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How to measure albedo

v1707

Subjects

- PV system performance monitoring
- the performance model
- standards and instruments
- recommendations

Introduction

- Hukseflux Thermal Sensors (NLD)
  - leading manufacturer of pyranometers and albedometers
- GroundWork Renewables (USA)
  - leader in providing meteorological and soiling data to the PV industry
  - experienced in deploying albedo monitoring systems
- Measurement to the next level

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Definitions

- Measurements
  - Global Horizontal Irradiance (GHI)
  - Plane of Array irradiance (POA)
  - Reflected Horizontal Irradiance (RHI)
  - Reflected in Plane of Array (RPOA)
  - Albedo = RHI/GHI
- Resource Assessment: pre-construction
- Performance Monitoring: operational

Pre-construction

Operational PV monitoring

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Work in progress ..

the PV industry is learning

- how to perform albedo measurements
- how to use albedo data as input to the performance model
- how to perform uncertainty evaluation

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Measurement challenges

- spatial variability (location, array shading)
- seasonal variability (vegetation, snow)
- difficult to find one representative location for RHI or RPOA

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Operational: classic POA+GHI

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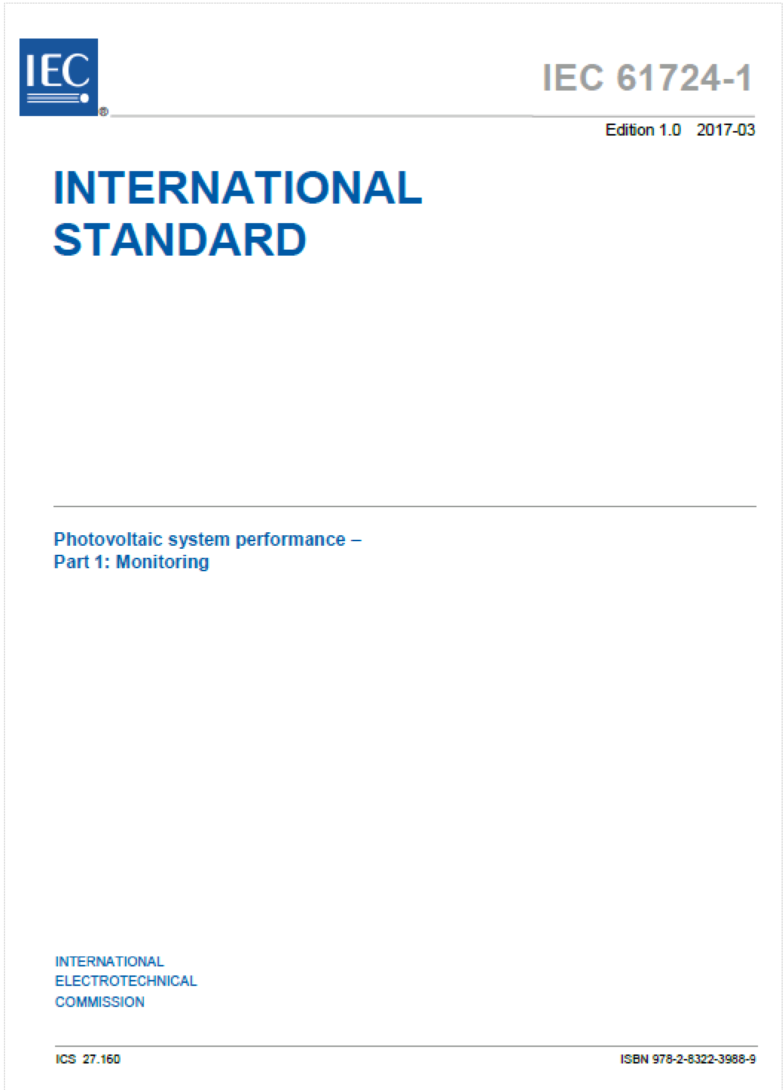
IEC group of standards


IEC 61724-1

Edition 1.0 2017-03

INTERNATIONAL STANDARD

Photovoltaic system performance –
Part 1: Monitoring

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 27.160 ISBN 978-2-8322-3988-9

- 61724-1, 2, 3
- **-1 monitoring**
- **-2 system capacity evaluation** (2 sunny days)
- **-3 system energy evaluation** (1 year, all condictions)

IEC definition

performance model a mathematical description of the electrical output of the PV system as a function of meteorological conditions, the system components, and the system design. This model is agreed upon in advance by the stakeholders of the test.

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purposes of monitoring

- localization of faults in a PV system
- identification of performance trends
- comparison of performance to design expectations and guarantees

- last 2 use the performance model

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Why & how to measure albedo

- end result of test: performance ratio or index with an uncertainty

- Step 1: what does the performance model requires as input
- Step 2 : what do you need for specific purposes (reducing uncertainty)

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IEC 61741-1: classes

indicator such as a flag; returning to the sensor, sight along a square edge of the sensor mounting plate while adjusting the mounting plate azimuthal angle until the sight line intersects the marker previously placed with the aid of the GPS receiver; tighten the mounting plate's azimuth adjustment when done.

7.2.1.7 Sensor maintenance

Irradiance sensor maintenance requirements are listed in Table 7.

Table 7 – Irradiance sensor maintenance requirements

Item	Class A High accuracy	Class B Medium accuracy	Class C Basic accuracy
Recalibration	Once per year	Once every 2 years	As per manufacturer's requirements
Cleaning	At least once per week	Optional	
Heating to prevent accumulation of condensation and/or frozen precipitation	Required in locations where condensation and/or frozen precipitation would affect measurements on more than 7 days per year	Required in locations where condensation and/or frozen precipitation would affect measurements on more than 14 days per year	
Ventilation (for thermopile pyranometers)	Required	Optional	
Desiccant inspection and replacement (for thermopile pyranometers)	As per manufacturer's requirements	As per manufacturer's requirements	As per manufacturer's requirements

Recalibration of sensors and signal-conditioning electronics should be performed on site when possible to minimize the time that sensors are offline. If sensors are to be sent off-site for laboratory recalibration, the site should be designed with redundant sensors or else backup sensors should be used to replace those taken offline, in order to prevent interruption of monitoring.

Cleaning of irradiance sensors without cleaning the modules can result in a lowering of the measured PV system performance ratio (defined in 10.3.1). In some cases contract requirements may specify that irradiance sensors are to be maintained in the same state of cleanliness as the modules.

Night-time data should be checked to ensure accurate zero-point calibration.

NOTE It is common for pyranometers to show a small negative signal, $-1\ W{\cdot}m^{-2}$ to $-3\ W{\cdot}m^{-2}$, at night time.

7.2.1.8 Additional measurements

7.2.1.8.1 Direct normal irradiance

Direct normal irradiance (*DNI*) is measured with a pyrheliometer on a two-axis tracking stage which automatically tracks the sun.

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IEC 61724-1

- defines 3 monitoring system classes: A, B and C
- utility-scale: Class A
- specifies requirements for:
  - instrument type
  - cleaning intervals
  - calibration intervals

Typical Class A system

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IEC 61724-1 Class A Systems

- Ventilated and heated, secondary-standard pyranometers:
  - Plane of Array (POA)
  - Global Horizontal Irradiance (GHI)
- Wind, panel temperature, air temperature, electrical parameters
- Calibration interval of 2 years
- Cleaning interval of 1 week

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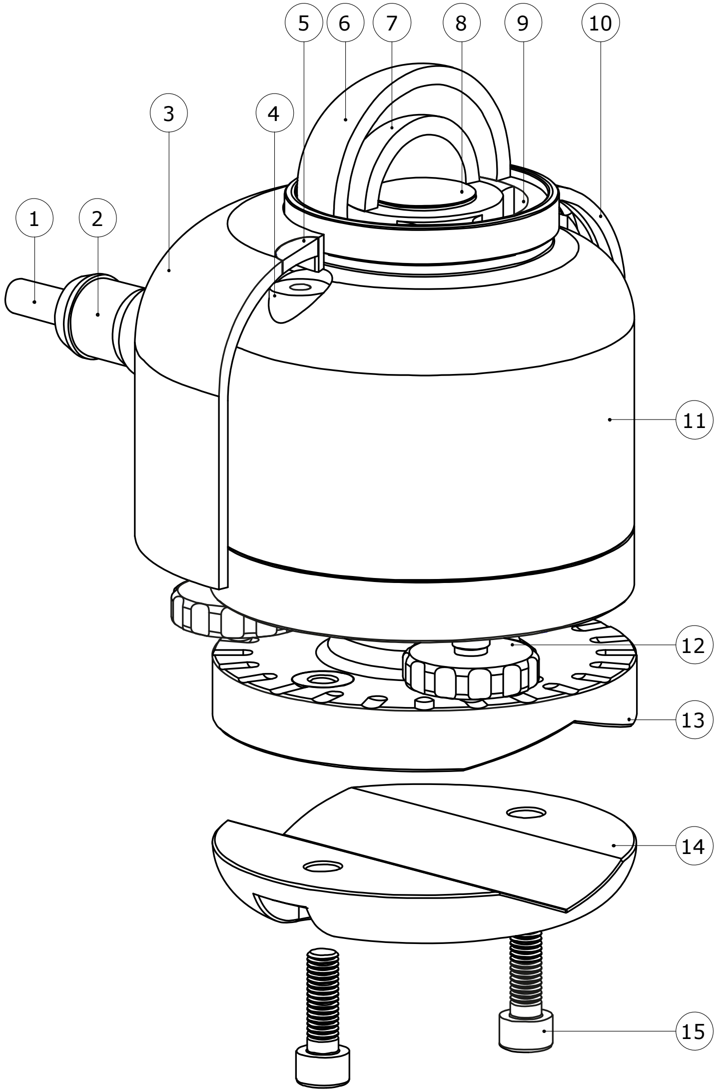
IEC 61724-1 class B, C

- you expect albedo on Class A systems, not class B or C

what is a pyranometer?



- glass domes
- thermal sensor
- calibration + test reports
- includes: heating and tilt sensor

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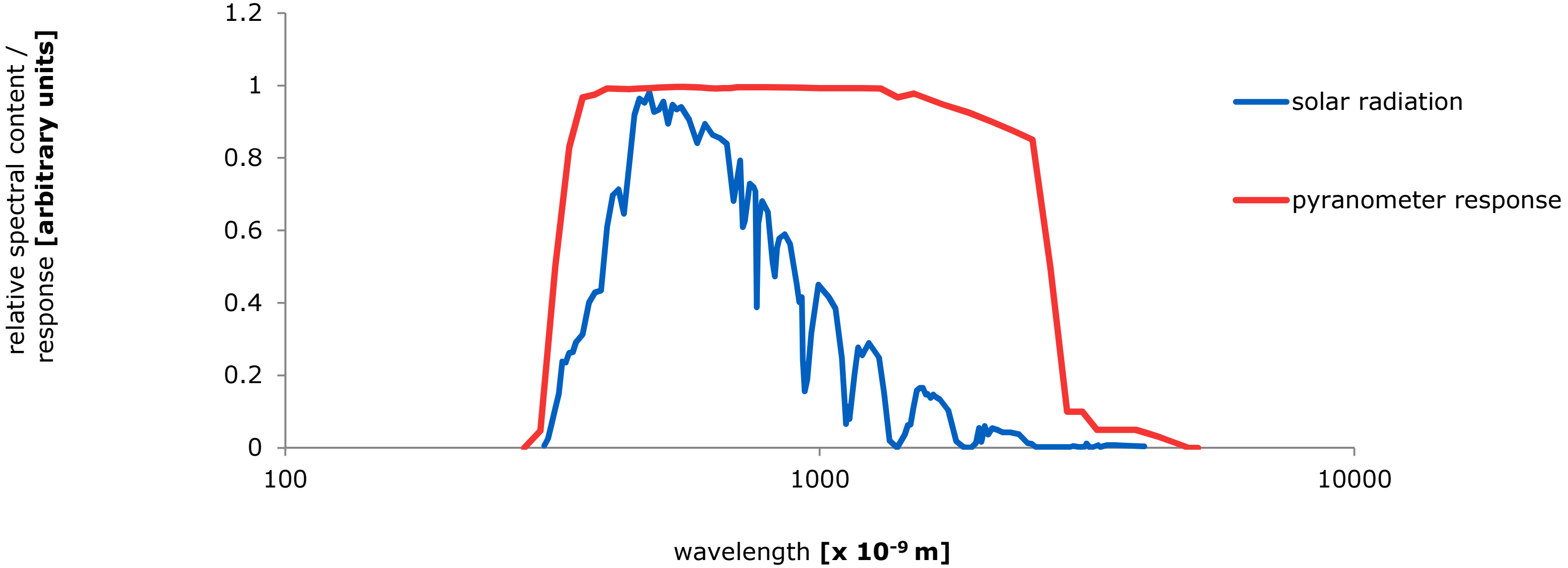
What is a pyranometer

- de-facto standard in PV monitoring
- measures solar irradiance in W/m^2
- maximum yield, independent of panel type
- characterised (perfect) directional-, temperature response

spectrally flat



spectral response (red line)

- suitable for GHI, POA, RHI, RPOA
- reference for all PV cell types

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Alternative: PV reference cell

De afbeelding kan momenteel niet worden weergegeven.

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Alternative: PV reference cell

- measures solar irradiance as used for power generation by PV panel
- must “match” PV panel of the power plant; cell type & AR coating
- not suitable for GHI (flat shape + directional response)

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Pyranometer versus refence cell

- IEC 61724-1:2017 allows both
- IEA PV Power Systems Programme "*Good Practices for Monitoring and Performance Analysis*" recommends use of pyranometers only (Report IEA-PVPS T13-03: 2014)

ISO 9060: pyranometer classes

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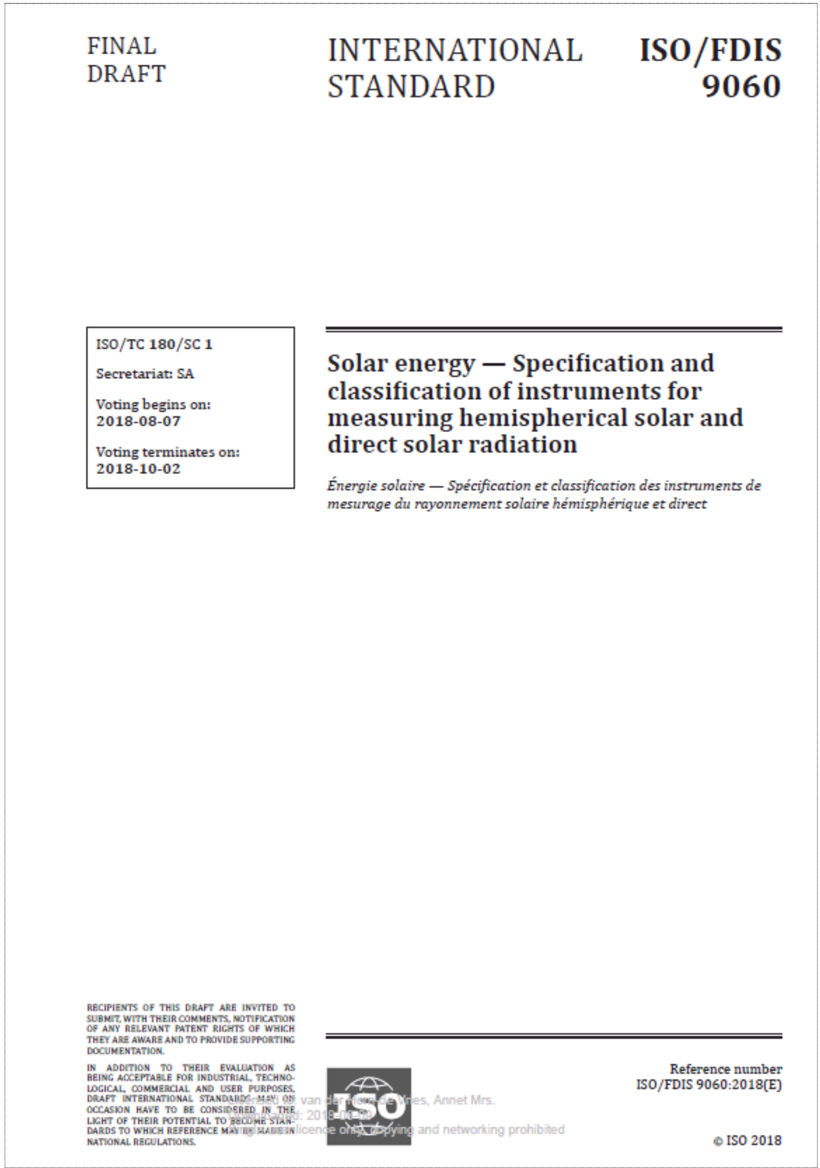

FINAL
DRAFT

INTERNATIONAL
STANDARD

ISO/FDIS
9060

ISO/TC 180/SC 1

Secretariat: SA

Voting begins on:
2018-08-07

Voting terminates on:
2018-10-02

Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation

Énergie solaire — Spécification et classification des instruments de mesurage du rayonnement solaire hémisphérique et direct

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Reference number
ISO/FDIS 9060:2018(E)

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Pyranometer classes

- class A: Heated & Ventilated
  SR30

- class B: SR15

- class C: SR05

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ISO to IEC connection

IEC monitoring class	A	B	C
ISO 9060:1990 pyranometer class	secondary standard	first class	second class
ISO 9060:2018 pyranometer class	spectrally flat class A	spectrally flat class B	spectrally flat class C or none
heating	yes	yes	no
ventilation	yes	yes	no
calibration	1 yr / 2 yr following manufacturer recommendation	2 yr or manufacturer recommendation	
cleaning	1 wk	2 wk	

Class A: heated instruments

IEC: starts with POA

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Traditional albedo

- with one-sided PV panels: outside of scope performance model
- albedo usually not measured

- with bifacial PV this changes:

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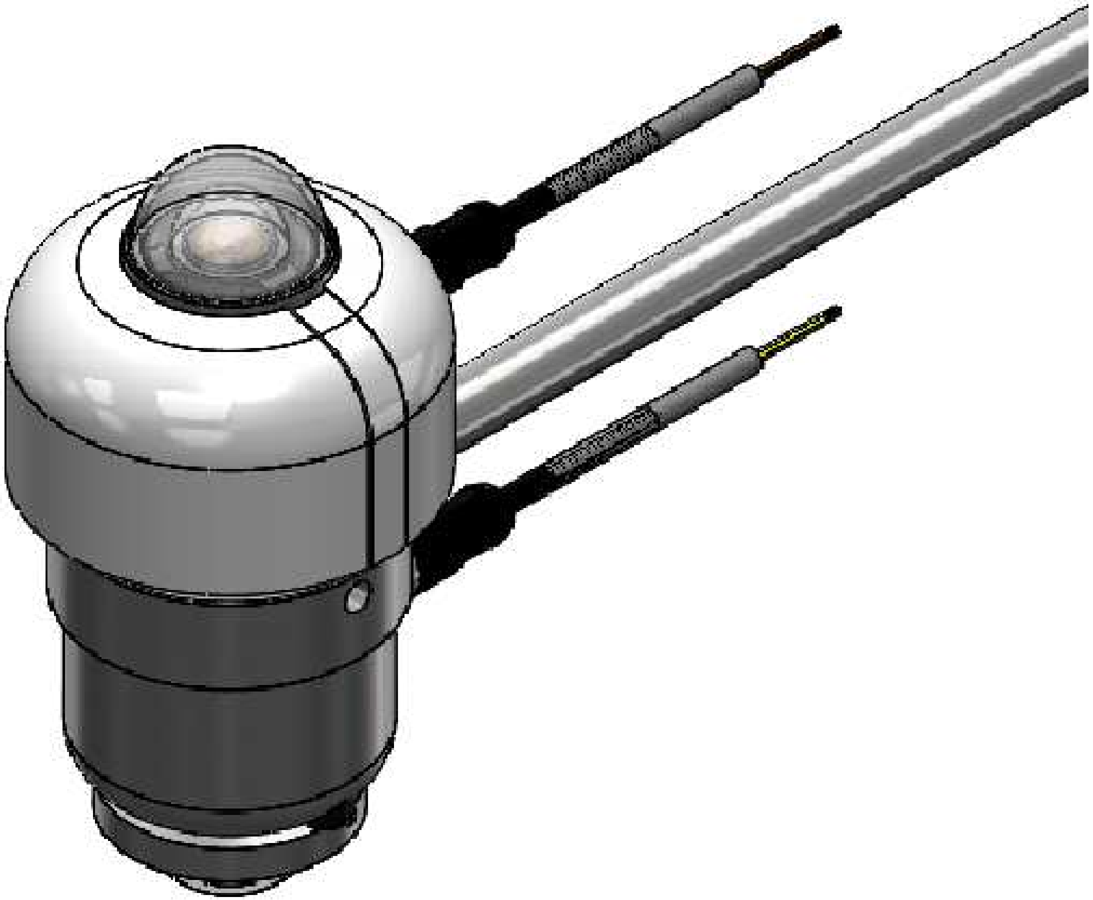
IEC guidance for albedo

- apply IEC 61724-3, clause 5
- for each POA:
  - measurement of the local albedo to *demonstrate consistency with what is assumed in the model*
  - include in *documentation of uncertainty*

Albedometer



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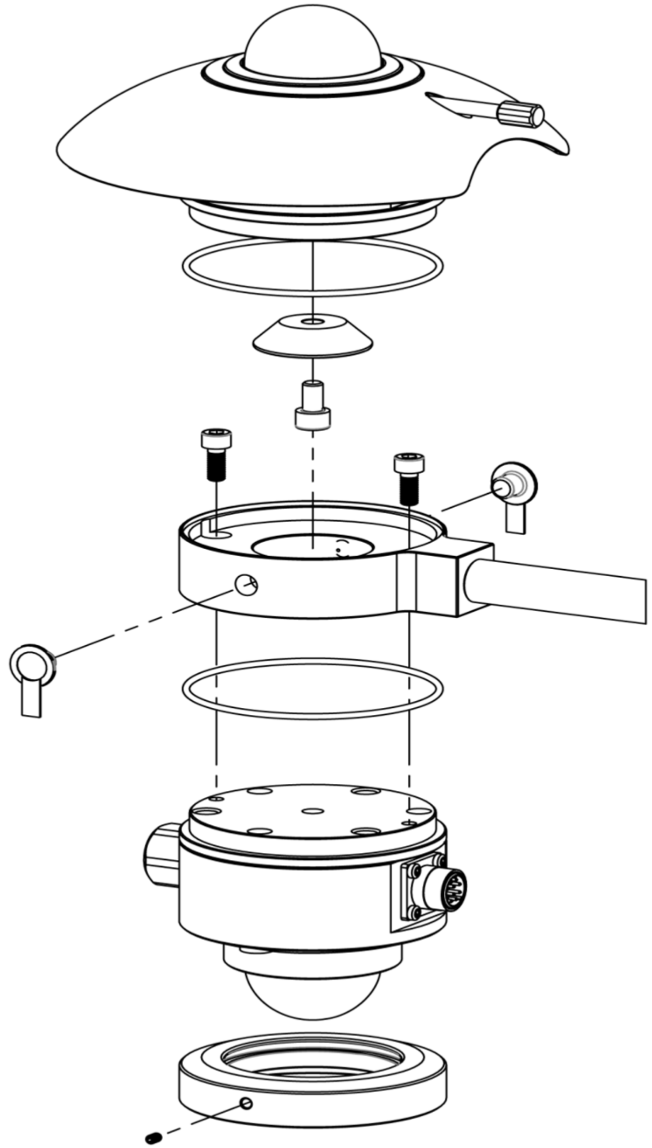
Albedometer modular



Albedometer + POA

Calibration services

Resource assessment

GroundWork

Resource assessment

- 1.5 – 2 m height (WMO)
- unobstructed site
- defined land management strategy (vegetated or bare)

Operational: GHI + POA

Operational: POA on tracker

GroundWork

Operational: 2 x pyrano

Operational: unobstructed RHI

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purposes of monitoring

- unobstructed albedo: reference for satellite measurements

- unobstructed albedo: reference for multiple instruments located at the PV array at every POA

GroundWork

RPOA + POA (bifacial PV)

GroundWork

RPOA + POA (bifacial PV)

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Most common instruments

- spectrally flat class A for GHI/RHI/ POA
- PVsyst model expects spectrally flat horizontal radiation as input
- empirical calculation in performance model RPOA (PVsyst "*albedo coefficient*")

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alternatives

- multiple (lower cost) instruments for RHI, like spectrally flat Class B
- reference cells for POA / RHI (not for GHI)

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Recommendations

- look at the requirements of your performance model
- focus on reducing spatial uncertainty by taking multiple RHI measurements (1 for every POA)
- deploy at least one unobstructed albedo measurement for reference (against albedo resource assessment and deployed RHI)

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Recommendations

- keep logistics and traceability simple; use the same instruments for POA, GHI and RHI measurements (usually spectrally flat Class A pyranometers)
- use separate pyranometers or modular albedometers consisting of 2x pyranometer (this is easier for recalibration than 1 instrument)

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Thank You!