Designation: E905 – 87 (Reapproved 2007)

Standard Test Method for Determining Thermal Performance of Tracking Concentrating Solar Collectors[1]

This standard is issued under the fixed designation E905; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of thermal performance of tracking concentrating solar collectors that heat fluids for use in thermal systems.

1.2 This test method applies to one- or two-axis tracking reflecting concentrating collectors in which the fluid enters the collector through a single inlet and leaves the collector through a single outlet, and to those collectors where a single inlet and outlet can be effectively provided, such as into parallel inlets and outlets of multiple collector modules.

1.3 This test method is intended for those collectors whose design is such that the effects of diffuse irradiance on performance is negligible and whose performance can be characterized in terms of direct irradiance.

NOTE 1—For purposes of clarification, this method shall apply to collectors with a geometric concentration ratio of seven or greater.

1.4 The collector may be tested either as a thermal collection subsystem where the effects of tracking errors have been essentially removed from the thermal performance, or as a system with the manufacturer-supplied tracking mechanism.

1.4.1 The tests appear as follows:

	Section
Linear Single-Axis Tracking Collectors Tested as Thermal Collection Subsystems	11–13
System Testing of Linear Single-Axis Tracking Collectors	14–16
Linear Two-Axis Tracking and Point Focus Collectors Tested as Thermal Collection Subsystems	17–19
System Testing of Point Focus and Linear Two-Axis Tracking Collectors	20–22

1.5 This test method is not intended for and may not be applicable to phase-change or thermosyphon collectors, to any collector under operating conditions where phase-change occurs, to fixed mirror-tracking receiver collectors, or to central receivers.

1.6 This test method is for outdoor testing only, under clear sky, quasi-steady state conditions.

1.7 Selection and preparation of the collector (sampling method, preconditioning, mounting, alignment, etc.), calculation of efficiency, and manipulation of the data generated through use of this standard for rating purposes are beyond the scope of this test method, and are expected to be covered elsewhere.

1.8 This test method does not provide a means of determining the durability or the reliability of any collector or component.

1.9 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

2.2 *Other Standard:*

ASHRAE 93-86, Methods of Testing to Determine the Thermal Performance of Solar Collectors[3]

NOTE 2—Where conflicts exist between the content of these references and this test method, this test method takes precedence.

NOTE 3—The definitions and descriptions of terms below supersede any conflicting definitions included in Terminology E772.

3. Terminology

3.1 *Definitions:*

3.1.1 *area, absorber, n*—total uninsulated heat transfer surface area of the absorber, including unilluminated as well as illuminated portions. **(E772)**

[1] This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sourcesand is the direct responsibility of Subcommittee E44.05 on Solar Heating and Cooling Systems and Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from the American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., 1791 Tullie Circle, N.E. Atlanta, GA 30329.

3.1.2 *collector, point focus, n*—concentrating collector that concentrates the solar flux to a point. **(E772)**

3.1.3 *collector, tracking, n*—solar collector that moves so as to follow the apparent motion of the sun during the day, rotating about one axis or two orthogonal axes. **(E772)**

3.1.4 *concentration ratio, geometric, n*—ratio of the collector aperture area to the absorber area. **(E772)**

3.1.5 *quasi-steady state, n*—solar collector test conditions when the flow rate, fluid inlet temperature, collector temperature, solar irradiance, and the ambient environment have stabilized to such an extent that these conditions may be considered essentially constant (see Section 8).

3.1.6 *Discussion*—The exit fluid temperature will, under these conditions, also be essentially constant (see ASHRAE 93-86).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *altazimuthal tracking, n*—continual automatic positioning of the collector normal to the sun's rays in both altitude and azimuth.

3.2.2 *area, aperture (of a concentrating collector), n*—maximum projected area of a solar collector module through which the unconcentrated solar radiant energy is admitted, including any area of the reflector or refractor shaded by the receiver and its supports and including gaps between reflector segments within a module. **(E772)**

3.2.3 *clear-sky conditions, n*—refer to a minimum level of direct normal solar irradiance of 630 W · m^{-2} (200 Btu · ft^{-2} · h^{-1}) and a variation in both the direct and total irradiance of less than ±4 % during the specified times before and during each test.

3.2.4 *end effects, n*—in linear single-axis tracking collectors, the loss of collected energy at the ends of the linear absorber when the direct solar rays incident on the collector make a non-zero angle with respect to a plane perpendicular to the axis of the collector.

3.2.5 *fluid loop, n*—assembly of piping, thermal control, pumping equipment and instrumentation used for conditioning the heat transfer fluid and circulating it through the collector during the thermal performance tests.

3.2.6 *module, n*—the smallest unit that would function as a solar energy collection device.

3.2.7 *near-normal incidence, n*—angular range from exact normal incidence within which the deviations in thermal performance measured at ambient temperature do not exceed ±2 %, such that the errors caused by testing at angles other than exact normal incidence cannot be distinguished from errors caused by other inaccuracies (that is, instrumentation errors, etc.).

3.2.8 *rate of heat gain, n*—the rate at which incident solar energy is absorbed by the heat transfer fluid, defined mathematically by:

$$\dot{Q} = \dot{m} C_p \Delta t_a \quad (1)$$

3.2.9 *response time, n*—time required for Δt_a to decline to 10 % of its initial value after the collector is completely shaded from the sun's rays; or the time required for Δt_a to increase to 90 % of its value under quasi-steady state conditions after the shaded collector at equilibrium is exposed to irradiation.

3.2.10 *quasi-steady state, n*—refers to that state of the collector when the flow rate and inlet fluid temperature are constant but the exit temperature changes "gradually" due to the normal change in solar irradiance that occurs with time for clear sky conditions.

3.2.10.1 *Discussion*—It is defined by a set of test conditions described in 10.1.

3.2.11 *solar irradiance, direct, in the aperture plane, n*—direct solar irradiance incident on a surface parallel to the collector aperture plane.

3.2.12 *solar irradiance, total, n*—total solar radiant energy incident upon a unit surface area (in this standard, the aperture of the collector) per unit time, including the direct solar irradiance, diffuse sky irradiance, and the solar radiant energy reflected from the foreground.

3.2.13 *thermal performance, n*—rate of heat flow into the absorber fluid relative to the incident solar power on the plane of the aperture for the specified test conditions.

3.3 *Symbols:*

A_a = collector aperture area, m^2 (ft^2).

A_{abs} = absorber area, m^2 (ft^2).

A_1 = ineffective aperture area, m^2 (ft^2).

C = geometric concentration ratio A_a/A_{abs}, dimensionless.

C_p = specific heat of the heat transfer fluid, J · kg^{-1} ·° C^{-1} (Btu · lb^{-1} · °F^{-1}).

$E_{s,d}$ = diffuse solar irradiance incident on the collector aperture, W · m^{-2} (Btu · h^{-1} · ft^{-2}).

$E_{s,D}$ = direct solar irradiance in the plane of the collector aperture, W · m^{-2} (Btu · h^{-1} · ft^{-2}).

$E_{s,DN}$ = direct solar irradiance in the plane normal to the sun, W · m^{-2} (Btu · h^{-1} · ft^{-2}).

$E_{s,2\pi}$ = global solar irradiance incident on a horizontal plane, W · m^2 (Btu · h^{-1} · ft^{-2}).

$E_{s,t}$ = total solar irradiance incident on the collector aperture, W · m^{-2} (Btu · h^{-1} · ft^{-2}).

f = focal length, m (ft).

g = spacing between the effective absorbing surfaces of adjacent modules, m (ft).

K = incident angle modifier, dimensionless.

L = length of reflector segment, m (ft).

l_r = length of receiver that is unilluminated, m (ft).

m = mass flow rate of the heat transfer fluid, kg · s^{-1} (lbm · h^{-1}).

$\dot{Q}$ = net rate of energy gain in the absorber, W (Btu · h^{-1}).

$\dot{Q}_L$ = rate of energy loss, W (Btu · h^{-1}).

r = overhang of the receiver past the end of the reflectors, m (ft).

$R(\theta)$ = ratio of the rate of heat gain to the solar power incident on the aperture, dimensionless.

s = angle which the collector aperture is tilted from the horizontal to the equator, and is measured in a vertical N-S plane, degrees.

t_{amb} = ambient air temperature, °C (°F).

$_{\Delta}t_a$ = temperature difference across the absorber, inlet to outlet, °C (°F).

$_{\Delta}t_{a,i}$ = temperature difference across the absorber inlet to outlet at the time of initial quasi-steady state conditions, °C (°F).

$_{\Delta}t_{a,f}$ = temperature difference across the absorber inlet to outlet at the time final quasi-steady state conditions are reached, °C (°F).

$_{\Delta}t_{a,T}$ = temperature difference across the absorber inlet to outlet at time T, °C (°F).

$t_{f,i}$ = temperature of the heat transfer fluid at the inlet to the collector, °C (°F).

w = width of reflector segment, m (ft).

β = solar altitude angle, degrees.

$\Gamma(\theta_{||})$ = end effect factor, dimensionless.

δ = solar declination, degrees.

θ = angle of incidence between the direct solar rays and the normal to the collector aperture, degrees.

$\theta_{||}$, $\theta_{\perp}$ = angles of incidence in planes parallel and perpendicular, respectively, to the longitudinal axis of the collector, degrees.

θ_t = maximum angle of incidence at which all rays incident on the aperture are redirected onto the receiver of the same module, degrees.

θ'_c = minimum angle of incidence at which radiation reflected from one module's aperture is intercepted by the receiver of an adjacent module, degrees.

φ = solar azimuth angle measured from the south, degrees.

4. Summary of Test Method

4.1 Thermal performance is the rate of heat gain of a collector relative to the solar power incident on the plane of the collector aperture. This test method contains procedures to measure the thermal performance of a collector for certain well-defined test conditions. The procedures determine the optical response of the collector for various angles of incidence of solar radiation, and the thermal performance of the collector at various operating temperatures for the condition of maximum optical response. The test method requires quasi-steady state conditions, measurement of environmental parameters, and determination of the fluid mass flow rate-specific heat product and temperature difference, Δt_a, of the heat transfer fluid between the inlet and outlet of the collector. These quantities determine the rate of heat gain, $\dot{m}C_p\Delta t_a$, for the solar irradiance condition encountered. The solar power incident on the collector is determined by the collector area, its angle relative to the sun, and the irradiance measured during the test.

4.2 Two types of optical effects are significant in determining the thermal performance: (*1*) misalignment of the focal zone with respect to the receiver due to tracking errors and errors in the redirection of the irradiance intercepted by the collector, and (*2*) changes in the solar power incident on the collector aperture due to decreased projected area (cosine response) and other optical losses. The first effect is accounted for primarily in terms of the data generated for near-normal incidence thermal performance for a given collector. The cosine response portion of the second effect is accounted for by the determination of the solar power incident on the plane of the aperture. The departure of the optical response of the collector from the cosine response is determined by obtaining the incident angle modifier data. The incident angle modifier is important in predicting such collector characteristics as all-day thermal performance.

5. Significance and Use

5.1 This test method is intended to provide test data essential to the prediction of the thermal performance of a collector in a specific system application in a specific location. In addition to the collector test data, such prediction requires validated collector and system performance simulation models that are not provided by this test method. The results of this test method therefore do not by themselves constitute a rating of the collector under test. Furthermore, it is not the intent of this test method to determine collector efficiency for comparison purposes since efficiency should be determined for particular applications.

5.2 This test method relates collector thermal performance to the direct solar irradiance as measured with a pyrheliometer with an angular field of view between 5 and 6°. The preponderance of existing solar radiation data was collected with instruments of this type, and therefore is directly applicable to prediction of collector and system performance.

5.3 This test method provides experimental procedures and calculation procedures to determine the following clear sky, quasi-steady state values for the solar collector:

5.3.1 Response time,

5.3.2 Incident angle modifiers,

5.3.3 Near-normal incidence angular range, and

5.3.4 Rate of heat gain at near-normal incidence angles.

NOTE 4—Not all of these values are determined for all collectors. Table 1 outlines the tests required for each collector type and tracking arrangement.

5.4 This test method may be used to evaluate the thermal performance of either (*1*) a complete system, including the tracking subsystems and the thermal collection subsystem, or (*2*) the thermal collection subsystem.

5.4.1 When this test method is used to evaluate the complete system, the test shall be performed with the manufacturer's tracker and associated controls, and thus the effects of tracking error on thermal performance will be included in the results. Linear single-axis tracking systems may be supplemented with the test laboratory's tracking equipment to effect a two-axis tracking arrangement.

5.4.2 When evaluating a thermal collection subsystem, the accuracy of the tracking equipment shall be maintained according to the restrictions in 10.3.

5.5 This test method is to be completed at a single appropriate flowrate. For collectors designed to operate at variable flowrates to achieve controlled outlet temperatures, the collector performance shall be characterized by repeating this test method in its entirety for more than one flowrate. These flowrates should be typical of the actual operating conditions of the collectors.

5.6 The response time is determined to establish the time required for quasi-steady state conditions to exist before each

TABLE 1 Required Tests for Each Collector and Tracking Arrangement

Collector Type and Test Configuration	Test Method				
	Response Time	Incident Angle Modifier	Determination of Near-Normal Incidence Angular Range for Rate of Heat Gain at NNI	Determination of Near-Normal Incidence (NNI) for Tracking Accuracy Requirements	Heat Gain at Near-Normal Incidence
Linear Single-Axis Tracking Subsystem:					
One-axis Tracking					
Manufacturer's	×	×	×	×	×
Laboratory's	×	×	×	**	×
Two-Axis Tracking					
Manufacturer's and Laboratory's	×	×		×	×
Laboratory's only	×	×		**	×
Linear Single-Axis Tracking System:					
One-Axis Tracking					
Manufacturer's only	×	×	×		×
Two-Axis Tracking					
Manufacturer's and Laboratory's	×	×			×
Linear Two-Axis Tracking and Point Focus Subsystem:					
Manufacturer's	×			⊗	×
Laboratory's	×				×
Linear Two-Axis Tracking and Point Focus System:					
Manufacturer's only	×				×

× = Required.
⊗ = Required but method may not be practicable for point focus collectors—Safety precautions and technical precautions must be followed because of potential damage to equipment and subsequent damage to personnel due to high levels of solar irradiance on the receiver support structure.
** = Optional test that may provide useful information on the effect of the accuracy of the manufacturer's tracking equipment on thermal performance.

thermal performance test to assure valid test data, and to determine the length of time over which the quasi-steady state performance is averaged. The response time is calculated from transient temperature data resulting from step changes in intercepted solar irradiance with a given flow rate. Initial quasi-steady state conditions are established, the irradiance level is then increased or decreased suddenly, and the final quasi-steady state conditions are established. For most collectors covered by this test method, the difference in the response time determined by each of the two procedures will be small in terms of actual time. It is recognized that for some collectors, particularly those with long fluid residence times, the difference in the two values of response time may be large. However, the difference has not been found to influence the remainder of the test method.

5.7 The incident angle modifier is measured for linear single-axis tracking collectors so that the thermal performance at arbitrary angles of incidence can be predicted from the thermal performance measured at near-normal incidence as required in this test method. This is necessary because, during actual daily operation, linear single-axis tracking collectors will usually be normal to the sun only once or twice.

5.7.1 At non-zero angles of incidence, the thermal performance of a linear single-axis tracking collector may change for several reasons:

5.7.1.1 Increased or decreased reflectance, transmittance, and absorptance at the concentrator and receiver surfaces, or

5.7.1.2 Increased or decreased interception of the reflected or refracted solar radiant energy by the receiver.

5.7.1.3 That part of the decreased interception that is due to loss of collected energy at the ends of the absorber can be calculated analytically from the collector geometry as an end effects factor (see Appendix X1).

5.7.2 The preferred procedure for determining the incident angle modifier minimizes heat loss from the receiver by requiring that the working heat transfer fluid be the same as is used in the rest of the test method, and that it be maintained at an inlet temperature approximately equal to ambient temperature. It is realized, however, that this procedure may not be practical to perform as specified, since some heat transfer oils become too viscous near ambient temperatures to be pumped through the fluid test loop, or the fluid test loop cannot practicably cool the working fluid sufficiently to approximate the ambient temperatures that typically occur in the winter in cold climates. In these cases, either Alternative Procedure A or B may be used at the discretion of the manufacturer or supplier. Alternative Procedure A uses water as the working fluid at an inlet temperature approximately equal to ambient to minimize heat losses, but the procedure requires careful cleaning of the collector fluid passages, possibly use of a separate fluid test loop, and may cause corrosion if the collector fluid passages are incompatible with water. Alternative Procedure B uses the same heat transfer fluid as is used in the rest of the test method, but at an elevated temperature which is as close as practicable to ambient. Alternative Procedure B involves higher heat losses from the receiver which must be calculated and corrected for. An approximate correction for these heat losses is obtained in

Alternative Procedure B by determining the nonirradiated heat loss for the same fluid inlet temperature.

5.8 Determination of the angular range of near-normal incidence is required to establish the test conditions under which the measured thermal performance will adequately represent the thermal performance at true normal incidence.

NOTE 5—Measurement of angular range of the near-normal incidence also provides data that can be used to evaluate the sensitivity of the thermal performance of the tracking accuracy.

5.9 The thermal performance of the solar collector is determined under clear sky conditions and at near-normal incidence because these conditions are reproducible and lead to relatively stable performance.

6. Interferences

6.1 Alignment error, tracker pointing error, and the distorting effects of wind and gravity on the reflector and receiver may contribute to decreased thermal performance by decreasing the fraction of solar radiation incident on the collector aperture that strikes the absorber. The degree to which these errors affect collector thermal performance depends on the incident angle to the collector and the limits of the tracker, collector position and orientation relative to wind direction, wind speed, structural integrity of the collector and its support system, and so forth. Warping and sagging of the reflector due to heat have been observed, particularly in the case of linear trough concentrating collectors, also causing a decrease in the ability of the concentrator to direct the incident solar radiation to the absorber. Thermal expansion of the receiver may also occur under operating conditions of concentrated solar energy, and could cause damage to the receiver or the seals, possibly resulting in increased heat losses.

6.2 Soiling of the collector surfaces (reflector/refractor, absorber cover, etc.) may effectively reduce the solar energy available to the collector, in a way that is neither quantifiable nor reproducible.

6.3 Small variations in the level of solar irradiance during testing may cause considerable difficulties in maintaining quasi-steady state as required in 10.1.

6.4 Variations in the quality of the direct irradiance, comprising solar and circumsolar radiation, may give rise to irreducible fluctuations in the thermal performance because the angular responses of the collector and of the pyrheliometer differ. The wide availability of standard pyrheliometers and the difficulty of making custom instruments make it impractical to test each collector relative to a pyrheliometer with the same angular response as the collector.

6.5 Variations in the level of diffuse irradiance may affect the measured thermal performance, particularly for lower concentration ratio collectors. Therefore total (global) solar irradiance measurements are to be made to indicate the conditions under which the tests are performed, and to allow comparisons to be made with available meteorological data.

7. Apparatus

7.1 *Solar Irradiance Instrumentation*—The direct component of the solar irradiance shall be measured using a pyrheliometer on a separate sun-tracking mount. The opening angle of the instrument's field-of-view shall be between 5° arc and 6° arc. The instrument shall be a secondary reference or field use pyrheliometer whose calibration is directly traceable to a primary reference pyrheliometer. Only the WRR scale is permitted; in no case shall the IPS 1956 or other radiometric scale be used. The instrument shall be recalibrated at no greater than six month intervals. After calibration, the instrument and associated readout electronics shall be accurate to ±1.0 % of the measured value. This accuracy may be met through application of correction factors for temperature and linearity, if appropriate. The pointing error of the associated tracking mount shall not degrade the accuracy of the direct component measurement more than 0.5 %.

7.1.1 The global solar irradiance shall be measured using a pyranometer mounted in a horizontal orientation with the detector surface leveled. The instrument location shall be free from obstruction or enhancement of solar radiation due to nearby structures. The instrument may be a reference or a field use pyranometer, but its calibration shall be directly traceable to a primary reference pyrheliometer. Only the WRR scale is permitted. The instrument shall be recalibrated at no greater than six-month intervals. After calibration, the instrument and its associated readout electronics shall be accurate to ±2.0 % of the measured value. This accuracy may be met through application of correction factors for temperature, linearity, and cosine response, if appropriate.

7.1.2 It is also recommended that total irradiance be measured in the plane of the aperture with a pyranometer mounted to the collector on a suitable part of the tracking mechanism such that the total irradiance measured is indicative of that to which the collector is exposed. The pyranometer and its mount shall not shade or block the collector. The instrument may be a reference or a field use pyranometer, but its calibration shall be directly traceable to a primary reference pyrheliometer. Only the WRR scale is permitted. The instrument shall be recalibrated at no greater than six-month intervals. After calibration, the instrument and its associated readout electronics shall be accurate to ±2.0 % of the measured value. This accuracy may be met through the application of correction factors for temperature, linearity, cosine response, and tilt, if appropriate.

7.2 *($\dot{m}C_p$), Product Determination*—The determination of the ($\dot{m}C_p$)-product for the heat transfer fluid shall be accurate to ±2.0 % for each data point. This requirement holds whether the mass flow rate and specific heat are determined separately, or their product is determined using a reference heat source or other technique. The fluid temperature to be used in each determination shall be the average of the fluid temperature at the inlet and outlet of the collector.

7.3 Temperature and temperature difference measurements shall be made in accordance with ASHRAE 93 and meet or exceed its requirements for accuracy and precision.

7.4 All angular measurements except measurement of wind direction shall be accurate to within ±0.1°.

7.5 Any tracking system other than the manufacturer's tracker used by the test lab shall limit the aperture normal tracking error to 0.1° in all principal tracking axes required by the collector.

7.6 Irrespective of the means of collecting data for the determination of thermal performance (see 7.7) irradiance and fluid temperature shall be monitored at not greater than 10-s intervals such that variations in irradiance and fluid temperature stability can be assessed during all periods of quasi-steady state, before and during testing.

7.7 A data point for any variable shall be the average of at least 10 observations taken at intervals (scan rate) of no greater than 30 s. Each data point must meet all the requirements for quasi-steady state conditions, as listed in 10.1, where the allowable variation in any variable refers to the difference between the maximum and minimum observed values.

8. Precautions

8.1 *Safety Precautions*—Potential hazards in operating concentrating solar collectors include high pressures and high temperatures; toxic, flammable, and combustible materials; mechanical and electrical equipment; and concentrated solar radiation.

8.1.1 Pressurized fluids can be released if a rupture occurs or if a relief valve opens. Flashing of the heat transfer fluid may occur. Inspection for leaks and any potential hazards should be conducted frequently.

8.1.2 Caution should be exercised against accidental contact or exposure to components with elevated temperature. Protective gloves should be worn when touching any heated surfaces, including valves which are subject to being heated.

8.1.3 Materials soaked with heat transfer oils are a potential fire hazard and may even undergo spontaneous combustion when exposed to temperatures below the flash point of the fluid (approximately 150°C for some oils). These fluids should be cleaned up immediately should a spill occur, and the materials properly disposed of. Chemicals used for fluid treatment or for solvents have potentially toxic effects. Gloves, eye protection, and aprons should be worn when handling these chemicals.

8.1.4 Moving elements associated with collector tracking may pose entanglement hazards while the collector is under test. If necessary, considerations should be given to shielding these moving elements and providing safety override/controls interlocks. General precautions applicable to the operation of electrical systems should be followed.

8.1.5 High levels of solar radiation that exist during collector testing present a high-temperature hazard to exposed skin and also an intense light hazard to the eyes. Therefore, concentrated solar radiation should be avoided whenever possible. When maintenance is required on the reflector side of the collector, the collector should be positioned so that the reflective surface is shadowed.

8.2 *Technical Precautions:*

8.2.1 Damage to equipment can occur very quickly if for any reason concentrated solar radiation is focused on parts of the collector other than the receiver. This may occur when the collector is not tracking in normal operation, but is not properly stowed so that solar radiation is still incident on the collector aperture and at some point is focused on a part of the receiver support structure, for example.

8.2.2 Damage to the tracker and any piping, wires, etc. attached to the collector may occur in attempting to achieve certain angles of incidence during testing, if precautions have not been taken to stay within the collector's operational limits.

8.2.3 Most concentrating solar collectors require very steady irradiance in order to maintain quasi-steady state conditions. Therefore, a two-axis tracking arrangement is preferred for testing, such that the collector is constantly directed at the sun for near-normal incidence testing, or is maintained at a given angle of incidence, unless such positioning would subject the collector to conditions for which it was not designed. (Such conditions must be specified by the manufacturer.) The testing laboratory's tracking devices may be used to supplement the collector's tracking mechanism to achieve two-axis tracking. If a two-axis tracking arrangement is not used, then the collector shall be allowed to track normally. A two-axis tracking arrangement may be required for testing collectors with long response times in order to maintain quasi-steady state conditions.

9. Preparation of Apparatus

9.1 The collector shall be installed and aligned properly according to a test method approved by the manufacturer.

9.2 Collector surfaces exposed to the environment shall be cleaned at the beginning of each test day according to the manufacturer's recommended procedures. The test method used for cleaning shall be reported in full.

9.3 The geographical location (latitude and longitude) of the collector shall be determined and reported to an accuracy of ±0.1°. Where applicable, the orientation of any fixed collector axis shall be measured to an accuracy of ±0.1 % and reported.

9.4 The pyrheliometer and pyranometer shall be inspected at the beginning of each day at which time the outer glass surface shall be cleaned and dried if dirt or moisture are present. Any evidence of moisture or debris in the interior of the instrument shall be cause to remove it from service.

9.5 The pyrheliometer tracker shall be checked and adjusted for proper alignment periodically throughout the test day.

10. Test Conditions

10.1 Since measurements for determining the rate of heat gain are not made simultaneously at the inlet and outlet of the collector and hence not on the same element of fluid, quasi-steady state conditions are required to ensure valid results. Except where noted, these conditions must exist for a time period equal to two times the response time before each test, and for the duration of each test, which shall be the longer of 5 min or one-half the response time. Quasi-steady state conditions will be said to exist when the requirements in 10.1.1 through 10.1.6 are met.

10.1.1 Inlet temperature to the collector, $t_{f,i}$, shall vary less than ±0.2°C (±0.4°F) or ±1.0 % of the value of Δt_a, whichever is larger, during the specified time before and during each test.