

FLORIDA SOLAR



ENERGY CENTER<sup>®</sup>

## COURSE MANUAL

# PV Training Laboratory Design Manual

FSEC-CM-1756-08

March 21, 2008

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A Research Institute of the University of Central Florida

# **PV TRAINING LABORATORY DESIGN MANUAL**

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## **INTRODUCTION**

This document serves as a written summary of some of the elements required for the design, specification, construction and operation of a successful laboratory for the training of photovoltaics systems. This document only discusses the equipment requirements for such a lab. A successful training lab for education and certification also requires qualified and trained personnel; in-service training to maintain competency; procedures and protocols for curriculum, evaluation, and reporting; careful adherence to the relevant Standards; protocols for quality assurance and calibration; detailed documentation of all procedures and protocols. Accreditation of the lab by an independent evaluating agency is also useful in providing third-party verification of the laboratory's qualifications for education. Third-party accreditation helps provide confidence in the lab and its products (materials, reports, test data, instruction etc) on the part of certification agencies as well as the general consumer.

The following text lists various measured parameters pertaining to photovoltaic performance during operation. It is recommended that ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories" be consulted in addition to this Manual, especially for issues pertaining to documentation, quality control, and reporting.

Following the text, figures and photos of actual equipment in operation are given as examples to help describe the required equipment and sensors. Table 1 at the end of the document summarizes FSEC test equipment and each piece's sensitivity.

## LIST OF ACRONYMS

|      |                                                                                                                 |
|------|-----------------------------------------------------------------------------------------------------------------|
| DAS  | Data Acquisition System, for the collection, storage and processing of test data.                               |
| FSEC | University of Central Florida's Florida Solar Energy Center, located in Cocoa, Florida, USA.                    |
| ID   | Inner diameter, usually of a pipe or tube.                                                                      |
| IEC  | International Electrotechnical Commission.                                                                      |
| ISO  | International Organization for Standardization. With the IEC it forms a specialized system for standardization. |
| MTP  | Mobile Test Platform. Used for supporting a collector during test, transport, tracking the sun. .               |
| NIP  | Normal Incidence Pyroheliometer. Used for measuring direct radiation.                                           |
| OD   | Outside diameter, usually of a pipe or tube.                                                                    |
| RTD  | Resistance Temperature Detector, used for accurate measurement of temperature.                                  |
| WRR  | World Radiometric Reference. The reference for all radiation measurement in the world.                          |

## ISO SENSOR REQUIREMENTS

### **Global Solar Irradiation (6.1): Class 1 pyranometer**

**Required Accuracy:** Class 1 (per ISO 9060), usage per ISO/TR 9901.

**Comments:** The pyranometer measures global short wave radiation from both the sun and the sky. It should be a Class 1 type as specified in ISO 9060. Section 6.1 should be referred to for very specific specifications regarding location and procedure. As can be seen from Figure 1, the FSEC MTPs meet the specifications regarding the pyranometer. Specifically, Eppley PSPs are used which satisfy the Class 1 requirements (6.1.1). The pyranometer is placed at collector midpoint (6.1.1.4). No more than 5% of the field of view of the collector or pyranometer is obstructed and buildings in the field of view subtend an angle of slightly less than  $15^\circ$  with the horizontal (1-5.6, 3-5.7.1). A grassy field is in the southern view, reducing the reflectance from horizontal (3-5.7.1).

When a collector is installed on an MTP for testing, care is taken to ensure that the pyranometer is coplanar with the collector  $\pm 1^\circ$ . Also, care is taken to ensure that neither the pyranometer nor the collector shade each other or reflect light on each other (6.1.1.4).

During testing, a warm up period of at least 30 minutes allows all the equipment including the pyranometer to equilibrate (6.1.1.1). Although not required in the Standard, a secondary pyranometer is placed next to the primary pyranometer. This allows a real-time check of the radiation measurement during testing. Discrepancies of more than 10 W/m<sup>2</sup> between the two instruments are flagged during data collection. The test engineer evaluates the reason for the discrepancy. He might throw out the data and require a calibration check, a leveling check, or a replacement pyranometer. There also is a third pyranometer on the ambient cart that can be used for real-time verification.

All pyranometers in service receive regular moisture checks of the desiccant (6.1.1.2). Damp desiccant is replaced with fresh silica gel, which is regenerated (dried out) in-house.

All pyranometers used in testing are calibrated annually (6.1.1.6). Historically, they have been calibrated by comparison to an absolute cavity reference pyrliometer, which is traceable to the WRR world standard, using the shade/unshade calibration procedure outlined in ASTM E941. Currently, pyranometers are calibrated using the ISO 9846 procedure.

ISO 9806-3 is similar to 9806-1 regarding pyranometer specification, calibration and location requirements. ISO 9806-3-6.1.5 also requires that if using a solar simulator, a map of the distribution of simulator radiation be made using a grid of maximum 150 mm spacing.

### **Direct Solar radiation: pyrliometer**

**Recommended Accuracy:** none given

**Comments:** There are no specific requirements given in the Standard for the measurement of direct solar radiation. The definitions define a pyrliometer as measuring direct or beam radiation from the sun in the wavelength range of 0.3 to 3 micrometers (i.e., the same range as the pyranometer), and with an acceptance angle of less than  $6^\circ$ . The definition given in 9459-1 mentions an acceptance angle of  $5^\circ$  to  $10^\circ$  in one place and “up to  $15^\circ$ ” in another place. Section 8.4 of both 9806-1 and 9806-3 and Section 10-3 of 9806-1 (discussing the time constant test) mention that the performance test must be made “under clear sky conditions”. Section 8.5 of 9806-1 and Section 7.5 of 9459-2 require that diffuse irradiance be obtained at the collector aperture. Section 8.8.3 allows for performance data collected at diffuse irradiance greater than 20%, as long as the incident angle of the collector can be determined with confidence. Performance data with high diffuse radiation must be corrected to equivalent normal conditions using the procedure in Annex B. Annex B points out that transmittance of diffuse irradiance is generally lower than for direct, leading to lower efficiencies. Annex B of 9806-1 and Annex D of 9459-1 also provide a means of calculating an equivalent normal irradiance taking into account diffuse irradiance and any direct irradiance at off-normal angles of incidence. Annex A of 9459-1 (discussing test day specifications for solar system performance testing) specifies the amount of diffuse as well as the amount of beam radiation to which the collector shall be exposed.

The FSEC test beds use Eppley normal incidence pyrliometers (NIPs) to measure direct solar irradiance. These are calibrated annually against an Eppley absolute cavity pyrliometer, which is

traceable to the WRR. A comparison of direct irradiance to global irradiance provides a measure of diffuse radiation. Typically, only data with diffuse measurements less than 20% have been considered valid.

### **Global Thermal radiation (6.2): pyrgeometer**

**Required Accuracy:** +/- 10W/m<sup>2</sup> for indoor testing.

**Comments:** Measurement of thermal (or infrared) radiation is a requirement for indoor testing under a solar simulator. Thermal radiation is generally not taken into consideration in outdoor testing (6.2.1) for 9806-1. However, it is suggested that it be measured at the collector mid-height and co-planar with the collector. The MTPs use Eppley pyrgeometers to measure infrared radiation. These are calibrated annually by comparing their outputs over an extended period of time (several days) to a reference pyrgeometer that has been calibrated by the manufacturer.

ISO 9806-3-6.2 has additional specifications. Long wave radiation measurement is implicitly required for both indoor and outdoor testing. The instrument's desiccator must be checked before and after each test, and the instrument must equilibrate for at least 30 minutes prior to testing. The instrument dome must also be ventilated. The instrument should be calibrated at least every twelve months, and more often if the calibration changes by more than 5%.

Section 8.9 of ISO 9806-3 allows a calculation of long wave irradiance outdoors based on the measured dew point temperature if a measurement of long wave radiation is not available. Section 6.3.3.1 specifies an accuracy of +/-0.5°C for the dew point sensor.

### **Module Temperature (6.3): RTD (Resistance Temperature Detector)**

**Required Accuracy:** +/- 0.1°C, resolution: +/- 0.02°C over range of collector testing temperatures (0°C to 100°C).

**Comments:** Several options are available for measuring temperature accurately. Omega Engineering lists the more common options to include: thermocouples, RTDs, thermistors, and I.C. (integrated circuit) Sensors. The FSEC MTPs use platinum RTDs calibrated in place for measurement of collector inlet temperature. RTDs are considered to be the most stable and most accurate of the four options. They tend to be more linear than thermocouples, more rugged than thermistors, and faster than I.C. sensors. However, practical limitations are that they are also relatively expensive and have a low response requiring higher resolution DAS. The primary RTDs use Wheatstone bridges to counteract the potential effect of impedance in the leads between the RTD sensor and the voltage measurement. For real-time check of the RTD measurement, secondary RTDs are installed in the plumbing circuit immediately after the primary RTDs. The secondary RTDs do not have Wheatstone bridges. Secondary readings can be compared to the primary readings continuously during testing, to check for drift or failure of the primary temperature sensor. Also, discrepancies of greater than 0.10°C between the primary and secondary RTDs are flagged during data collection. This alerts the test engineer to examine the data for deficiencies and/or instabilities. As a result, the test engineer may throw out that data point, and might require a calibration check of the RTDs.

**Calibration:** The FSEC MTP RTDs have an accuracy to the nearest 0.01°C and a resolution of +/- 0.005°C. When a new collector is mounted on the MTP for testing, inlet and outlet RTD readings are checked for agreement by connecting the RTDs together in the plumbing circuit, flowing water across both sensors and checking to see if the sensors give the same reading. In addition, the RTDs are calibrated at least once a year. The RTDs are calibrated by placing them in a well mixed and highly stable water bath, allowing the water bath temperature to stabilize, and comparing the sensor output to a reference measurement of the water bath temperature. A large number of samples (over 100) are taken and the average is used. This procedure is repeated for at least three different temperatures over the range of anticipated operating temperatures. Usually, the anticipated operating temperature range is 0 to 100°C.

The RTDs are calibrated "in-place". That is, the same wiring, connections, and DAS that are used during testing are used during calibration. Hence, the calibration procedure provides a reliable

measurement of the accuracy of the wiring and DAS as well as the sensor. This helps diffuse concerns about inaccuracies potentially present in the cabling and intermediate connections.

The reference sensor historically has been a glass thermometer with divisions of  $0.01^{\circ}\text{C}$ . Now, a new water bath is being used which provides a digital temperature reference measurement with the same accuracy.

**Location:** A photo of the inlet temperature sensor is shown in Figure 2 with the insulation removed to display the piping network. To meet the requirements in section 6.3.1.2, the RTDs are mounted no more than 200 mm from the inlet of the collector. The RTDs point upstream into the flow and several bends in the pipe work and a mixing device are used upstream of both RTDs to ensure that the fluid is well mixed when contacting the sensors. Insulation consists of several centimeters of pipe insulation inside a white PVC jacket to help reflect solar radiation and reduce surface heating.

### **Temperature Difference across the collector (6.3.2): RTD**

**Required Accuracy:**  $\pm 0.1^{\circ}\text{C}$ .

**Comments:** The Standard claims that accuracies of  $\pm 0.02\text{K}$  are attainable, allowing accurate measurement of temperature differences of  $1$  or  $2^{\circ}\text{C}$ . ISO 9806-3-6.3.2.1 echoes this by cautioning against temperature difference measurements of less than  $2^{\circ}\text{C}$ . The FSEC MTPs measure collector outlet temperature in the same way that they measure inlet temperature. Hence, the accuracy of measurement of temperature difference is assumed to meet the Standard down to a temperature difference of about  $1^{\circ}\text{C}$ . Performance data with inlet-outlet temperature differences less than  $1^{\circ}\text{C}$  are generally not needed nor used for performance calculations. Discrepancies of greater than  $0.10^{\circ}\text{C}$  between the primary and secondary temperature difference are flagged during data collection. This alerts the test engineer to examine the data for deficiencies and/or instabilities. As a result, the test engineer may throw out that data point, and might require a calibration check of the RTDs.

### **Ambient Air temperature (6.3.3): RTD and thermocouple**

**Required accuracy:**  $\pm 0.50^{\circ}\text{C}$

**Comments:** To meet the requirements of the Standard, the MTPs measure ambient temperature on a cart located in the vicinity (within 10 meters) of the MTP. As is seen in Figure 4, the air temperature is located in a white vertical canister on the ambient cart. The air temperature sensor is an RTD with bridge that is calibrated once a year in the same manner as described for the other RTDs. The range of operating temperatures is smaller: generally  $0$  to  $35^{\circ}\text{C}$ . This allows a slightly tighter calibration curve. The RTD can also be field-checked during testing by a calibrated thermocouple located next to it. The two sensors are located about 1 meter above the ground in a white shelter to shade them from radiation. Double walls on the shelter improve the shading and meet the requirement of shading the shelter. The shelter is actively ventilated by a small fan located downstream of the sensors. A passively ventilated gill radiation shield will also satisfy the sensor protection requirements in the Standard. Six-plate and twelve-plate shields are readily available.

ISO 9806-3-6.3.3 has slightly tighter requirements, requiring ambient air temperature to be accurate within  $\pm 0.1^{\circ}\text{C}$ , and allowing the dew point temperature to be accurate within  $\pm 0.5^{\circ}\text{C}$ . It also requires an additional reading of ambient air temperature behind the collector to assure uniformity, and specifies that airflow from a wind generator shall be within  $\pm 1^{\circ}\text{C}$  of ambient air temperature. If the wind generator is large enough, then all wind passing through the wind generator could be considered as the ambient air temperature.

### **Wind velocity (6.5): ultrasonic anemometer, three-cup anemometer, and wind vane.**

**Required accuracy:**  $\pm 0.5$  m/s of the surrounding air over the collector's front surface.

ISO 9806-3-6.5.1 requires an accuracy of  $\pm 10\%$  of the reading.

**Comments:** The Standard points out the lack of quantitative understanding of the influence of wind direction on collector heat losses, hence it does not require measurement of wind direction (6.5). It also comments on the inherent variability and randomness of wind speed, requiring an average wind

speed to be recorded for a test period (6.5.1). This could be achieved from an average of wind speed measurements, say from an anemometer. It could also be achieved from a wind totalizer instrument. However, it also requires that before a test a series of wind speed measurements should be made over the surface of the collector at a distance of 100 mm from the aperture, and the average recorded. These measurements should be repeated after the test. During the test, the instrument should be removed and not interfere with the collector. ISO 9806-3-6.5.2 clarifies this requirement somewhat, indicating that air speed must be monitored during test from a convenient point that has been calibrated relative to the mean air speed. For outdoor testing, the instrument should be at the midheight of the collector, not be shielded from the wind, and not cast a shadow on the collector. Presumably, the shadow refers to a sunlight shadow, since a “wind shadow” would be immeasurable on the collector and moving the instrument too far from the collector would result in erroneous readings. The standard also requires an artificial wind generator for winds below 3 m/s.

The FSEC MTPs meet the spirit of this requirement to the best extent practicable. Wind measurement on the MTPs is shown in Figures 6 and 7. A three-cup anemometer records horizontal wind speed at a point about 1.5 m above the ground and less than 10 m from the collector. Although not required by the Standard, wind direction is also recorded using a wind vane. Although not explicitly stated in Section 6, section 7.1 of the Standard implies that wind speed should be recorded using a three-cup anemometer in the plane of the collector, not in the horizontal plane. However, most three-cup anemometers are not designed with bearings that tolerate operation at non-horizontal orientations. Hence, the MTPs use a more expensive ultrasonic anemometer that can measure wind speed and direction, independent of orientation. The anemometer is installed at the same angle as the collector, at the collector midpoint and to one side, and offset from the aperture plane by 100 mm. A plate is also added on the other side of the anemometer to approximate the sensor being in the middle of a flat plate and to reduce the discrepancies in turbulence due to wind direction.

ISO 9806-3-5.9 calls for wind speeds on unglazed collectors to be in the range of 1.5-4 m/s and measured in a similar fashion as is specified in 9806-1. It also calls for turbulence to be between 20-40% 100 mm above the leading edge of the collector, and checked with a linearized hot wire anemometer with a frequency response of at least 100 Hz (3-5.9). FSEC currently does not monitor this parameter with a hot wire anemometer. However, some measurement of the turbulence can be made with the ultrasonic anemometer.

### **Collector area (6.9): calibrated tape rule**

**Required Accuracy:**  $\pm 0.1\%$

ISO 9806-3 has similar accuracy requirements.

**Comments:** This requirement is for measurement of the collector area. If a tape measure has 1 mm gradations, we can assume that its best accuracy is  $\pm 0.5$  mm (i.e., a measurement of 10.5 mm would be mis-read as either 10 mm or 11 mm). Note that this error of 0.5 mm is the same magnitude as the thickness of mechanical pencil lead (usually 0.4mm) or a paper clip. Also, it can be argued that, if the gradations are in 1 mm increments then the technician is allowed to approximate to the nearest 0.5 mm resulting in an accuracy of  $\pm 0.25$  mm.

If the tape measure is used to measure 500 mm with an accuracy of  $\pm 0.25$  mm, then it could be mis-read as either 499.75 mm or 500.25 mm. A square area of 500 mm on a side could be read between 249,750.06 mm<sup>2</sup> and 250,250.06 mm<sup>2</sup>. The maximum possible error would be 500 mm<sup>2</sup>, or 0.2% of the actual area. Thus, an area of 0.25 m<sup>2</sup> is theoretically the smallest area that a tape measure with 1 mm gradations could measure and meet the required accuracy. If the best accuracy is  $\pm 0.5$  mm, the smallest measurable area is 1 m<sup>2</sup>.

Practically speaking, there are many places where error can be introduced during area measurement. The metal tape measure might expand or contract with ambient temperature. The rivet on the end might stretch over time. Different technicians might measure slightly differently, or might not view the reading exactly perpendicular to the tape. Indeed, exactly where to start and stop a

measurement is a somewhat subjective choice, as is the inclusion or exclusion of flanges, finish markings, gaskets, manufacturing variations, etc. All these are on the order of a few millimeters.

FSEC technicians use “calibrated” tape measures whose gradations have been independently verified. These are re-verified every few years. Ambient temperatures in the high bay where measurements are made seldom exceed the 20-30°C range during a year. Changes in dimension of either the tape measure or the collector over this range of temperature are negligible. Finally, the technician takes readings of the same dimension at three different locations, and averages the three to minimize the error. Also, due to other issues in the Standard the minimum allowable collector size for testing is 3 m<sup>2</sup>: ISO 9806-1 only requires “full-size” collectors to be tested (5.1), but ISO 9806-3 recommends a minimum gross collector area of 3 m<sup>2</sup> to minimize edge effects (5.1, 5.3). Hence, the FSEC area measurement procedure is considered to meet the Standard.

## ISO TEST STAND REQUIREMENTS

Section 7 of ISO 9806-1 gives requirements for the construction and operation of a solar thermal test stand. A review of these requirements follows, along with examples of how to meet the Standard using the FSEC test stands. Generally, specifications in ISO 9806-3 are the same as those in ISO 9806-1. Differences between the two Standards are pointed out as needed.

Section 7.1 gives two sketches of basic required components: one of a closed test loop and one of an open test loop. The FSEC MTPs are configured following the closed test loop sketch. Each of the sensors shown was discussed in the previous section. In addition, several other operational components will be discussed below when appropriate.

The FSEC Flow Calibration Stand is configured following the open test loop sketch. Each of the sensors shown was discussed in the previous section. A photo of a collector under test at the Flow Calibration Stand is given in Figure 5. Since a collector is tested at the Flow Calibration Stand while also using an MTP, most of the sensors used at the Flow Calibration Stand are the same ones as used on the MTP. In addition, several other operational components will be discussed below when appropriate.

### **Incident Angle Modifier test (ISO 9806-1 section 11)**

**Comments:** The Incident Angle Modifier is an important parameter in determining performance of a collector at off-normal incidence radiation. During actual operation, solar radiation is rarely perpendicular (normal) to the aperture of the collector. The equipment and sensor requirements for the incident angle modifier are equivalent to those for the performance test and the same equipment may be used for both tests. As with the performance test, a test stand that employs altazimuth (or two axis) tracking will be a significant time saver compared to a fixed, variable-tilt only test stand. The fixed test stand may also be used, but the technician is restricted to certain times of day that he can collect data. At these times, other ambient conditions may not be desirable.

The Standard also allows for this test to be conducted under a solar simulator. If a simulator is used, the radiation distribution map should be checked at the different angles to be tested, since different parts of the collector will be at different distances from the simulator lamp, depending on the angle tested.

Note that ISO 9806-3 does not give specifications for testing Incident Angle Modifier in unglazed collectors, although the test is outlined in 9806-3 Annex B. It is an important parameter to know for unglazed collectors, and the procedures outlined in 9806-3 Annex B or in ISO 9806-1 should be used.

## **High Temperature Resistance Test (9806-2 section 6)**

**Equipment comments:** This test is intended to assess damage to the collector exposed to the high temperatures of stagnation. Like the internal pressure test, at FSEC this test must be done indoors under a solar simulator for collectors tested to the “climate Class C: Very sunny”. The same chamber required for the internal pressure test is used for the high temperature resistance test. In fact, as recommended in Table 1 the high temperature test ought to be done on organic absorbers before the internal pressure test. Also note that wind conditions of less than 1 m/s are specified for this test, which includes quiescent air.

The installation of the thermocouple on the absorber is a process that requires significant attention so that the collector sample is not damaged. Many flat plate glazed collectors can be carefully dismantled, the absorber removed, and the thermocouple attached to the back side of the absorber to shield it from radiation. Then the collector must be carefully re-assembled and re-sealed using the manufacturer’s fasteners, sealants, and gaskets. Alternatively, some collectors can be drilled from the backside to attach the thermocouple. Again, the hole must be resealed to approximate the original insulation and water penetration characteristics. The collector should not be damaged by the test lab in such a way as to adversely affect any subsequent testing. The manufacturer should be consulted when determining how to install the thermocouple. It may even be prudent to have the manufacturer install a thermocouple at the factory on the selected collector(s).

The Standard also allows for collectors “for which it is not appropriate to measure the stagnation temperature at the absorber” (section 6, Note 4) or “difficult to attach a thermocouple to the absorber” (section 6, Note 5). The Standard allows for a small amount of a known fluid to be sealed in the absorber and the vapor pressure measured as the temperature rises. Because of anticipated difficulty in conducting this procedure (difficulties such as leakage, accuracy of measurement, possibility of over-pressurization, etc), FSEC currently does not use this procedure. The Standard also allows for a hot fluid loop to be used instead of solar irradiation. However, the collector will be subjected to different thermal stresses than would be seen under true stagnation.

FSEC currently uses the option given in Note 4 that is to place the temperature sensor at a suitable location in the collector. A thermocouple is inserted deep into the top header and its location is recorded in the report. This location very closely approximates the absorber temperature and provides an accurate reading of the stagnation temperature to which the working fluid will be exposed. This procedure also greatly minimizes the potential for damage to the collector caused by the test lab.

## **Exposure Test (9806-2 section 7)**

**Required Parameters:** air temperature, global irradiance in the plane of the collector, daily rainfall.

**Required Accuracy:** air temperature: 1K (or +/-0.5K); global irradiance: class 1 pyranometer per ISO 9060; rainfall: no required accuracy given.

**Equipment Comments:** This test provides a quick but very small indication of aging effects on the collector and also allows the collector to “settle” and give a performance more typical of actual service. The test requires 30 days of minimum irradiance, irradiation and air temperature.

The FSEC test lab uses the exposure stands shown in Figure 8 to conduct the exposure test. Although the Standard does not require the collector to be tilted, the FSEC exposure stand allows the collector to be tilted and a tilt procedure can be followed such that the incident angle of solar radiation at solar noon is never more than 4 degrees off normal. This allows a greater daily insolation compared to a horizontal tilt, which helps the test to be completed sooner. A dedicated pyranometer is tilted at the same angle as the collector.

A thermocouple is used to measure the air temperature in the vicinity of the exposure stand. This thermocouple is calibrated once a year. A tipping bucket records any rain fall. The tipping bucket has a resolution of about 0.254 mm (0.01 inch) per tip and is not regularly calibrated.

**Procedural Comments:** During the 30 day test, the collector must experience at least 30 hours of combined high irradiance and high temperature levels given for the chosen climate class. Typical weather conditions at the FSEC test labs do not often provide the combined conditions of “Class C

very sunny”. Hence, the 30 hours are conducted under the solar simulator. Although the Standard does not require that the hours be consecutive, the test is done in as few separate periods as is practical. In addition, the external and internal thermal shock tests can be conducted while under the simulator.

#### **Optional Impact Resistance Test (9806-2 Section 12)**

**Equipment Comments:** This test is designed to evaluate how resistant the test collector is to impacts such as those that might be experienced by vandalism, hail, or during installation. The test requires a steel ball of mass 150g +/-10g, and a test rig to mount the collector and ball. It also specifies drop heights for the ball, and distance from the collector edge for the points of impact. The ball is dropped on the collector from a series of increasing heights, following specifications in the Standard until either the collector sustains damage or the drop height reaches the maximum height of 2.0 meters.

The FSEC test labs currently do not have such a test rig in place. However, such a rig can easily be built when there is a demand for such a test.



Figure 1. Pyranometers on MTP1. Primary is in the middle and secondary on the left. Pyrgeometer is on right. Flat black surface in upper background is a plastic swimming pool solar heater under test.



Figure 2a. General view of Inlet RTD's with insulation removed. Insulation and white PVC radiation shield are in upper part of picture.



Figure 3a. Ambient cart. Pyranometer and pyroheliometer are on the right. Anemometer and wind direction indicator are on the upper left. Ambient temperature RTD, thermocouple and humidity bulk polymer sensor are in vertical canister on lower left. Oven with data acquisition modules are on lower left.

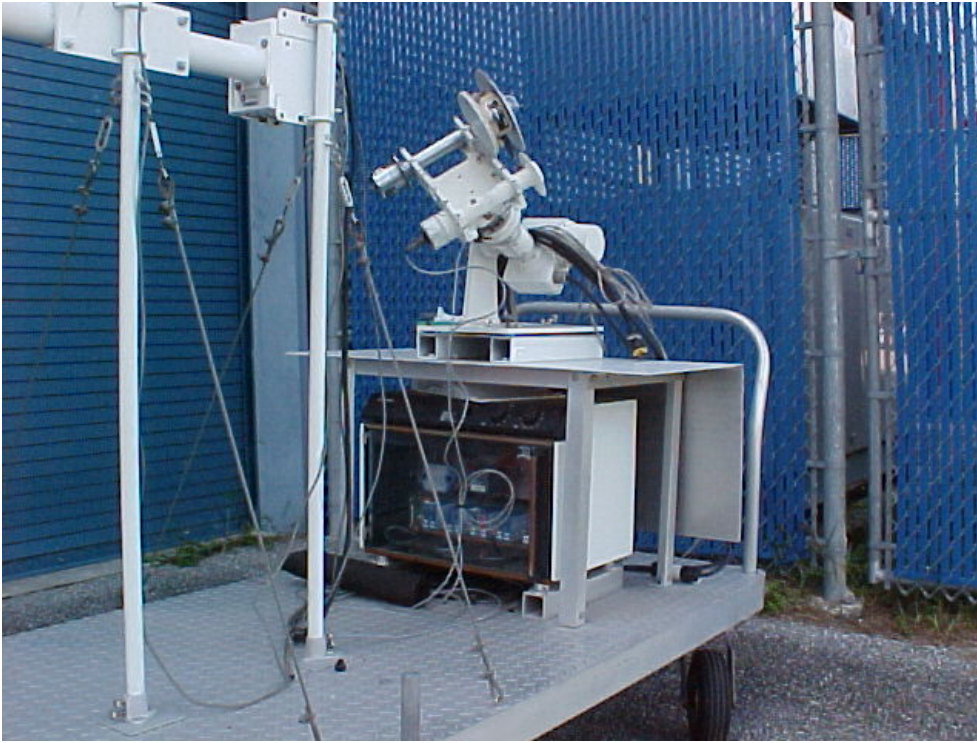


Figure 3b. Detail view of ambient cart data acquisition modules. Temperature-controlled oven allows the electronics to operate at constant temperature all year, improving repeatability.

**Table 1. FSEC Test Equipment.**

| Mfg Model     | Mfg Name       | Device Name                        | Device Range                             | Calib Freq | Critical (Yes/No)<br>(Y/N) | Cal Source<br>(Int/Ext) |
|---------------|----------------|------------------------------------|------------------------------------------|------------|----------------------------|-------------------------|
| D1602         | Omega          | Frequency Counter                  | 1 to 20,000 Hz                           | annual     | Y                          | I                       |
| D1622S        | Omega          | Event Counter                      | 0 to 9,999,999 count totalizer           | annual     | N                          | I                       |
| D1602         | Omega          | Frequency Counter                  | 1 to 20,000 Hz                           | annual     | Y                          | I                       |
| D1622S        | Omega          | Event Counter                      |                                          | annual     | N                          | I                       |
| D1602         | Omega          | Frequency Counter                  | 1 to 20,000 Hz                           | annual     | Y                          | I                       |
| D1712         | Omega          | Digital I/O                        |                                          | annual     | N                          | I                       |
| PX 771-300WDI | Omega          | Transmitter, Differential Pressure | 0 - 300 in/H2O                           | before use | Y                          | I                       |
| RIS CL-6000   | RIS            | Calibrator                         |                                          | annual     | N                          | I                       |
| 6B13          | Analog Devices | Analog to Digital Converter        |                                          | annual     | Y                          | I                       |
| DS-100        | Raydec Inc.    | IV Curve Tracer, Portable          | x-600 Volts, x-100 Amps/ASTME1036 6.7&.8 | annual     | Y                          | E                       |
| 6B13          | Analog Devices | Analog to Digital Converter        |                                          | annual     | Y                          | I                       |
| PX 81/100 G5V | Omega          |                                    |                                          |            | N                          | I                       |
| PX181/100G 5V | Omega          | Transducer, Pressure               |                                          |            | N                          | I                       |
| E100          | EDC            | Millivolt Standard, DC             | -11.111V to +11.111V                     | annual     | Y                          | E                       |
| 2338 CME      | Lufkin         | Tape Rule                          | 0-26 ft., 0-8 meter                      | indefinite | Y                          | E                       |
| 2338 CME      | Lufkin         | Tape Rule                          | 0-26 ft., 0-8 meter                      | indefinite | Y                          | E                       |
| 2338 CME      | Lufkin         | Tape Rule                          | 0-26 ft., 0-8 meter                      | indefinite | Y                          | E                       |
| 2338 CME      | Lufkin         | Tape Rule                          | 0-26 ft., 0-8 meter                      | indefinite | Y                          | E                       |
| P1210         | Photon         | Primary Reference Module           | PolyCrystal (EFG)                        | annual     | Y                          | E                       |
| 6B11          | Analog Devices | Analog to Digital Converter        |                                          | annual     | Y                          | I                       |
| P1210         | Photon         | Primary Reference Module           | PolyCrystal (EFG)                        | annual     | Y                          | E                       |
| 6B11          | Analog Devices | Analog to Digital Converter        |                                          | annual     | Y                          | I                       |
| Si            | LiCor          | Pyranometer                        | 9.57 mV/kW/m2                            | annual     | N                          | I                       |
| 2030          | Qualimetrics   | Anemometer                         |                                          | annual     | N                          | I                       |
| CR-10         | Campbell Sci   | Data Acquisition System            |                                          | before use | Y                          | I                       |

|        |                |                                 |                              |        |   |              |
|--------|----------------|---------------------------------|------------------------------|--------|---|--------------|
| 6B11   | Analog Devices | Analog to Digital Converter     |                              | annual | Y | I            |
| Si     | LiCor          | Pyranometer                     | 8.67 mV/kW/m2                | annual | N | I            |
| Si     | LiCor          | Pyranometer                     | 9.49 mV/kW/m2                | annual | N | I            |
| NIP    | Eppley Lab     | Pyrheliometer, normal incidence | 8.66 uV/W/sq m               | annual | N | I            |
| NIP    | Eppley Lab     | Pyrheliometer, normal incidence | 8.56 uV/W/sq m               | annual | N | I            |
| Saturn | BP Solar       | Primary Reference Module        | Mono Si                      | Annual | Y | NREL,<br>SNL |
| Poly   | BP Solar       | Primary Reference Module        | PolyCrystal                  | Annual | Y | NREL,<br>SNL |
| CZ     | BP Solar       | Primary Reference Module        | Single Crystal (CZ)          | Annual | Y | NREL,<br>SNL |
| PSP    | Eppley Lab     | Pyranometer                     | 7.00 uV/W/sq m               | annual | Y | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 7.04 uV/W/sq m               | annual | N | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 8.57 uV/W/sq m               | annual | N | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 7.38 uV/W/sq m               | annual | Y | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 9.51 uV/W/sq m               | annual | Y | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 5.82 uV/W/sq m               | annual | Y | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 8.45 uV/W/sq m               | annual | Y | I            |
| 2020   | Qualimetrics   | Wind vane micro response        |                              | annual | N | I            |
| 6B11   | Analog Devices | Analog to Digital Converter     |                              | annual | Y | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 9.94 uV/W/sq m               | annual | N | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 8.19 uV/W/sq m               | annual | N | I            |
| Si     | LiCor          | Pyranometer                     | 10.33 mV/kW/m2               | annual | N | I            |
| Si     | LiCor          | Pyranometer                     | 10.09 mV/kW/m2               | annual | N | I            |
| Si     | LiCor          | Pyranometer                     | 10.66 mV/kW/m2               | annual | N | I            |
| Si     | LiCor          | Pyranometer                     | 10.26 mV/kW/m2               | annual | N | I            |
| 6B11   | Analog Devices | Analog to Digital Converter     |                              | annual | Y | I            |
| 31564  | Toledo Spinks  | Scale                           | 0 to 213 Pounds X 0.5 pounds | annual | Y | I            |
| Si     | LiCor          | Pyranometer                     | 11.75 mV/kW/m2               | annual | N | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 9.44 uV/W/sq m               | annual | N | I            |
| PSP    | Eppley Lab     | Pyranometer                     | 9.10 uV/W/sq m               | annual | N | I            |
| 6B11   | Analog Devices | Analog to Digital Converter     |                              | annual | Y | I            |
| ST-10  | Siemens        | Primary Reference Module        | CIS Multi Junction           | annual | Y | E            |
| ST-10  | Siemens        | Primary Reference Module        | CIS Multi Junction           | annual | Y | E            |

|                      |                |                                 |                            |                       |   |
|----------------------|----------------|---------------------------------|----------------------------|-----------------------|---|
| PSP                  | Eppley Lab     | Pyranometer                     | 8.55 uV/W/sq m             | annual N              | I |
| NIP                  | Eppley Lab     | Pyrheliometer, normal incidence |                            | N                     | I |
|                      | Sonic          | Anemometer                      |                            | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.65 uV/w/sq m             | annual N              | I |
| Aug-48               | Eppley Lab     | Pyranometer, Black & White      | 9.86uV/W/sq m              | annual Y              | E |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.56 uV/W/sq m             | annual Y              | I |
| 2030                 | Qualimetrics   | Anemometer Micro response       |                            | annual N              | I |
| 2030                 | Qualimetrics   | Anemometer Micro response       |                            | annual N              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.41 uV/W/sq m             | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.49 uV/W/sq m             | annual Y              | I |
| 6B13                 | Analog Devices | Analog to Digital Converter     |                            | annual Y              | I |
| 33F                  | CYCLOPS        | Thermometer                     |                            | N                     | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.91 uV/W/sq m             | annual N              | I |
| 6B13                 | Analog Devices | Analog to Digital Converter     |                            | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 9.38 uV/W/sq m             | annual N              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.83 uV/W/sq m             | annual Y              | I |
|                      |                |                                 |                            | Every 2 years, prefer |   |
| H-F Self-Calibrating | Eppley Lab     | Pyrheliometer, Absolute Cavity  | 0.99948 w/ 0.10% std. Dev. | annual Y              | E |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.82 uV/W/sq m             | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 8.21                       | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 9.07 uV/W/sq m             | annual Y              | I |
| NIP                  | Eppley Lab     | Pyrheliometer, normal incidence | 8.47 uV/W/sq m             | annual Y              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 9.99 uV/W/sq m             | annual N              | I |
| PSP                  | Eppley Lab     | Pyranometer                     | 9.93 uV/W/sq m             | annual                | I |
| 6B11                 | Analog Devices | Analog to Digital Converter     |                            | annual Y              | I |
| Si                   | LiCor          | Pyranometer                     | 12.18 mV/kW/m2             | annual N              | I |
| Si                   | LiCor          | Pyranometer                     | 15.87 mV/kW/m2             | annual N              | I |
| Si                   | LiCor          | Pyranometer                     | 15.67 mV/kW/m2             | annual N              | I |
| Si                   | LiCor          | Pyranometer                     | 12.92 mV/kW/m2             | annual N              | I |
| Si                   | LiCor          | Pyranometer                     | 14.63 mV/kW/m2             | annual N              | I |
| 6B11                 | Analog Devices | Analog to Digital Converter     |                            | annual Y              | I |
| 335D                 | Fluke          | Voltage Standard                |                            | annual Y              | E |

|       |                |                                                |                       |                         |   |
|-------|----------------|------------------------------------------------|-----------------------|-------------------------|---|
| PSP   | Eppley Lab     | Pyranometer                                    | 8.74 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 9.18 uV/W/sq m        | annual Y                | I |
| NIP   | Eppley Lab     | Pyrheliometer, normal incidence                |                       | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.16 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 9.22 uV/W/sq m        | annual Y                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.87 uV/W/sq m        | annual N                | I |
| NIP   | Eppley Lab     | Pyrheliometer, normal incidence                |                       | N                       | I |
| 6B11  | Analog Devices | Analog to Digital Converter                    |                       | annual Y                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.62 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.25 uV/W/sq          | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.21 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.09 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.96 uV/W/sq m        | annual N                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.55 uV/W/sq m        | annual Y                | I |
| PIR   | Eppley Lab     | Pyrgeometer, Precision Infrared Radiometer     | 3.97 uV/W/sq. m.      | annual N                | E |
| 2020  | Qualimetrics   | Wind vane micro response                       |                       | annual N                | I |
| 2020  | Qualimetrics   | Wind vane micro response                       |                       | annual N                | I |
| 6B11  | Analog Devices | Analog to Digital Converter                    |                       | annual Y                | I |
| CR10  | Campbell Sci   | Data logger (9) Single Ended 7.500 mV channels |                       | Before IR calibration Y | I |
| CR-10 | Campbell Sci   | Datalogger                                     |                       | before use Y            | I |
| 1120  |                | Thermocouple                                   | Simulator/ Calibrator | annual N                | I |
| 6B11  | Analog Devices | Analog to Digital Converter                    |                       | annual Y                | I |
| NIP   | Eppley Lab     | Pyrheliometer, normal incidence                | 8.80 uV/W/sq m        | annual N                | I |
| Si    | LiCor          | Pyranometer                                    | 4.60 mV/kW/m2         | annual N                | I |
| 6B11  | Analog Devices | Analog to Digital Converter                    |                       | annual Y                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.04 uV/W/sq. m.      | annual Y                | I |
| PSP   | Eppley Lab     | Pyranometer                                    | 8.12 uV/W/sq. m.      | annual N                | I |
| PIR   | Eppley Lab     | Pyrgeometer, Precision Infrared Radiometer     | 4.02 uV/W/sq. m.      | annual N                | I |
| PIR   | Eppley Lab     | Pyrgeometer, Precision Infrared Radiometer     | 4.04 uV/W/sq. m.      | annual N                | I |
|       | Sonic          | Anemometer                                     |                       | annual Y                | I |
| PIR   | Eppley Lab     | Pvrgeometer. Precision Infrared                | 3.27 uV/W/sq. m.      | annual N                | I |

|                                                          |                              |                                            |                                                      |             |  |     |
|----------------------------------------------------------|------------------------------|--------------------------------------------|------------------------------------------------------|-------------|--|-----|
|                                                          |                              | Radiometer                                 |                                                      |             |  |     |
| 22644-D7-AS-FC                                           | Brooklyn                     | Thermometer, Glass (with ice point)        | 89 to 101 C in 0.01 divisions                        | ref. Std. N |  | I   |
| PIR                                                      | Eppley Lab                   | Pyrgeometer, Precision Infrared Radiometer | 3.37 uV/W/sq. m.                                     | annual N    |  | I   |
| PIR                                                      | Eppley Lab                   | Pyrgeometer, Precision Infrared Radiometer | 3.85 uV/W/sq. m.                                     | annual N    |  | I   |
| 4612-01                                                  | Magtrol                      | Power Analyzer - Digital                   | 20 to 6000 Watts                                     | Annual N    |  | E   |
| 2100A                                                    | Fluke                        | Thermometer, Digital                       |                                                      | annual N    |  | I   |
| PSP                                                      | Eppley Lab                   | Pyranometer                                | 7.81 uV/W/sq m                                       | annual N    |  | I   |
| TUVR                                                     | Eppley Lab                   | Total Ultraviolet Radiometer               |                                                      | annual N    |  | I   |
| SA5LV                                                    | BP Solar                     | Primary Reference Module                   | Amorphous Silicon                                    | annual Y    |  | E   |
| 8060A                                                    | Fluke                        | Multimeter, Digital                        |                                                      | annual N    |  | I   |
| RD 1200 S                                                | Multitracer II<br>Raydec Inc | PV I-V Curve Tracer and Load               | 1200 W, 0-15 A, 0-100V                               | annual N    |  | I   |
| 8060A                                                    | Fluke                        | Multimeter, Digital                        |                                                      | annual N    |  | I   |
| 8060A                                                    | Fluke                        | Multimeter, Digital                        |                                                      | annual N    |  | I   |
| 8060A                                                    | Fluke                        | Multimeter                                 |                                                      | annual N    |  | I   |
|                                                          | Climatronics                 | Meteorological system                      |                                                      | N/A N       |  | I   |
| 22642-AS-D7-FC                                           | Brooklyn                     | Thermometer, Glass (with ice point)        | 79 to 91 C in 0.01 divisions                         | ref. Std. N |  | I   |
| 6B11                                                     | Analog Devices               | Analog to Digital Converter                |                                                      | annual Y    |  | I   |
| SPI-SUN 660                                              | Spire Solar                  | Flash Simulator - Electrical Calibration   | 1-25 Volts, 1.2-20A/ ASTM E1036 6.7&8                | annual Y    |  | I   |
| Solar Flash Simulator -Non-uniformity Calibration        |                              |                                            | Class A (.88 X 1.58m), Class B (2 X 2m)/ASTM-E927    | annual Y    |  | I   |
| Solar Flash Simulator - Spectrum Calibration             |                              |                                            | Class B per ASTM-E 927-91                            | annual Y    |  | E/I |
| Solar Flash Simulator - Temperature Calibration          |                              |                                            | Act. error 0.3 °C., limit<=1.0 C., range 17 to 45 C. | annual Y    |  | I   |
| Solar Flash Simulator - Temporal Instability Calibration |                              |                                            | Class A (+/-2%) (immediate) /ASTM-E927               | annual Y    |  | I   |
| 6B11                                                     | Analog Devices               | Analog to Digital Converter                | +/- 15 mV                                            | annual Y    |  | I   |
| HH509                                                    | Omega                        | Thermometer, Digital                       |                                                      | annual Y    |  | E   |
| GE600                                                    | General                      | Scales/Digital Indicator                   | 200016                                               | annual Y    |  | I   |
| 6B11                                                     | Analog Devices               | Analog to Digital Converter                |                                                      | annual Y    |  | I   |
| 6B11                                                     | Analog Devices               | Analog to Digital Converter                |                                                      | annual Y    |  | I   |
| 6B12                                                     | Analog Devices               | Analog to Digital Converter                |                                                      | annual Y    |  | I   |
| 6B12                                                     | Analog Devices               | Analog to Digital Converter                |                                                      | annual N    |  | I   |
| SM-6                                                     | Siemens                      | Primary Reference Module                   | Single Crystal (CZ)                                  | annual Y    |  | E   |

|              |                  |                             |                                              |          |   |
|--------------|------------------|-----------------------------|----------------------------------------------|----------|---|
| SM-6         | Siemens          | Primary Reference Module    | Single Crystal (CZ)                          | annual Y | E |
| 0-200PSI     | Omega            | Pressure Gauge 0-200 psi    | Spec+/-0.5 Cal +/-0.0 perfect                | Annual Y | E |
| GE600        | General          | Scale/Digital Indicator     | 200016                                       | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| CM 6B        | KIPP & ZONEN     | Pyranometer                 | 4.85 uV/W/sq m                               | annual N | I |
| CM 6B        | KIPP & ZONEN     | Pyranometer                 | 4.54 uV/W/sq m                               | annual N | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| MSX-5        | BP Solar         | Primary Reference Module    | PolyCrystal (Ingot)                          | annual N | E |
| MSX-5        | BP Solar         | Primary Reference Module    | PolyCrystal (Ingot)                          | annual Y | E |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 87           | Fluke Multimeter | - true RMS                  | AC&DC V&I, Resistance & Freq(34 ranges tot.) | annual Y | E |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 87           | Fluke            | Multimeter-true RMS         |                                              | annual N | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| CM 6B        | KIPP & ZONEN     | Pyranometer                 |                                              | annual N | I |
| CM 6B        | KIPP & ZONEN     | Pyranometer                 |                                              | annual N | I |
| CM 6B        | KIPP & ZONEN     | Pyranometer                 |                                              | annual N | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 6B11         | Analog Devices   | Analog to Digital Converter |                                              | annual Y | I |
| 1114-08H2G1A | Brooks           | Flow Meter, Rotameter       | 0 to 2.05 gpm                                | N        |   |
| PORTA        | General          |                             |                                              |          |   |
| TRONIC 820   | Electronic       | Scale, Digital              | 0 to 213 Pounds X0.1 pound                   | annual Y | I |
| 6B13         | Analog Devices   | Analog to Digital Converter |                                              | annual N | I |
| 1114-        | Brooks           | Rotameter                   | 0-10.8 gpm                                   | N        | I |

|                     |                                                |                                     |                                                 |                             |                     |     |
|---------------------|------------------------------------------------|-------------------------------------|-------------------------------------------------|-----------------------------|---------------------|-----|
| 10H4G1A             |                                                |                                     |                                                 |                             |                     |     |
| 2175A               | Omega                                          | Thermometer, Digital                |                                                 |                             | annual N            | I   |
| 6B11                | Analog Devices                                 | Analog to Digital Converter         |                                                 |                             | annual N            | I   |
| 6B11                | Analog Devices                                 | Analog to Digital Converter         |                                                 |                             | annual Y            | I   |
| NIP                 | Eppley Lab                                     | Pyrheliometer, normal incidence     |                                                 |                             | N                   | I   |
| 6B11                | Analog Devices                                 | Analog to Digital Converter         |                                                 |                             | annual N            | I   |
| FT4-8AENW-<br>LEG-2 | EG&G Flow<br>Technology                        | Flow meter, turbine                 |                                                 |                             | with each<br>test Y | I   |
| FT4-8AENW-<br>LEG-2 | EG&G Flow<br>Technology                        | Flow meter, turbine                 |                                                 |                             | with each<br>test Y | I   |
| 6B11                | Analog Devices                                 | Analog to Digital Converter         |                                                 |                             | annual N            | I   |
| 6B11                | Analog Devices                                 | Analog to Digital Converter         |                                                 |                             | annual Y            | I   |
| FT6-8AENW<br>LEG-1  | EG&G Flow<br>Technology                        | Flow Meter, Turbine                 |                                                 |                             | with each<br>test Y | I   |
| FT4-8AENW<br>LEG-2  | EG&G Flow<br>Technology                        | Flow Meter, Turbine                 |                                                 |                             | with each<br>test Y | I   |
| FT4-8AENW-<br>LEG-2 | EG&G Flow<br>Technology                        | Flow meter, turbine                 |                                                 |                             | with each<br>test Y | I   |
| FT4-8AENW-<br>LEG-2 | EG&G Flow<br>Technology                        | Flow meter, turbine                 |                                                 |                             | with each<br>test Y | I   |
| FT8-8AENW-<br>LEG-1 | EG&G Flow<br>Technology                        | Flow meter, turbine                 |                                                 |                             | with each<br>test Y | I   |
| ST-3                | Eppley Lab                                     | Solar Tracker                       |                                                 |                             | annual N            | I   |
| 200                 | Vortek Solar Simulator - Continuous Large Area |                                     | Class B (5%) 9'4"x4'4", Class C (10%) 13'x4'4"  |                             | annual N            | I   |
| 200                 | Vortek Solar Simulator - Continuous Large Area |                                     | ASTM E927 Class C in 'Direct' and 'Global'      |                             | annual N            | E/I |
| 200                 | Vortek Solar Simulator - Continuous Large Area |                                     | Class A (2%) at 30 minutes, Class B ~ instantly |                             | annual N            | I   |
| 22630-AS-<br>D7-FC  | Brooklyn                                       | Thermometer, Glass (with ice point) |                                                 | 19 to 31 C in 0.01 Division | ref. Std. N         | I   |
| 22638-AS-<br>D7-FC  | Brooklyn                                       | Thermometer, Glass (with ice point) |                                                 | 59 to 71 C in 0.01 Division | ref. Std. N         | I   |
| 22634-AS-<br>D7-FC  | Brooklyn                                       | Thermometer, Glass (with ice point) |                                                 | 39 to 51 C in 0.01 Division | ref. Std. N         | I   |
| PX771/300W<br>DI    | Omega                                          | Transducer, Differential Pressure   |                                                 | 300 in H2O                  | annual Y            | I   |
| PX771-<br>300WDI    | Omega                                          | Differential Pressure Transmitter   |                                                 | 0-300in/H2O                 | before use Y        | I   |
| 5610                | Hart Scientific                                | Thermistor probe                    |                                                 |                             | annual Y            | E   |

|                |                    |                                     |                                     |           |   |     |
|----------------|--------------------|-------------------------------------|-------------------------------------|-----------|---|-----|
| 1504           | Meriam Instrument  | Converter, Pressure                 | 200 PSIG                            | N/A       | N | I   |
|                | Hart Scientific    | Thermometer - thermistor            |                                     | annual    | Y | E   |
|                | ASHCROFT           | Gauge, Temperature                  | 30 - 130 F                          |           | N | I   |
| DP2000I        | Meriam Instrument  | Pressure Calibrator                 | 0 to 2,000 in H2O = 72.12 PSI       | annual    | Y | E   |
| MBT25-14M      | Kepco              | Power Supply, Programmable          | 0-25V, 0-14A                        |           | N | I   |
|                | Embros             | Current Shunt                       | 10A=100mV                           | annual    | Y | I   |
|                | FSEC               | Voltage Divider w/ capacitors       |                                     | Annual    | Y | I   |
| 22636-D7-AS-FC | Brooklyn           | Thermometer, Glass (with ice point) | 49 to 61 °. C. in 0.01 °. Divisions | ref. Std. | N | I   |
| 22626-D7-FC    | Brooklyn           | Thermometer, Glass                  | -1 to 11 C in 0.01 Division         | annual    | N | I   |
|                | Sagebrush          | MTP1-Dual Axis Tracker              |                                     | Annual    | Y | I   |
|                | Sagebrush          | MTP2-Dual Axis Tracker              |                                     | Annual    | Y | I   |
|                | Sagebrush          | MTP3-Dual Axis Tracker              |                                     | Annual    | Y | I   |
|                |                    | Barometer                           |                                     | N/A       | N | I   |
| LI-1800-Temp.  | LiCor              | Transfer Spectroradiometer          | 300-1100nm                          | annual    | Y | I/E |
| Q-8631         | Omega              | Gauge, Pressure                     | 0-600 psi                           | annual    | Y | E   |
| RTD RT2        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTD RT4        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTD ST2        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTD ST4        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTD-AR00F      | Rosemount-National | Temperature Measure, Ambient        |                                     | annual    |   | I   |
| RTD-RT3        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTD-ST3        | Rosemount-National | Temperature Measure                 |                                     | annual    | Y | I   |
| RTDRT1         | Rosemount-National | Temperature Measure                 |                                     | annual    | N | I   |
| RTDST1         | Rosemount-National | Temperature Measure                 |                                     | annual    | N | I   |

|                |                                   |                                                      |                            |                                        |   |
|----------------|-----------------------------------|------------------------------------------------------|----------------------------|----------------------------------------|---|
| T8813thruT8820 | Cast Iron Weight Set, Calibration | 1 thru 100 Pounds, in 8 steps, 213 # Total           |                            | annual Y                               | E |
| X09082         | Campbell Sci.                     | Datalogger                                           |                            | annual Y                               | I |
| 60103          | Qualimetrics                      | Precipitation gauge calibrator                       |                            | annual N                               | I |
| 6410           | Qualimetrics                      | Precipitation gauge wind screen                      |                            | N/A N                                  | I |
| 1500 1501      | Qualimetrics                      | Relative humidity module                             |                            | annual with relative humidity sensor N | I |
| 1240-A         | Qualimetrics                      | Wind direction module                                |                            | annual with wind direction sensor N    | I |
| 1222           | Qualimetrics                      | Wind speed module pulse input                        |                            | annual with wind speed sensor N        | I |
| 1705-001       | Qualimetrics                      | Barometric pressure module                           |                            | annual N                               | I |
| 18TB           | Payne Engineering                 | Power Control                                        |                            | N/A N                                  | I |
| M1303/0493     | Omega                             | Temperature/Process Controller, Microprocessor-Based |                            | N/A N                                  | I |
| 2166A          | Fluke                             | Thermometer, Multipoint Digital                      |                            | annual N                               | I |
| 4470-A         | Qualimetrics                      | Temperature Probe, Platinum                          |                            | annual N                               | I |
| 5320           | Qualimetrics                      | Dew Point Thermistor probe                           |                            | annual N                               | I |
| 5150-A         | Qualimetrics                      | Humidity calibration chamber                         |                            | 3 to 6 months N                        | I |
| 1420-A 1421-A  | Qualimetrics                      | Temperature module                                   | platinum resistance sensor | annual N                               | I |
| 1540 1541      | Qualimetrics                      | Dew point temperature                                | module thermistor input    | annual N                               | I |
| 1600 1601      | Qualimetrics                      | Event accumulator module                             |                            | annual N                               | I |