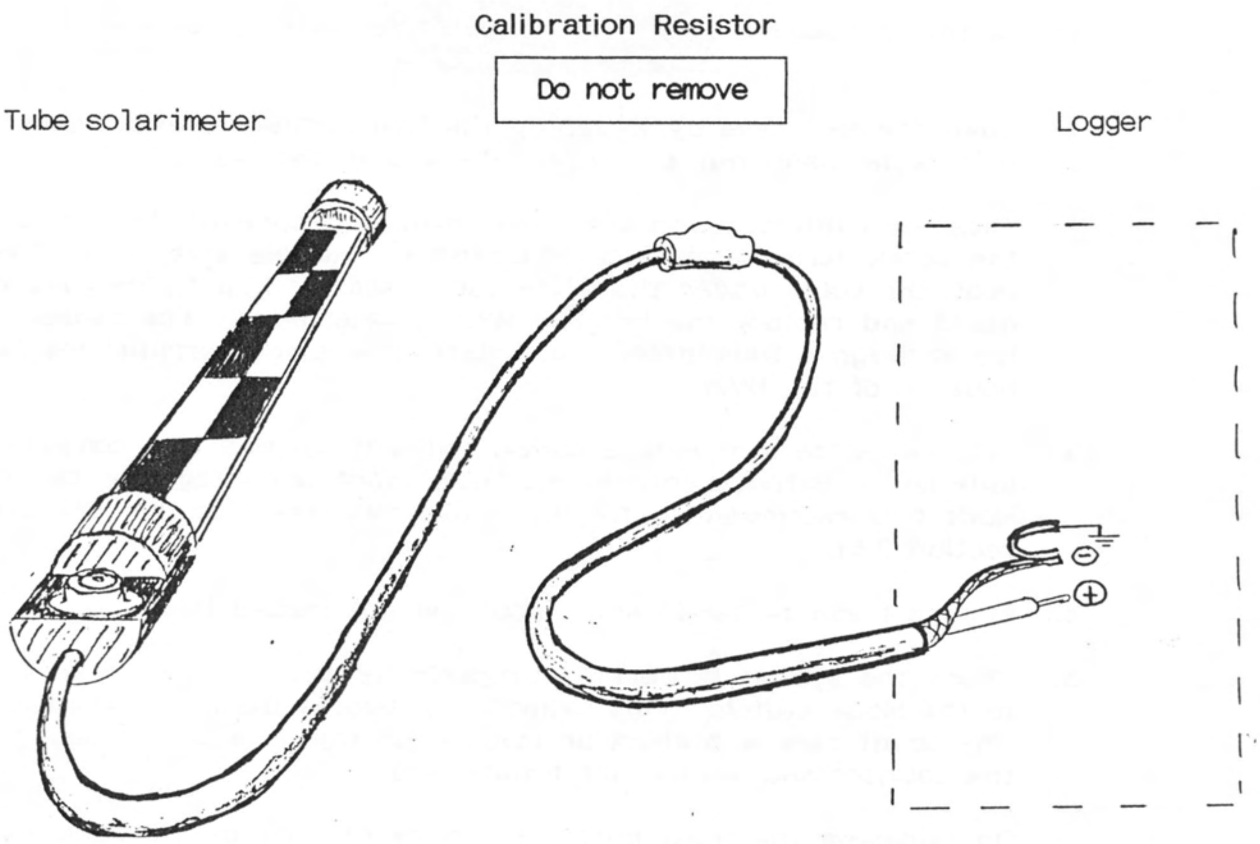

Fig 6. Connection to a Delta-Logger

2.5.1 Configuring a Delta Logger. In general there are three stages to configuring the logger:

1. Create a sensor library, using the Sensor Library Editor.

   The tube solarimeter is one of the standard types already programmed into the logger, so this step is omitted. Simply declare sensor type code "TSR" in the next stage.

2. Create a logging configuration, using the Logging Configuration Editor (i.e. decide which channel to connect the sensor to and how often you want to take readings).

3. Transfer (download) the configuration to the Delta Logger.

   The user should refer to the appropriate section of the Delta Logger user manual for further information.

3. Operation

Please refer to section 8. for an explanation of the terms and units used. Further applications are outlined in the Applications Note "Using Tube Solarimeters to Measure Radiation Intercepted by Crop Canopies and to Analyse Stand Growth" by J.L. Monteith.

3.1 Measuring solar irradiance

A tube solarimeter measures the total solar irradiance (0.35 - 2.5 µm) incident on its upper surface. The output is a voltage, with a conversion factor of 15 mV/kWm^{-2} under diffuse lighting conditions, i.e.

$$\text{Irradiance } (kWm^{-2}) = \frac{\text{measured voltage (mVolts)}}{15}$$

The maximum output in strong overhead sunlight (irradiance 1.1 kWm^{-2}) would be 16.5 mV.

3.2 Referencing

Tube solarimeters have a directional variation in sensitivity (see section 1.4), which may lead to unacceptable errors if **instantaneous** absolute values of irradiance are required. In that case, the actual sensitivity of the tubes at any time of day may be found by comparison of the output of one tube above the crop with the output of a dome solarimeter (or silicon cell energy sensor) placed next to it. If this tube gives a low relative output owing to a glancing sun angle, then any other tubes with the same alignment can be assumed to have a similarly low sensitivity.

> ***CAUTION:** When comparing the output of solarimeters with different response times in conditions of varying irradiance, it will be necessary to integrate over a suitable time period (e.g. 15 minutes).*

When measuring light transmission within a crop, the solar radiation may be in the form of sunflecks, to which the tubes will have a similar directional variation in sensitivity. To obtain the absolute value of solar irradiance transmitted through the crop, the upper tube should be referenced to a dome solarimeter (see also fig. 4).

> ***CAUTION:** Rain or dew on the tubes can alter the directional sensitivity and may lead to erroneously high readings. This would give inaccurate results when comparing the outputs from different solarimeters if the moisture on them was different.*

3.3 Daily integrals

The directional variation of sensitivity of a tube solarimeter tends to average out over a day and consequently daily integrals can usually be expected to have an error of less than ±2%. This error can be further reduced by recalibrating the tube solarimeter against a good standard dome solarimeter using daily integrals rather than "instantaneous" readings under diffuse light conditions.

As a result, you may be able to use either a dome solarimeter or a tube solarimeter for referencing when taking daily integrals, depending on the level of acceptable errors.

3.4 Typical output from a tube solarimeter

The output of a tube solarimeter over a 4 day period is shown in Fig. 7. The outputs of two other types of sensor are shown superimposed - from a Kipp solarimeter and a Delta-T type ES silicon cell energy sensor. The TSL tracked the other two sensors reasonably well. However, tube solarimeters are not designed to be used for absolute measurements, but rather for comparative measurements, one against another.

The daily integral is represented by the area under the curve for one day. Using a spreadsheet program this can easily be calculated by adding up all the averaged readings. Users with an MVI or MV2 integrator would obtain the integral directly.

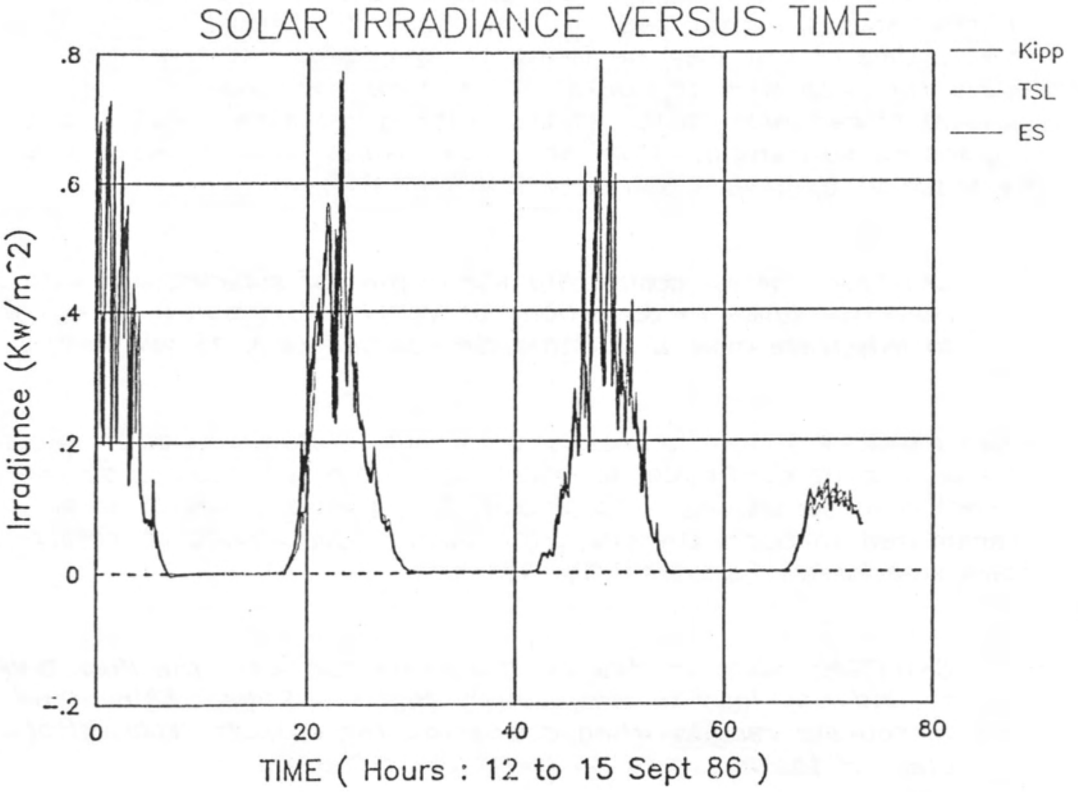

Fig. 7 Typical Output from a Tube Solarimeter

4. Maintenance

4.1 Routine maintenance

As far as possible keep the tube clean by an occasional wipe with a damp cloth or chamois leather.

4.2 Condensation

The tubes are supplied filled with dry air and sealed. However, even the minutest leak may eventually lead to condensation appearing in the tube. If this occurs, the flushing screws should be removed from each end and dry air blown through for 15 minutes, and then the ends resealed. A threaded tubing connector is supplied to facilitate this.

Purging kits can be supplied - see section 6 for details.

> ***CAUTION*** *Tube solarimeters should not be purged when in use - continuously purging with a significant flow of air would produce errors due to temperature differentials, and sensitivity changes due to disturbance of the convection patterns.*

4.3 Re-calibration

Tubes are supplied calibrated in diffuse light to a sensitivity of 15 mV/kW m^{-2}. The output of the tube has been preset by a shunt resistor fitted to the cable.

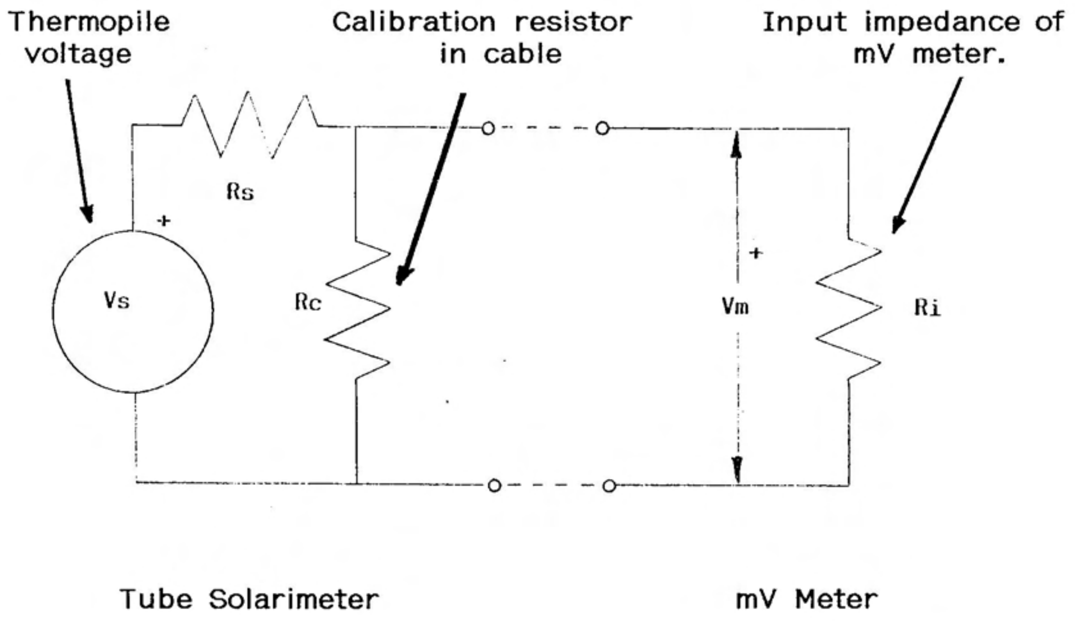

Fig 8. Resistance of element and cable.

Any re-calibration should be made under diffuse lighting conditions (e.g. under a cloudy sky - in summer in temperate zones) in comparison with a standard Solarimeter. If the irradiance is constant the mV outputs may be compared when steady. If the irradiance is varying, it is best to integrate the outputs over a period of time (say 15 min) to eliminate any effect due to differing response times of the Solarimeters.

Factory re-calibration can be carried out for a small charge.

4.4 Re-tensioning

If the element ever becomes slack, it can be tightened again by turning the tensioning screw (see section 5.3 below).

5. Construction

5.1 Sensor element construction

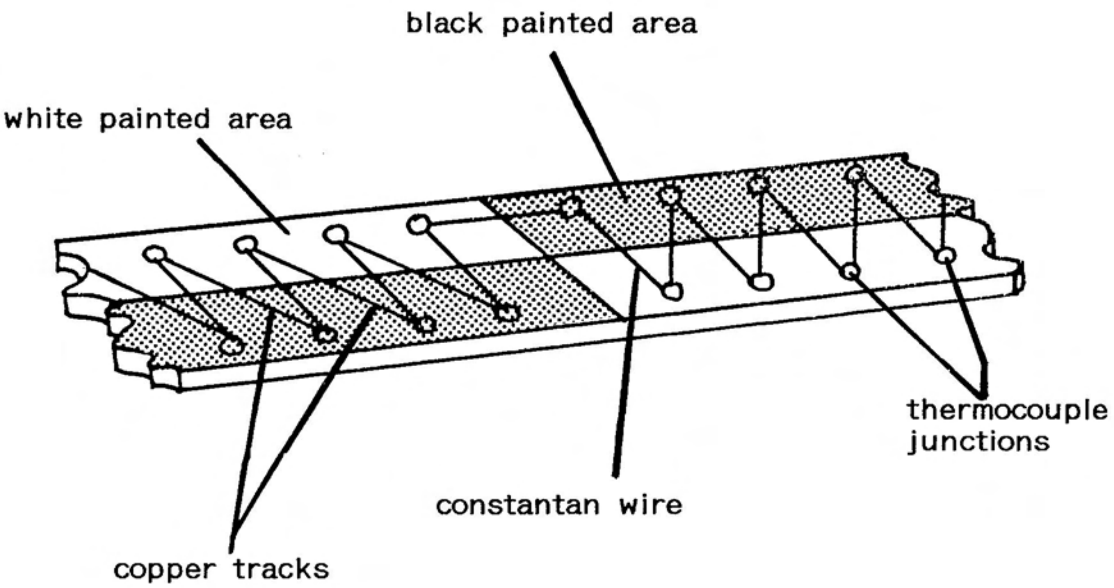

Fig. 9 Construction of a TSL element (TSM similar)

5.2 Principle of measurement

The incident energy flux results in a small temperature difference between the black and white areas, and this is turned into a voltage output by a copper-constantan thermopile. The black and white areas are alternated so that when radiation heats one side of the tube more than the other, the mean temperature difference between black and white surfaces is not affected.

The element is protected by a Pyrex glass envelope which limits the response to visible and infra-red radiation in the waveband 0.35 - 2.5 µm.

Delta-T Solarimeters are all calibrated with a shunt resistor to give an output of 15 mV/kWm^{-2} irradiance in diffuse light.

5.3 Dismantling and reassembling large tubes

***NOTE:** Miniature tube solarimeters, type TSM, cannot be dismantled.*

5.3.1 Dismantling. The MK II Large Tube Solarimeter as illustrated can be dismantled if necessary:

1. Slacken and remove the tensioning screw.
2. Loosen the end plugs by twisting. Heat them **cautiously** if they do not free easily. Prise off the tensioning end plug, separating it from the element puller.
3. Withdraw the element, attached to the bubble end plug. If required the element can be separated by removing the two pins.

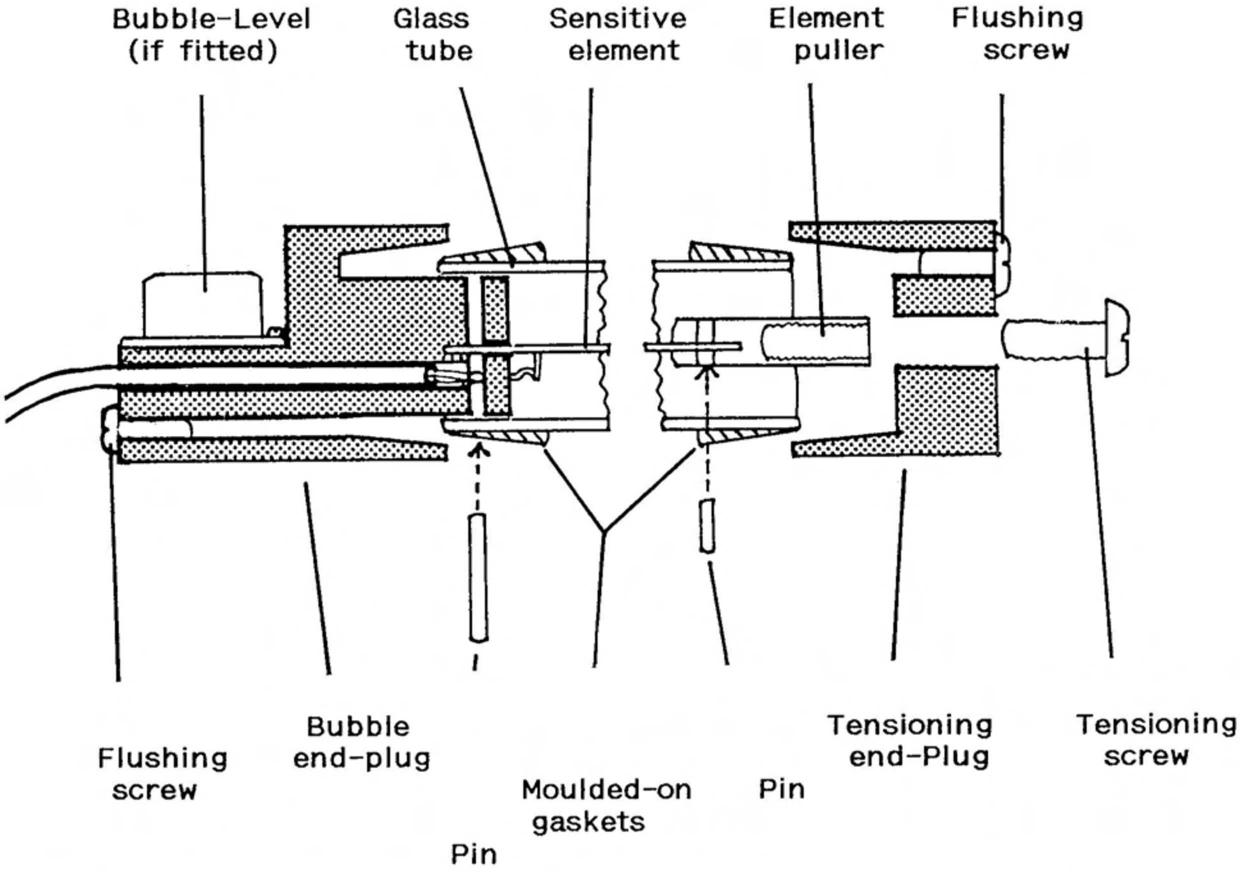

Fig. 10 Section through a Large Tube Solarimeter (diagrammatic)

5.3.2 <u>Re-assembly</u>. This is the procedure for re-assembly:

1. If necessary attach the element to the bubble end-plug and the element puller with the pins. If it is not connected, solder the cable to the pins on the element underside - the red wire to the pin furthest from the cable hole in the plug.

2. Clean the inside of the tube by pulling through a soft cloth. Brush off any dust on the element.

3. Grease the gaskets moulded on the ends of the tubes.

4. Insert the element, brushing off any dust while proceeding. Push home the bubble end-plug.

5. Engage the tensioning end plug, flushing screw uppermost, so that the hexagonal hole in the plug fits the hexagonal element puller.

6. Insert the tensioning screw and start to tighten. Before the element is fully tensioned, look through the flushing screw hole in the tensioning end plug and turn the plug to correct any twist in the element. Do not overtighten, but apply sufficient tension so that the centre of the element doesn't flap about when the tube is tapped.

7. Flush the tube with dry air as described in section 4.2 above.

6. Accessories

The following accessories are available, either from our local agent or from Delta-T Devices direct.

1. Spare glass tube for large Tube Solarimeters.

2. Dry air purging kit consisting of:
   Pump type: 240 V AC or 110 V AC or 12 V DC (please specify).
   Drying chamber containing self indicating silica gel.
   PVC airline connector.
   500g jar of silica gel.

3. Spare copies of this manual.

4. Copies of application notes (see section 7)

7. References and application notes

References

1. *Szeicz G., Monteith J.L., & dos Santos J. (1964)*
   A Tube Solarimeter to measure radiation among plants.
   J. Appl. Ecol.1 169-174

2. *Green G.C.F., & Deuchar C.N. (1985)*
   On Improved Tube Solarimeter Construction.
   Jnl. Exp. Bot. Vol 36, No 165, 690-693

3. *Russell G., Jarvis P.G., & Monteith J.L. (1988)*
   *Absorption of solar radiation and stand growth. In "**Plant Canopies: Their Growth, Form and Function**", Eds. Russell G., Jarvis P.G., & Marshall B., Publ. Cambridge University Press, pp 21-39.*

Delta-T application notes

1. *N. Webb (1986 a)*
   The effect of small deviations from horizontal on the solar irradiance incident upon a flat plate Solarimeter tube.
   Pub. Delta-T Devices.

2. *J. L. Monteith (1993)*
   Using Tube Solarimeters to measure radiation intercepted by crop canopies and to analyse stand growth.
   Pub. Delta-T Devices, document code TSL-AN-4-1

8. Radiation terms and units

Radiant Flux

The rate of propagation of radiant energy through space. Units are Watts. In this manual we have generally used the term **Energy Flux** to help distinguish between this and the corresponding quantum flux.

Radiant Flux Density

Net radiant flux through unit area perpendicular to that area ($W\ m^{-2}$).

Irradiance

The radiant energy flux incident on unit surface area. Units are in Watts per square meter ($W\ m^{-2}$).

Total Solar Irradiance

Irradiance in the waveband 0.3 - 3.0 µm. (units $W\ m^{-2}$). Tube Solarimeters measure irradiance in the waveband 0.35 - 2.5 µm, effectively the same. Sometimes called global solar radiation.

Photosynthetically Active Radiation (PAR)

Radiation in the waveband 0.4 - 0.7 µm. (a dimensionless description of part of the spectrum). PAR irradiance is therefore irradiance in this waveband - this quantity is also occasionally called photosynthetic irradiance, and quite commonly and confusingly called just PAR.

Quantum Flux

The rate of propagation of photons through space. More correctly called **Photon Flux,** but the sensors are always called quantum sensors! Units are moles per second ($mol\ s^{-1}$).

Quantum Flux Density

The net quantum flux passing through unit area perpendicular to that area ($mol\ m^{-2}\ s^{-1}$).

Quantum Irradiance

The number of photons incident on a surface of unit area in unit time. Units are $mol\ m^{-2}\ s^{-1}$.

Canopy Transmittance

The fractional transmission of radiation through the canopy, i.e. the ratio of the average flux density below the canopy to the corresponding value above. A dimensionless quantity. Since the rate of transmission is not the same for all wavelengths, it should normally be stated whether the transmittance is being derived for PAR or total solar radiation, and for quantum flux or energy flux.

Absorptance, Reflectance, and **Interceptance** are similarly defined. Note that the **efficiency**, e, is sometimes expressed in terms of interceptance and sometimes in terms of absorptance.

Solarimeter/Pyranometer

Terms used interchangeably for instruments which measure solar irradiance.

9. Service and Guarantee

9.1 Servicing

We recognise that some users of our instruments may not have easy access to technically specialised backup.

Should it be necessary, instruments may be returned to our works for servicing. We normally expect to complete repairs of our instruments within two days of receiving the equipment.

Users of our equipment in countries which have a Delta-T agent or Technical Advisor should contact them in the first instance.

9.2 Guarantee conditions

Instruments manufactured by Delta-T are guaranteed for one year against defects in manufacture or materials used. The guarantee does not cover damage through misuse or inexpert servicing, or other circumstances beyond our control.

For the UK this means that no charges are made for labour, materials or return carriage for guarantee repairs.

For other countries, the guarantee covers free exchange of faulty parts during the guarantee period.

Alternatively, if the equipment is returned to us for repair under guarantee, we make no charge for labour or materials but we do charge for carriage and UK customs clearance.

We strongly prefer to have such repairs discussed with us first, and if we agree that the equipment does need to be returned, we may at our discretion, waive these charges.