METHOD 505.7

SOLAR RADIATION (SUNSHINE)

CONTENTS

CONTENTS - Continued

CONTENTS - Continued

Paragraph **Page**

ANNEX A TABLE

METHOD 505.7, ANNEX B
INSTRUMENTATION INSTALLATION, PLACEMENT AND GUIDANCE

ANNEX B TABLE

METHOD 505.7, ANNEX C
GUIDANCE ON TABLES AND FIGURES

ANNEX C TABLES

ANNEX C FIGURES

(This page is intentionally blank.)

METHOD 505.7

SOLAR RADIATION (SUNSHINE)

NOTE: Tailoring is essential. Select methods, procedures, and parameter levels based on the tailoring process described in Part One, paragraph 4.2.2, and Annex C. Apply the general guidelines for laboratory test methods described in Part One, paragraph 5 of this standard.

1. SCOPE.

1.1 Purpose.

This method has two purposes:

a. To determine the heating effects of solar radiation on materiel.

b. To help identify the actinic (photo degradation) effects of exposure to solar radiation.

1.2 Application.

Use this method to evaluate materiel likely to be exposed to solar radiation during its life cycle in the open in hot climates, and when heating or actinic effects are of concern. This Method is valuable in evaluating the effects of direct exposure to sunlight (solar spectrum and energy levels at sea level). Procedure I is useful in determining the temperature increase (over ambient) of materiel caused by solar loading. Although not intended for such, Procedure II may be used to simulate the ultraviolet effect of solar radiation at different locations and altitudes by using various radiation sources that allow reasonable comparison to measurements of these natural solar radiation conditions.

In addition to using Procedure I to evaluate the effects of direct sunlight (actinic effects as well as directional and non-uniform heating for exposed materiel), use Procedure I for determining the heating effects (response temperature) for materiel enclosed within an outer container.

Use Procedure II to evaluate the actinic effects on materiel exposed to long periods of sunshine. The spectrum of the solar array must be measured and conform to the spectrum identified in Table 505.7-I. Deviations from this table may be justified if the test requirements are based on the tailoring process, or if a specific frequency band is of concern. Detail and justify any deviation.

1.3 Limitations.

a. This test Method does not consider all of the effects related to the natural environment (see Annex A, paragraph 7.2) and, therefore, it is preferable to test materiel at appropriate natural sites.

b. If the installed environment for an item is within an enclosure, the enclosure must be provided in order to characterize the environment and properly address the heating effects. Once the enclosed environment has been characterized, further testing could be done using Method 501.7.

c. This Method is not intended to be used for space applications due to the change in irradiance.

2. TAILORING GUIDANCE.

2.1 Selecting this Method.

After examining requirements documents, review of the LCEP, and applying the tailoring process in Part One of this Standard to determine where solar radiation effects are foreseen in the life cycle of the test item, use the following to confirm the need for this Method and to place it in sequence with other methods.

2.1.1 Effects of Solar Radiation Environments.

2.1.1.1 Heating Effects.

The heating effects of solar radiation differ from those of high air temperature alone in that solar radiation generates directional heating and thermal gradients. In the solar radiation test, the amount of heat absorbed or reflected depends primarily on the absorptive or reflective surface properties (e.g., roughness, color, etc.) on which the radiation is incident. If a glazing system (glass, clear plastic, or translucent media, e.g., windshield) is part of the test item configuration, and the component of concern is exposed to solar energy that has passed through the glazing system, use a full spectrum source. In addition to the differential expansion between dissimilar materials, changes in the intensity of solar radiation may cause components to expand or contract at different rates that can lead to severe stresses and loss of structural integrity. In addition to those identified in Method 501.7, consider the following typical problems to help determine if this Method is appropriate for the materiel being tested. This list is not intended to be all-inclusive.

a. Jamming or loosening of moving parts.

b. Weakening of solder joints and glued parts.

c. Changes in strength and elasticity.

d. Loss of calibration or malfunction of linkage devices.

e. Loss of seal integrity.

f. Changes in electrical or electronic components.

g. Premature actuation of electrical contacts.

h. Changes in characteristics of elastomers and polymers.

i. Blistering, peeling, and de-lamination of paints, composites, and surface laminates applied with adhesives such as radar absorbent material (RAM).

j. Softening of potting compounds.

k. Pressure variations.

l. Sweating of composite materials and explosives.

m. Difficulty in handling.

2.1.1.2 Actinic Effects.

In addition to the heating effects of paragraph 2.1.1.1, certain degradation from solar energy may be attributable to other portions of the spectrum, particularly the ultraviolet. Since the rate at which these reactions will occur generally increases as the temperature rises, use the full spectrum to adequately simulate the actinic effects of solar radiation. The following are examples of deterioration caused by actinic effects. The list is not intended to be comprehensive.

a. Fading of fabric and plastic color.

b. Checking, chalking, and fading of paints.

c. Deterioration of natural and synthetic elastomers and polymers through photochemical reactions initiated by shorter wavelength radiation. (High strength polymers such as Kevlar are noticeably affected by the visible spectrum. Deterioration and loss of strength can be driven by breakage of high-order bonds (such as pi and sigma bonds existing in carbon chain polymers) by radiation exposure.)

2.1.2 Sequence Among Other Methods.

a. General. Use the anticipated life cycle sequence of events as a general sequence guide (see Part One, paragraph 5.5).

b. Unique to this Method. Generally, consider applying the solar radiation test at any stage in the test program. However, high temperatures or actinic effects could affect material's strength or dimensions that could affect the results of subsequent tests such as vibration.

2.2 Selecting Procedures.

This Method includes two test procedures: Procedure I (Cycling for heating effects) and Procedure II (Steady State for actinic effects). Determine the procedure(s) to be used.

2.2.1 Procedure Selection Considerations.

When selecting procedures, consider:

a. The operational purpose of the test item. Physical degradation that occurs during exposure may produce adverse effects on materiel performance or reliability. Based on the purpose of the materiel, determine functional modes and test data needed to evaluate the performance of the test item during and after exposure to solar radiation.

b. The anticipated areas of deployment.

c. The test item configuration.

d. The anticipated exposure circumstances (use, transportation, storage, etc.).

e. The expected duration of exposure to solar radiation.

f. The expected problem areas within the test item.

Caution: When temperature conditioning, ensure the total test time at the most severe temperature does not exceed the life expectancy of any material (see Part One, paragraph 5.19).

2.2.2 Difference Between Procedures.

While both procedures involve exposing test items to simulated solar radiation, they differ on the basis of timing and level of solar loads. Procedure I is designed to determine the heat produced by solar radiation, and effects of that heat by exposing materiel to continuous 24-hour cycles of simulated solar radiation (or thermal loading) at realistic maximum levels typical throughout the world. Procedure II (Steady State (actinic effects)) is designed to accelerate photo degradation effects produced by solar radiation. This procedure exposes materiel to cycles of intensified solar loads (approximately 2.5 times normal levels) interspersed with dark periods to accelerate actinic effects that would be accumulated over a longer period of time under normal solar loads. Actual acceleration ratios are material dependent, and 2.5 times the natural solar exposure may not provide equal acceleration. This could, however, provide a more rapid test provided the failure mechanisms follow the path expected in the real environment. The key to using either procedure successfully is maintaining enough airflow to prevent the test item from exceeding temperatures that would be attained under natural conditions. Therefore, prior to conducting Procedure II, the maximum response temperature from procedure I or field/fleet data must be known. However, do not use so much airflow that it produces unrealistic cooling.

a. <u>Procedure I – Cycling (heating and/or minimal actinic effects)</u>. Use Procedure I to investigate response temperatures when materiel is exposed in the open in realistically hot climates, and is expected to perform without degradation during and after exposure. Although Procedure I can be performed using simple heat-generating lamps (providing the guidance in paragraph 4.1.2 is followed), limited evaluation of actinic effects is possible if full spectrum lamps are used instead. It is preferable to use the solar radiation test (as opposed to the High Temperature test, Method 501.7) when the materiel could be affected by differential heating (see paragraph 2.1.1.1), or when the levels or mechanisms of heating caused by solar radiation are unknown (this encompasses almost all materiel).

b. <u>Procedure II – Steady State (actinic effects)</u>. Use Procedure II to investigate the effects on materiel of long periods of exposure to sunshine. Actinic effects usually do not occur until materiel surfaces receive large amounts of sunlight (as well as heat and moisture). Therefore, it is inefficient to use the repeated, long cycles of normal levels of solar radiation (as in Procedure I) to generate actinic effects. Using Procedure I for this purpose could take months. The approach, therefore, is to use an accelerated test that is designed to reduce the time to reproduce cumulative effects of long periods of exposure. The 4-hour "lights-off" period of each 24-hour cycle allows for test item conditions (physical and chemical) to return toward "normal" and provide some degree of thermal stress exercising. The key to using Procedure II successfully is maintaining enough cooling air to prevent the test item from exceeding peak response temperatures that would be attained under natural conditions or Procedure I.

Temperatures of Categories A1 and A2 in °C, Solar Radiation (W) in W/m²

A1	37	35	34	34	33	33	32	33	35	38	41	43	44	47	48	48	49	48	48	46	42	41	39	38	37
A2	33	33	32	32	31	30	30	31	34	37	39	41	42	43	44	44	44	43	42	40	38	36	35	34	33
W	0	0	0	0	0	0	55	270	505	730	915	1040	1120	1120	1040	915	730	505	270	55	0	0	0	0	0

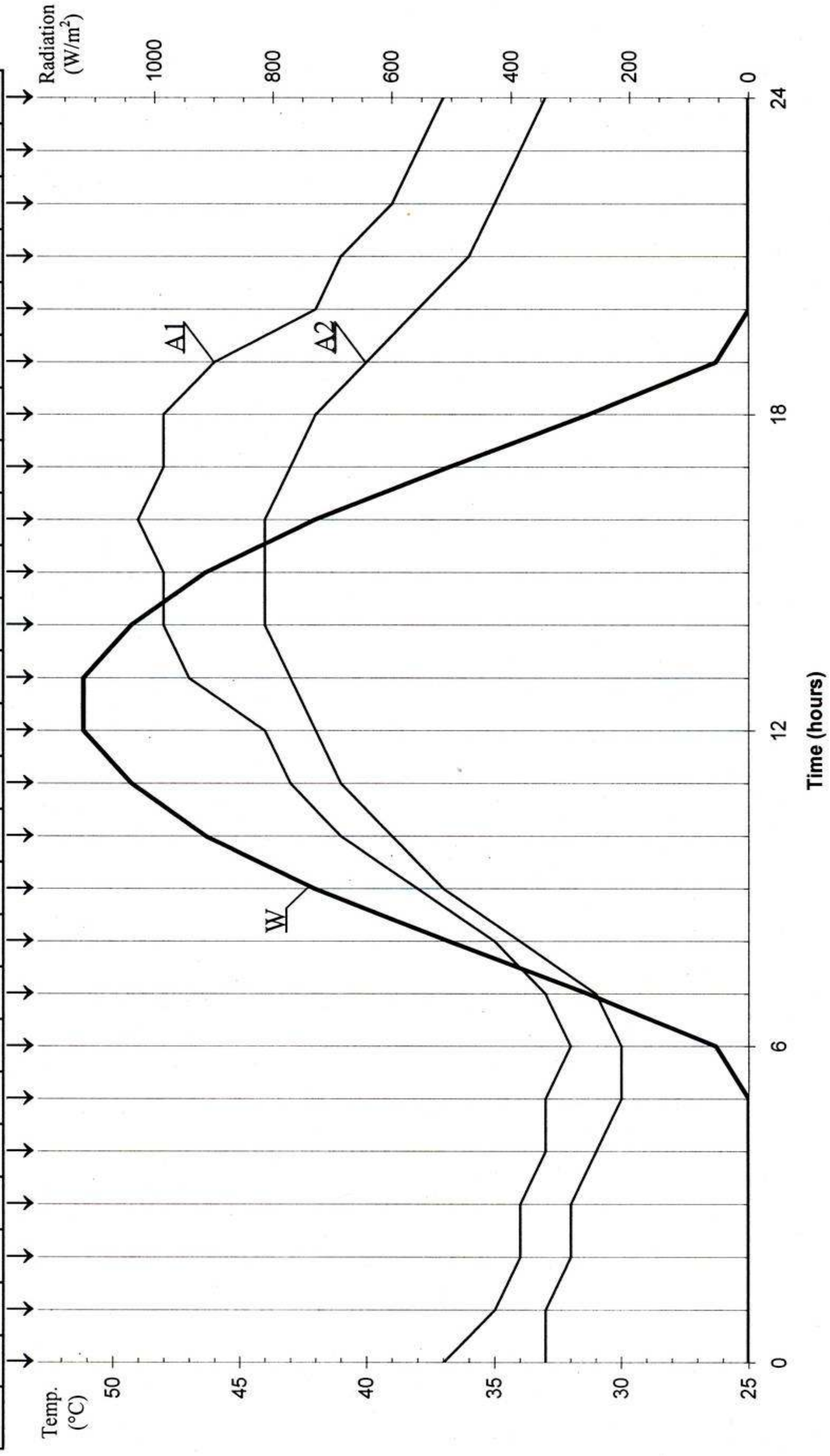


Figure 505.7-1. Procedure I – Cycling test.

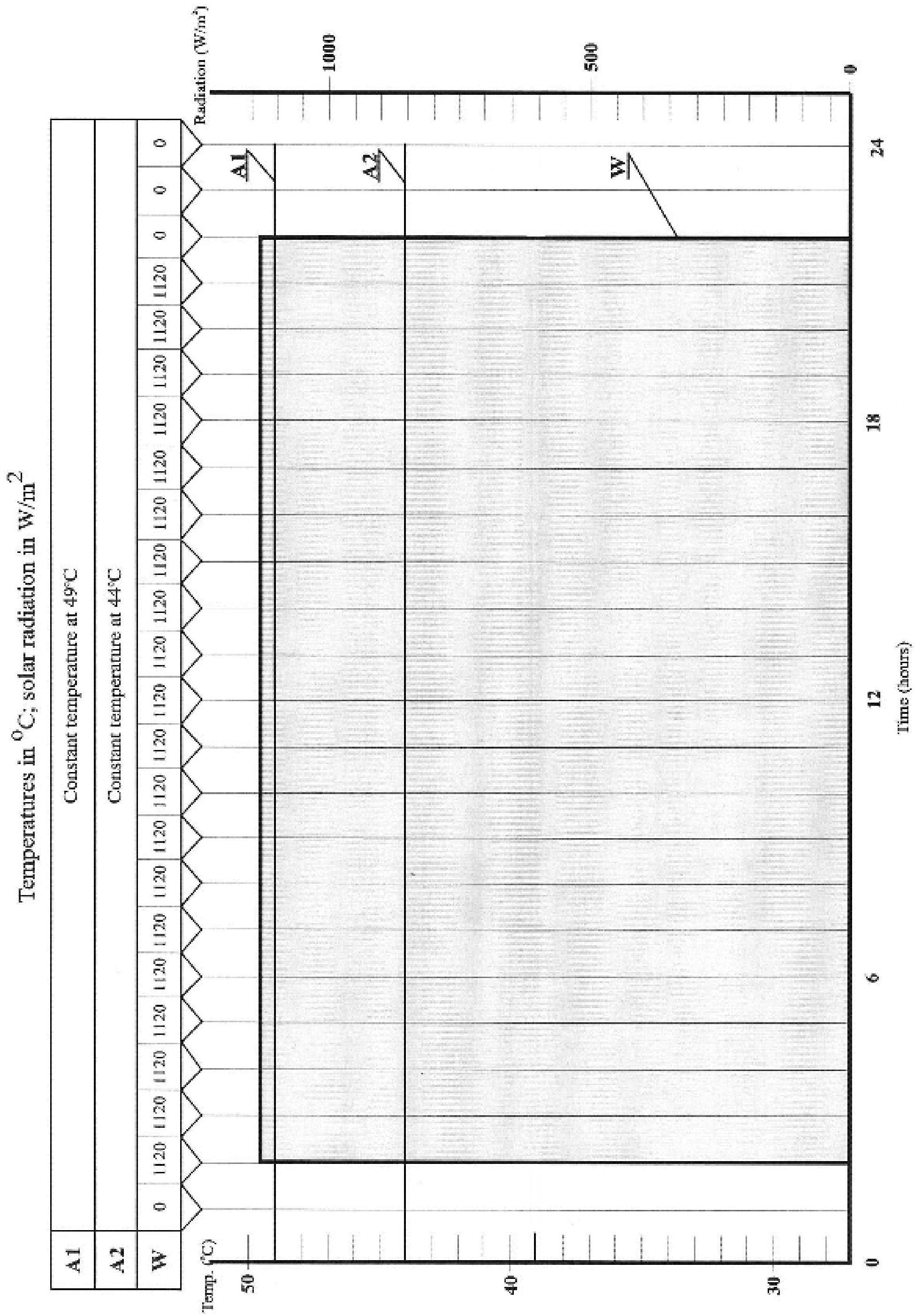


Figure 505.7-2. Procedure II – Steady state test.

2.3 Determine Test Levels and Conditions.

Having selected this Method and relevant procedures (based on the materiel's requirements documents and the tailoring process), complete the tailoring process by identifying appropriate parameter levels, special test conditions and techniques for these procedures such as the diurnal cycle, test duration, test item configuration, relative humidity, and any additional appropriate conditions. Base these test parameter levels on the Life Cycle Environmental Profile (LCEP – Part One Task 402), requirements documents (see Part One, Figure 1-1), and information provided with this Method. Consider the following in light of the operational purpose and life cycle of the materiel.

2.3.1 Climatic Conditions.

For Procedure I, there are two high temperature diurnal cycles included that correspond to the maximum meteorological conditions in the two climatic categories, A1 and A2 of MIL-HDBK-310 (paragraph 6.1, reference a). Figure 505.7-1 shows the daily cycles of temperature and solar radiation corresponding to categories A1 and A2 for Procedure I. Choose the conditions for the test according to the planned climatic categories for use of the materiel:

a. Worldwide deployment. Cycle A1 has peak conditions of 1120 W/m^2 (355 BTU/ft^2/hr) and 49 °C (120 °F) (but not occurring at the same time of day), and is normally accompanied by some degree of naturally occurring winds. It represents the hottest conditions exceeded not more than one percent of the hours in the most extreme month at the most severe locations that experience very high temperatures accompanied by high levels of solar radiation, namely, hot, dry deserts of north Africa, southwest and south central Asia, central and western Australia, northwestern Mexico, and the southwestern USA.

b. Cycle A2 has peak conditions of 1120 W/m^2 and 43 °C (110 °F) (but not occurring at the same time of day) and represents less severe conditions at locations that experience high temperatures accompanied by high levels of solar radiation, winds, and moderately low humidity, namely, the most southerly parts of Europe, most of the Australian continent, south central Asia, northern and eastern Africa, coastal regions of north Africa, southern parts of the US, and most of Mexico. Use this cycle when the materiel is to be used only in geographical locations described in category A2, but not in category A1.

c. Figure 505.7-2 shows the corresponding temperature and solar radiation levels for Procedure II.

2.3.2 Test Duration.

a. Procedure I. Expose the test item to continuous 24-hour cycles of controlled simulated solar radiation and temperature as indicated on Figure 505.7-1 or as identified in the requirements documents. A goal of this test is to establish the highest temperature that the test item will reach during repeated cycles. Perform at least three continuous cycles. If the maximum of the peak response temperature of the previous 24-hour cycle) is not reached (±2 °C (±3.6 °F)) during three cycles, continue the cycles until repeated peak temperatures are reached, or for seven cycles, whichever comes first. In the absence of other guidance, the maximum test duration of seven cycles was chosen because the peak high temperature for the selected climatic region occurs approximately one hour in each of seven cycles in the most extreme month. If more exact simulation is required, consult meteorological data for the particular areas under consideration. This may include adjustment of solar energy, if appropriate, to account for latitude, altitude, month of anticipated exposure, or other factors (for example, a product exclusively used in northern areas, or exclusively used in winter months). Any deviation from the standard conditions must be detailed and justified in the test report.

b. Procedure II. Procedure II produces an acceleration factor of approximately 2.5 as far as the total energy received by the test item is concerned, i.e., one 24-hour cycle as shown on Figure 505.7-2 provides approximately 2.5 times the solar energy experienced in one 24-hour (natural) diurnal cycle plus a 4-hour lights-off period to allow for alternating thermal stressing and for the so-called "dark" processes to occur. To simulate 10 days of natural exposure, for instance, perform four 24-hour cycles as shown on Figure 505.7-2. Recommend ten 24-hour cycles (as on Figure 505.7-2) for materiel that is occasionally used outdoors, such as portable test items, etc. For materiel continuously exposed to outdoor conditions, recommend 56 or more 24-hour cycles. Do not increase the irradiance above the identified level. Presently there is no indication that attempting to accelerate the test in this way gives results that correlate with materiel response under natural solar radiation conditions.

2.3.3 Humidity.

Various levels of relative humidity occur naturally, and humidity combined with temperature and solar radiation can, in many cases, have deleterious effects on materiel. If the materiel is known or suspected to be sensitive to RH, include it in the Procedure I test requirements. MIL-HDBK-310 and NATO STANAG 4370, AECTP 230, (paragraph 6.1, references a and b) have temperature-humidity data for various regions of the Earth.

2.3.4 Configuration.

a. Use the same test item configuration as during exposure to natural solar radiation. The orientation of the test item relative to the direction of radiation will have a significant impact on the heating effects. In cases where several test item components are already known to be sensitive to solar effects, consider adjusting the relative test item/solar radiation source orientation to simulate a natural diurnal cycle. Whenever possible, mount the test item so that its configuration is representative of actual deployment, as provided in the requirements document. This mounting may include supports or a substrate of specified properties (e.g., a layer of concrete of specified thickness or a sand bed of certain reflectivity). (See paragraph 4.1.1.)

b. Surface contamination. Dust and other surface contamination may significantly change the absorption characteristics of irradiated surfaces. Unless otherwise required, ensure the test items are clean when tested. However, if the effects of surface contamination are to be assessed, include in the relevant requirements document the necessary information on preparation of surfaces.

2.3.5 Spectral Power Distribution - Sea Level versus High Ground Elevations.

At high ground elevations solar radiation contains a greater proportion of damaging UV radiation than at sea level. Although the internationally agreed spectrum shown in Table 505.7-I is recommended for general testing, it is a closer representation of the real environment at sea level. This standard spectrum may be used (unless other data are available) for both sea level and high ground elevations.

Table 505.7-I. Spectral power distribution.

Spectral Region	Bandwidth (nm)	Natural Radiation (% of total)	Tolerance (% of total)		Irradiance (W/m^2)	Spectral Region Irradiance (W/m^2)
			Min	Max		
Ultraviolet - B	280-320	0.5	0.3	0.7	5.6	5.6
Ultraviolet - A	320-360	2.4	1.8	3	26.9	62.7
	360-400	3.2	2.4	4.4	35.8	
Visible	400-520	17.9	16.1	19.7	200.5	580.2
	520-640	16.6	14.9	18.3	185.9	
	640-800	17.3	12.8	19	193.8	
Infrared	800-3000	42.1	33.7	50.5	471.5	471.5
				Totals	1120	1120

NOTE: The amount of radiation wavelength shorter than 300 nm reaching the Earth's surface is small but the effect on the degradation of material can be significant. Short wavelength energy below 300 nm can cause materials to fail unnecessarily (if not present in the natural exposure). In reverse, if energy below 300 nm is present in the natural environment and not present in the accelerated exposure, material that should fail may pass the test. This is entirely material dependent because it relates to the end use in natural exposure. Values in the above table have been taken from DIN 75220. (See Annex A, paragraph 2.2.)

2.3.6 Temperature.

In addition to the temperature guidance given elsewhere in this Method, it is essential to maintain the air temperature in the vicinity of the test item to that in the respective profile (A1 or A2) or as specified in the test plan. To do so requires necessary airflow and air temperature measurement (sensors shielded from radiation) in the immediate vicinity of the test item. See Annex A, paragraph 5.2 for temperature measurement guidance.

2.3.7 Airflow.

The key to using this Method successfully is maintaining enough airflow to obtain the test item peak response temperatures that would be attained under natural conditions.

For Procedure I, use an airspeed of 1.5 to 3.0 m/sec (300 to 600 ft/min) unless otherwise specified. If the deployed environment will subject the item to either limited or no wind speed (shielded from natural wind), then use a minimum air speed, no less than 0.25 m/sec (50 ft/min), when conducting Procedure I. Generally, an airflow of as little as 1 m/s

(200 ft/min) can cause a reduction in temperature rise of over 20 percent as compared to still air. To ensure test repeatability, the air speed must be measured and recorded in the test report.

For Procedure II, use the minimum required airspeed required to maintain the thermal response as measured in the natural environment or Procedure I. This implies that before this test can be performed, the maximum temperature response the materiel would experience under natural conditions (by using field/fleet data or as determined by running Procedure I) must be known. However, do not use so much cooling air that it produces unrealistic cooling. Similarly, if multiple and identical test items are to be tested, use one or more of the items for the preliminary test to determine the maximum temperature response. Since actinic effects are highly dependent upon the solar radiation spectrum (as well as intensity and duration), the spectrum must be as close as possible to that of natural sunlight (see Table 505.7-I).

2.4 Test Item Operation.

When it is necessary to operate the test item, use the following guidelines for establishing test operating procedures.

WARNING: If the sheltered environment is intended to be occupied by personnel during exposure to high temperature, it is recommended that sensors are installed to detect VOCs, CO, and Phthalates due to potential out-gassing.

a. General. See Part One, paragraph 5.8.2.

b. Unique to this Method.

(1) Include operating modes that consume the most power (generate the most heat).

(2) Include the required range of input voltage conditions, if changes in voltage could affect the test item thermal dissipation or response (e.g., power generation or fan speed).

(3) Introduce any cooling media that normally would be applied during service use (e.g., forced air or liquid coolant). Consider using cooling medium inlet temperatures and flow rates that represent both typical and worst-case degraded temperature and flow conditions.

3. INFORMATION REQUIRED.

3.1 Pretest.

The following information is required to conduct solar radiation tests adequately.

a. General. Information listed in Part One, paragraphs. 5.7 and 5.9, and Annex A, Task 405 of this Standard.

b. Specific to this Method.

(1) Appropriate diurnal cycle (for Procedure I) to include humidity if appropriate.

(2) Test item operational requirements.

(3) Spectral power distribution of the source lighting (e.g., to reproduce conditions of a previous test).

(4) Any additional guidelines.

(5) Temperature/radiation measurement techniques and locations.

(6) Substrate or method of test item mounting.

(7) Wind speed.

(8) Identify sensor location(s) for determination of peak response temperature stabilization.

(9) Location and mounting configuration for the pyranometer (see Annex B, paragraph 1.3)

c. Tailoring. Necessary variations in the basic test procedures to accommodate environments identified in the LCEP.

3.2 During Test.

Collect the following information during conduct of the test:

a. General. Information listed in Part One, paragraph 5.10, and in Annex A, Tasks 405 and 406 of this Standard.

b. Specific to this Method.

(1) Record of chamber temperatures (and humidity if required) and light intensity versus time conditions.

(2) Record of the test item temperature-versus-time data for the duration of the test.

(3) Record of test wind speed.

3.3 Post-Test.

The following post-test data shall be included in the test report.

a. General. Information listed in Part One, paragraph 5.13, and in Annex A, Task 406 of this Standard.

b. Specific to this Method.

(1) Location of temperature sensors on the test item.

(2) Test item response temperatures (and humidity if required), and number of diurnal cycles or exposure periods.

(3) Record of test wind speed.

(4) Spectral power distribution of the source lighting (e.g., to reproduce conditions of a previous test).

(5) Solar lamp bank identification.

(6) Any additional data required.

(7) Any deviations from the original test plan – to include wind speed (if necessary to adjust it).

(8) Any deviation from the required spectral power distribution as stated in Table 505.7-I, and justification.

(9) Location and mounting configuration for the pyranometer

4. TEST PROCESS.

4.1 Test Facility.

a. The facility requirements consist of a chamber or cabinet, auxiliary instrumentation, and a solar lamp bank. This apparatus must be capable of maintaining and monitoring (see Part One, paragraph 5.18) the required conditions of temperature, airflow, and irradiation.

b. Full spectrum lamps are recommended for both procedures, however Procedure I can be performed using lamps that do not meet the spectral energy distribution of Table 505.7-I, provided the guidance in paragraph 4.1.2 is followed.

c. For both procedures consider the possible cooling effects of airflow over the test specimens. Caution is advised on the use of the low airspeed; rarely do high solar and high temperature events occur in nature without accompanying winds.

(1) Procedure I: Unless otherwise justified, use an airspeed between 1.5 to 3.0 m/sec (300 to 600 ft/min). See paragraph 2.3.7 for additional details.

(2) Procedure II: Unless otherwise justified, use an airflow rate sufficient enough to maintain the test item response temperature that was either determined from Procedure I or obtained from field data.

d. To minimize or eliminate re-radiation from chamber surfaces, experience has shown that the best method is when the volume of the test chamber is a minimum of 10 times that of the envelope volume of the test item. (Consider the beam angles of the light source hitting the walls of the test chamber.)

e. It is recommended that the solar radiation source area be such that the length and width of the target area of the test item are no more than one-half the dimensions of the lamp bank.

4.1.1 Substrate.

Mount the test item either on raised supports or on a substrate of specified properties, e.g., a layer of concrete of specified thickness or a sand bed of a thermal conductivity and reflectivity representative of actual deployment, as provided in the requirements documents.

4.1.2 Solar Radiation Source.

a. Full spectrum lamps are recommended for both procedures.

b. Use a maximum irradiance intensity of 1120 W/m^2 (±4 percent or 15 W/m^2, whichever is greater) and ensure the radiation across the upper surface of the test item area of concern is uniform to within 10 percent of the desired value.

c. The diurnal variation in solar energy may be applied continuously (see Figure 505.7-I) or incrementally (see Figures 505.7C-5 and -6), with a minimum of eight levels, provided that the total energy of the cycle is maintained.

d. Where only thermal effects, Procedure I, are being assessed, it is essential to maintain at least the visible and infrared portions of the spectrum as in Table 505.7-I. However, if not feasible, deviate from the spectral distribution as necessary, but adjust the irradiance to give an equivalent heating effect. Document any deviation from the solar power distribution (Table 505.7-I), and record it in the test report. If using infrared lamps, exercise caution because infrared-reflecting/absorbing coatings will reflect or absorb energy based on spectrum and an infrared light system may not produce realistic thermal effects when various material colors and structures are under evaluation. If a glazing system is incorporated in the materiel (see paragraph 2.1.1.1), verify that the infrared transmission is not affected when using an infrared source. Use a full spectrum source if attenuating coatings, glazing, or other systems that may affect spectral reflection/absorption are used in/on the test item. In order to determine the amount of adjustment necessary, employ either of two methods below, and document it in the test report:

(1) Mathematically calculate the adjustment using the spectral reflectance or transmittance of the irradiated surfaces, and the spectral energy distribution of the particular lamps being used (and also the effect of any associated reflectors or glasses).

(2) Empirically determine the adjustment by conducting a pre-test on samples that are representative of the materiel (the most important characteristics are material composition, color, and surface roughness). Measure the temperature rise above ambient air temperature of test samples under natural solar radiation conditions (the climatic category identified in the LCEP as the most extreme), and compare the results with the temperature rise above ambient (chamber) air temperature of test samples under simulated solar radiation. Gather an adequate amount of data under the natural condition portion of the test to account for the cooling effects of airflow over the samples (i.e., outdoor conditions rarely provide zero wind), and extrapolate the temperature rise at zero wind conditions to be comparable to results from chamber samples. This process requires the use of extensive multi-year stable data sets to establish a statistically viable analysis.

e. Where actinic effects are to be assessed, (Procedure II), ensure the spectral distribution of the light source adheres to the distribution given in Table 505.7-I (within the given tolerances).

f. Direct the radiation onto the test item and irradiate the entire surface of the test item facing the solar radiation source. To provide the highest degree of confidence in the measurements, the value of 1120 W/m^2 theoretically includes all radiation received by the test item, including any radiation reflected from the chamber walls and any long-wave infrared radiation (but not greater than 3 μm) emitted by the chamber walls. Radiation reflected or emitted from the chamber walls is generally substantially lower than the radiation emitted directly from the light source, and a measurement device that has a measurement range of 285-2800 nm should be sufficient to measure direct and reflected radiation. Additionally, if the intent of the test is to determine thermal heat loading (see paragraph 4.1.2h(2)), use a radiation measuring device that has the capability to measure infrared energy, and calibrate the radiation measuring device in the full wavelength range it is designed to measure.

g. To prevent localized effects such as unintentional heating from individual bulbs, locate the radiation source at least 76 cm (30 inches) away from any surface of the test item. Spot lamps (as opposed to flood lamps) may produce a non-uniform exposure.

h. Light source. The following lists are not intended to exclude new lamps made available by advanced technology. It may be necessary to use filters to make the spectrum comply with that specified in Table 505.7-I. Further guidance is given in Annex A.

(1) Tests conducted for degradation and deterioration of materials due to actinic effects as well as heat buildup within the test items must satisfy the full spectrum of Table 505.7-I and may use one of the following acceptable radiation sources:

(a) Metal halide lamps (designed for full spectrum application).

(b) Xenon arc or mercury xenon arc (used singularly) with suitable reflector.

(c) Combination of high pressure sodium vapor and improved mercury vapor with suitable reflectors.

(d) High-intensity multi-vapor, mercury vapor (with suitable reflectors), and incandescent spot lamps.

NOTE: Use other combinations of the lamps listed above and below if it is proven that the combination produces the spectrum of Table 505.7-I.

(2) Use the appropriate lamps from the following list for tests conducted to assess heating effects alone (and not actinic effects).

(a) Mercury vapor lamps (internal reflector type only).

(b) Combination of incandescent spot and tubular-type mercury vapor lamps w/ external reflectors.

(c) Combination of incandescent spot lamps and mercury vapor lamps with internal reflectors.

(d) Metal halide.

(e) Xenon arc or mercury xenon arc lamps with suitable reflectors.

(f) Multi-vapor (clear or coated bulb) with suitable reflectors.

(g) Tungsten filament lamps.

(h) Any other heat producing lamp.

4.2 Controls.

a. Temperature. Maintain the chamber air temperature (as specified in the test plan) in accordance with Part One, paragraph 5.2a. In order to adequately measure the temperature of the air surrounding the test item, measure it (with adequate shielding from radiated heat - see Annex A, paragraph 5.2) at a point or points in a horizontal reference plane at the approximate elevation of the upper surface of the test item, and as close as possible to the test item, making adequate provision for shielding from the effects of radiant heat from the test item. This is one way to ensure reasonable control of the envelope of air surrounding the test item. The temperature sensors used to measure the thermal response of the test item will also be affected by direct radiation of the light source. When practical, mount these sensors to the inside surface of the external case (upper surface) of the test item.

b. Test Sensors and Measurements. Use a pyranometer, pyrheliometer or other suitable device to measure the total radiated energy imposed on the test item. Use a pyranometer with suitable filters or a spectroradiometer to measure the spectral distribution of the radiation imposed on the test item. A filtered pyranometer can only provide an approximate measurement of the spectral distribution. However, a spectroradiometer, although more delicate to employ, can provide a precise measurement of the spectral distribution. Use other measuring instruments only if they can satisfy the required specifications. See Annex B for the required measurement accuracy of these commonly used instruments. Test parameter tolerances appear in Table 505.7-II.

Table 505.7-II. Test parameter tolerances.

Test Parameter	Description	Tolerance
Total Spectral Irradiance	Sum of energy for all spectral bandwidths at a target irradiance level on the test profile (diurnal curve or constant irradiance).	±4 percent or ±15 W/m^2 (whichever is greater) of the target irradiance.
Spectral energy Distribution	Energy within each spectral bandwidth at a single measurement point.	See Table 505.7-I tolerance for each bandwidth.
Irradiance Uniformity	Deviation between the measured and target irradiance at all measurement points on the target plane. The number of points shall be adequate to define irradiance variation across the target plane(s) to meet the specific test requirement.	±10 percent deviation from the target irradiance
Instrumentation	Pyranometer, pyrheliometer, or radiometer	See Annex B
Temperature	Chamber control	±2 ºC (±3.6 ºF)
Air Speed	Across the test item	1.5 to 3.0 m/sec (300 to 600 ft/min)

Note: When performing Procedure I, it is not required to provide a total irradiance energy level below a minimum level of 55 W/m^2 (280-3000 nm). If the diurnal curve calculated energy value is below 55 W/m^2 (280-3000 nm), a target value of 55 W/m^2 (280-3000 nm) may be used for the specified time period.

c. Calibration of chamber. Because of the variety of permissible lamps and chamber designs, it is particularly important that the chamber be calibrated to assure the proper levels of radiant infrared energy are impacting the test area when heat alone is of concern, and that the proper intensity and spectral distribution of solar radiation are impacting the test area when actinic effects are of concern. See Table 505.7-I for spectral distribution and permitted tolerances.

If the test item is not available at the time the chamber is being calibrated, ensure the radiation uniformity is within 10 percent of the desired value when measured over the area covered by the test item, at a horizontal reference plane at the approximate elevation of the upper surface position of the test item. If the test item is available at the time the chamber is being calibrated, ensure the radiation uniformity is within 10 percent of the desired value when measured over the upper surface of the test item. As most types of lamps age, their spectral outputs change. To ensure that solar radiation chambers meet established specifications, perform a thorough check on spectral distribution, intensity, and uniformity at intervals not exceeding 500 hours of operation. Conduct a check of the overall intensity and uniformity before and after every test.

d. Record chamber temperature, solar radiation intensity, spectral distribution, wind speed, and humidity (if required) at a sufficient rate to capture data necessary for post-test analysis (see Part One, paragraph 5.18).

4.3 Test Interruption.

Test interruptions can result from two or more situations, one being from failure or malfunction of test chambers or associated test laboratory equipment. The second type of test interruption results from failure or malfunction of the test item itself during required or optional performance checks.

4.3.1 Interruption Due to Chamber Malfunction.

a. General. See Part One, paragraph 5.11, of this Standard.

b. Specific to this Method.

(1) Undertest interruption.

(a) Procedures I and II. The test rationale is based on the total cumulative effect of the solar environment. Except as noted in (b) below, follow any undertest interruption by re-stabilization at the identified levels and continuation of the test from the point of the interruption.

(b) Procedure I. The test is considered complete if an interruption occurs after 19 hours of the last cycle of Procedure I. (At least 92 percent of the test would have been completed, and the probability of a failure is low during the remaining reduced levels of temperature and solar radiation.)

(2) Overtest interruption. Follow any overtest conditions by a thorough examination and checkout of the test item to verify the effect of the overtest. Since any failure following continuation of testing will be difficult to defend as unrelated to the overtest, use a new test item and restart the test at the beginning.

4.3.2 Interruption Due to Test Item Operation Failure.

Failure of the test item(s) to function as required during mandatory or optional performance checks during testing presents a situation with several possible options.

a. The preferable option is to replace the test item with a "new" one and restart from Step 1.

b. A second option is to replace / repair the failed or non-functioning component or assembly with one that functions as intended, and restart the entire test from Step 1.

> **NOTE**: When evaluating failure interruptions, consider prior testing on the same test item and consequences of such.

4.4 Test Execution.

The following steps, alone or in combination, provide the basis for collecting necessary information concerning the test item in a solar radiation environment.

4.4.1 Preparation for Test.

4.4.1.1 Preliminary Steps.

Before starting the test, review pretest information in the test plan to determine test details (e.g., procedures, item configuration, cycles, durations, parameter levels for storage/operation, etc.). (See paragraph 3.1 above.)

a. The required test procedures.

b. The diurnal cycle to be used.

c. Other variables, such as number of cycles, etc.

d. Degree of removal of surface contamination necessary (see paragraph 4.2b). If the effects of surface contamination are to be assessed, include in the relevant requirements document the necessary information on preparation of surfaces.

e. Comparative information. For eventual comparison between pre- and post-test items, photograph the test item and take material samples (if required).

4.4.1.2 Pretest Standard Ambient Checkout.

All items require a pretest standard ambient checkout to provide baseline data. Conduct the checkout as follows:

Step 1. In order to determine thermal response (paragraph 3.3b(2)), install temperature sensors in, on, or around the test item as described in the test plan.

Step 2. Install the test item in the chamber (Part One, paragraph 5.8) and stabilize it at standard ambient conditions (Part One, paragraph 5.1) and in a manner that will simulate service use, unless the storage configuration is specified (see paragraph 2.3.4). Position the test item in accordance with the following:

a. As near the center of the test chamber as practical and so that the surface of the item is not closer than 30 cm (12 in.) to any wall or 76 cm (30 in.) to the radiation source when the source is adjusted to the closest position it will assume during the test

b. Oriented, within realistic limits, to expose its most vulnerable parts to the solar radiation, unless a prescribed orientation sequence is to be followed.

c. Separated from other items that are being tested simultaneously, to ensure that there is no mutual shading or blocking of airflow unless this, also, is representative of the materiel's field use.

Step 3. Conduct a visual examination of the test item with special attention to stress areas, such as corners of molded cases, and document the findings.

Step 4. Conduct an operational checkout in accordance with the test plan and record the results.

Step 5. If the test item operates satisfactorily, place it in its test configuration (if other than operational) and proceed to the first test as identified in the test plan. If not, resolve the problem and restart the checkout procedure.

4.4.2 Procedure I - Cycling.

Step 1. Adjust the chamber temperature and stabilize the test item to the conditions shown in the appropriate climatic category (zone A1 or A2) for time 0000.

Step 2. Expose the test item to continuous 24-hour cycles of controlled simulated solar radiation and dry-bulb temperature as indicated on Figure 505.7-1 or as identified in the requirements document, measuring and recording test item temperatures throughout the exposure period. If the test facility is unable to perform the continuous curve of Figure 505.7-1, increase and decrease the solar radiation intensity in a minimum of eight levels (see Annex C, Figures 505.7C-5 and C-6 for the stepped levels) for each side of the cycle, provided the total energy of the cycle as well as the spectral power distribution is maintained. Perform at least three continuous cycles. If the maximum of the peak response temperature of the previous 24-hour cycle is not reached (±2 °C (±3.6 °F)) during three cycles, continue the cycles until repeated peak temperatures are reached, or for seven cycles, whichever comes first.

Step 3. Based on the requirements document, the test item may or may not be operated continuously throughout the test. If operation is required, operate the test item when the peak response temperature occurs. For some single-use items (e.g., rockets), use thermocouples affixed to critical portions of the test item to determine the time and value of peak temperature. Conduct the operational checkout of the test item as in paragraph 4.4.1.2, Step 5. Document the results as well as the peak temperature. If the test item fails to operate as intended, follow the guidance in paragraph 4.3.2 for test item failure.

Step 4. Adjust the chamber air temperature to standard ambient conditions and maintain until temperature stabilization of the test item has been achieved.

Step 5. Conduct a complete visual examination of the test item and document the results. For comparison between pre- and post test items, photograph the test item and take material samples (if required).

Step 6. Conduct an operational checkout of the test item as in paragraph 4.4.1.2, Step 5. See paragraph 5 for analysis of results.

Step 7. Compare these data with the pretest data.

4.4.3 Procedure II - Steady State.

NOTE: If Procedure I has not been previously performed and no field/fleet data are available, conduct a preliminary test carried out in accordance with Procedure I (absolute minimum of three complete cycles) to determine the approximate maximum response temperature of the test item.

Step 1. Adjust the chamber air temperature to the max temperature shown in the appropriate climatic zone (zone A1 or A2) as indicated on Figure 505.7-2 or the temperature identified in the test plan.

Step 2. Adjust the solar radiation source to a radiant energy rate of 1120 ±47 W/m^2 or as identified in the test plan. Use sufficient air speed to maintain the test item temperature to the peak response temperature obtained in procedure I or obtained from field data.

Step 3. Maintain these conditions for 20 hours, measuring and recording the test item temperatures. If required, conduct operational checks during the last four hours of each 20-hour exposure when test temperatures are maximized. If the test item fails to operate as intended, follow the guidance in paragraph 4.3.2 for test item failure.

Step 4. Turn off the solar radiation source for four hours.

Step 5. Repeat Steps 1 through 4 for the number of cycles identified in the test plan.

Step 6. At the end of the last radiation cycle, allow the test item to return to standard ambient conditions.

Step 7. Conduct a visual examination and an operational check as in Steps 3 and 5 of paragraph 4.4.1.2, and document the results. Take photographs of the test item and material samples (if required) for comparison between pre- and post-test items. See paragraph 5 for analysis of results.

5. ANALYSIS OF RESULTS.

In addition to the guidance provided in Part One, paragraphs 5.14 and 5.17, the following information is provided to assist in the evaluation of the test results. Analyze any failure of a test item to meet the requirements of the materiel specifications.

a. Procedure I. Do not alter the performance characteristics either at the peak temperature or after return to standard ambient conditions to the extent that the test item does not meet its requirements. Record as observations only those actinic effects that do not affect performance, durability, or required characteristics.

b. Procedure II. Do not alter the performance and characteristics (such as color or other surface conditions) of the test item to the extent that the test item does not meet requirements. Record actinic effects that do not affect performance, durability, or required characteristics as observations only. The fading of colors could result in higher heating levels within the test item.

6. REFERENCE/RELATED DOCUMENTS.

6.1 Referenced Documents.

a. MIL-HDBK-310, Global Climatic Data for Developing Military Products.

b. NATO STANAG 4370, Allied Environmental Conditions and Test Publication (AECTP) 230; Climatic Conditions.

c. “Ultraviolet Radiation,” L.R. Koller; Wiley, 2nd Edition, 1965.

d. ISO 9060, “Solar Energy – Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation,” 1990-11-01.

e. ISO-9847 “Solar Energy – Calibration of Field Pyranometers by Comparison to a Reference Pyranometer,” 1992.

f. ASTM E824-05, Standard Test Method for Transfer of Calibration from Reference to Field Radiometers, 2005

g. The Photonics Dictionary, 2002 48th edition; Laurin Publishing.

6.2 Related Documents.

a. AR 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions.

b. Synopsis of Background Material for MIL-STD-210B, Climatic Extremes for Military Equipment. Bedford, MA: AF Cambridge Research Laboratories, January 1974. DTIC number AD-780-508.

c. Egbert, Herbert W. “The History and Rationale of MIL-STD-810 (Edition 2),” January 2010; Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

d. NATO STANAG 4370, Allied Environmental Conditions and Test Publication (AECTP) 300, Climatic Test Methods, Method 305, Solar Radiation.

e. “Ultraviolet Spectral Energy Distribution of Natural Sunlight and Accelerated Test Light Sources,” R.C. Hirt, R.G. Schmitt, N.D. Searle and A.P. Sullivan; Journal of the Optical Society of America, July 1960, vol. 50, p. 706.

f. “Studies of Spectral Energy Distribution of Different Light Sources in Connection with Solar Simulation,” D.W. Gibson and J. Weinard; Institute of Environmental Sciences 1962 Proceedings, p. 453. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

g. “An Artificial Sunshine Solarium,” G.F. Prideaux, Illuminating Engineering, 1946, Vol. 12, p.762.

h. “'Project Assess - a Report of a Long Term Solar Simulation Test,” R. Kruger, Institute of Environmental Sciences 1966 Proceedings, p. 271. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

i. “Spectral Distribution of Typical Daylight as a Function of Correlated Color Temperature,” D.B. Judd, D.L. MacAdam and G. Wyszecki; Journal of the Optical Society of America, August 1964, vol. 54, p. 1031.

j. “Simulating the Solar Spectrum with a Filtered High-pressure Xenon Lamp,” E.A. Boettner and L.J. Miedler, Applied Optics, 1963, vol. 2, p. 105.

k. “Modular Xenon Solar Simulation of Large Area Application,” J.A. Castle, Institute of Environmental Sciences, 1967 Proceedings, p. 687. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

l. “Four-foot Solar Simulation System,” R.N. Harmon, Institute of Environmental Sciences 1966 Proceedings p. 531. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

m. “Radiation Instruments and Measurements,” International Geophysical Year Manual, Part VI, 1958, Pergamon Press.

n. “Deterioration of Materials,” G.A. Greathouse and C.J. Wassel, Reinhold, New York, 1954.

o. “The Simulation of Solar Radiant Energy,” P.W. Baker, Environmental Engineering Quarterly June 1963, p. 17-19 and Sept 1963, p. 14-17.

p. “Measurement of Spectral Irradiance,” J. Arveson, Handbook of Solar Simulation for Thermal Vacuum Testing, Section 9B Institute of Environmental Sciences, 1968. Institute of Environmental Sciences and Technology, Arlington Place One, 2340 S. Arlington Heights Road, Suite 100, Arlington Heights, IL 60005-4516.

q. “The Solar Constant and the Solar Spectrum Measured from a Research Aircraft,” M.P. Thekaekara, NASA TR R-351, Washington, DC, Oct 1970.

(Copies of Department of Defense Specifications, Standards, and Handbooks, and International Standardization Agreements are available online at https://assist.dla.mil.

ASTM documents are available from the ASTM International Website.

Requests for other defense-related technical publications may be directed to the Defense Technical Information Center (DTIC), ATTN: DTIC-BR, Suite 0944, 8725 John J. Kingman Road, Fort Belvoir VA 22060-6218, 1-800-225-3842 (Assistance--selection 3, option 2), http://www.dtic.mil and the National Technical Information Service (NTIS), Springfield VA 22161, 1-800-553-NTIS (6847), http://www.ntis.gov/.

METHOD 505.7, ANNEX A

DETAILED GUIDANCE ON SOLAR RADIATION TESTING

1. INTRODUCTION.

This Annex describes methods of simulation designed to examine the effects of solar radiation on materiel. The main quantities to be simulated are the spectral energy distribution of the sun as observed at the Earth's surface and the intensity of received energy, in combination with controlled temperature conditions. However, it may be necessary to consider a combination of solar radiation - including sky radiation - with other environments, e.g., humidity, air velocity, etc.

2. IRRADIANCE AND SPECTRAL DISTRIBUTION.

The effect of radiation on the materiel will depend mainly on the level of irradiance and its spectral distribution.

2.1 Irradiance.

The irradiance by the sun on a plane perpendicular to the incident radiation outside the Earth's atmosphere at the mean Earth-Sun distance is known as the solar constant "I_0." The irradiance at the surface of the Earth is the result of the solar constant and the influence of attenuation and scattering of radiation in the atmosphere. For test purposes, a maximum intensity of 1120 W/m^2 is specified to simulate the global (total) radiation at the surface of the Earth from the Sun and the sky with the Sun at zenith, based on a solar constant I_0 = 1350 W/m^2. The true solar constant is thought to be about 1365-1370 W/m^2.

2.2 Spectral Distribution - Sea Level versus High Altitude.

At high altitude, solar radiation contains a greater proportion of damaging UV radiation than at sea level. The internationally-agreed spectrum (see Table 505.7-I) recommended for general testing is a representation of the real environment at sea level. This spectrum is recommended for use at both sea level and at high altitude.

3. OTHER ENVIRONMENTAL FACTORS TO BE CONSIDERED.

Attention is drawn to the possible cooling effects of air flow over materiel. In practice, high solar radiation conditions are rarely accompanied by complete absence of wind. It may be necessary, therefore, to assess the effect of different air velocities over materiel under test. The materiel specification should state any special requirements in this respect. It is essential, therefore, to measure and control the rate of air flow in order to maintain the required air temperature at the test item. Excessive or un-controlled air flow can also result in misleading errors in open-type thermopiles used to monitor radiation intensity; ventilation of pyranometers may be necessary to keep the glass dome cool.

4. RADIATION SOURCES.

4.1 General.

The radiation source may comprise one or more lamps and their associated optical components, e.g., reflectors, filters, etc., to provide the required spectral distribution and irradiance. The high pressure xenon arc lamp with filters can provide the best spectral match. Mercury vapor and xenon-mercury lamps have considerable deficiencies in matching that would lead to error. If not already covered in test method characteristics of these sources, features of filters, optical arrangements, etc., are covered in the following paragraphs. The following general information about several light sources may be helpful.

a. Xenon lamps. The configuration and size of the lamp(s) used will depend on the test required. The relative spectral distribution of the xenon arc radiation has been found to be substantially independent of lamp power. However, variation of lamp power will change the temperature of the electrodes and hence the spectral distribution of their radiation. With long arc lamps, it is relatively simple to mask off the electrode radiation. The form of construction of the short arc lamp leads to considerably wider manufacturing variation compared with the long arc, a point particularly important when replacement becomes necessary. Routine replacement of either type of lamp will be needed, since the emission will change continuously with life, and there may be wide variations of the life characteristic from lamp to lamp.

b. Metal Halide (HMI). Metal Halide lamps that are properly filtered and using proper electrical power supply to the lamp can meet the defined spectral requirements. Care must be taken regarding lamp age and lamp power adjustment as spectral shifting can occur leading to changes in spectrum (critical for Procedure II testing).

4.2 Filters.

Liquid filters have certain disadvantages such as the possibility of boiling, the temperature coefficient of spectral transmission, and long term drift in spectral characteristics. The present preference is for glass filters to be used, although the characteristics of glass filters are not as accurately reproduced as those of a chemical solution filter. Some trial and error may be necessary to compensate for different optical densities by using different plate thicknesses. Glass filters are proprietary articles and manufacturers should be consulted concerning the choice of filters suitable for particular purposes. The choice will depend on the source and its methods of use. For example, a xenon source may be test-compensated by a combination of infrared and ultraviolet absorbing filters. Some glass infrared filters may be prone to rapid changes in spectral characteristics when exposed to excessive ultraviolet radiation. This deterioration may be largely prevented by interposing the ultraviolet filter between the source and the infrared filter. Interference type filters, that function by reflecting instead of absorbing the unwanted radiation, (thus resulting in reduced heating of the glass), are generally more stable than absorption filters.

4.3 Uniformity of Irradiance.

Owing to the distance of the sun from the Earth, solar radiation appears at the Earth's surface as an essentially parallel beam. Artificial sources are relatively close to the working surface and means of directing and focusing the beam must be provided with the aim of achieving a uniform irradiance at the measurement plane within specification limits (i.e., 1120 W/m^2 (see Table 505.7-I)). This is difficult to achieve with a short-arc xenon lamp with a parabolic reflector because of shadows from the lamp electrodes and supports. Also, the incandescence of the anode can produce considerable radiation at a much lower color temperature, slightly displaced from the main beam, if only the arc itself is at the focus of the reflector. Uniform irradiation is more readily achieved with a long arc lamp mounted in a parabolic 'trough' type reflector. However, by employing very elaborate mounting techniques, it is possible to irradiate, with some degree of uniformity, a large surface by a number of short arc xenon lamps. It is generally advisable to locate radiation source(s) outside the test enclosure or chamber. This avoids possible degradation of the optical components, e.g., by high humidity conditions, and contamination of test items by ozone that has been generated by xenon and other types of arc lamps. Precise collimation of the radiation beam is not normally required except for testing special materiel such as solar cells, solar tracking devices, etc. However, some of the simulation techniques developed for space research purposes could be adapted for Earth surface solar radiation studies.

5. MEASUREMENTS.

5.1 Measurement of Spectral Distribution.

Total intensity checks are readily made, but detailed checks on spectral characteristics are more difficult. Major spectral changes can be checked by inexpensive routine measurements, using a pyranometer in conjunction with selective filters. For checking the detail spectral distribution characteristics of the facility, it would be necessary to employ sophisticated spectroradiometric instrumentation. However, there seems to be no practical instrumentation obstacle to prevent this calibration being done either as a service by the facility manufacturer or by a visit from a national calibration center. Achieve correlation between the filter/pyranometer and spectroradiometric methods at regular intervals. Changes in the spectral characteristics of lamps, reflectors and filters may occur over a period of time that could result in the spectral distribution being seriously outside the permitted tolerances. Manufacturing tolerances may mean that lamp replacement could result in unacceptable changes in both the level of irradiation and spectral distribution compared with that initially set up. Regular monitoring is therefore essential, but monitoring of the detailed spectral distribution within the test facility may not be possible while an item is undergoing test. A method of measuring the intensity of radiation below 320 nm based on the exposure of polysulphone film and that would permit the monitoring of this wavelength range within the test facility is now established. Lower cost commercially available spectrometers provide reasonable results, however extreme care must be taken when measuring the ultraviolet range. Unless properly calibrated and evaluated, values in the ultraviolet range may be unreliable.

5.2 Measurement of Temperature.

Because of the high level of radiation, it is essential that temperature sensors are adequately shielded from radiant heating effects. This applies both to measuring air temperatures within the test enclosure, and monitoring test item temperatures. When monitoring test item temperatures, sensors, e.g., thermocouples, should be located on the inside surfaces of the external case and should not be attached to the outside surfaces, unless the surface temperature is of concern. Temperature-indicating paints and waxes are unsuitable for monitoring the temperature of irradiated surfaces, since their absorption characteristics will not be the same. Commercially available self-adhesive surface mount thermocouples can be used if properly insulated from the source radiation.

Table 505.7A-I. Test parameter tolerances.

Test Parameter	Description	Tolerance
Total Spectral Irradiance	Sum of energy for all spectral bandwidths at a target irradiance level on the test profile (diurnal curve or constant irradiance).	±4 percent or ±15 W/m^2 (whichever is greater) of the target irradiance.
Spectral energy Distribution	Energy within each spectral bandwidth at a single measurement point.	See Table 505.7-I tolerance for each bandwidth.
Irradiance Uniformity	Deviation between the measured and target irradiance at all measurement points on the target plane. The number of points shall be adequate to define irradiance variation across the target plane(s) to meet the specific test requirement.	±10 percent deviation from the target irradiance
Instrumentation	Pyranometer, pyrheliometer, or radiometer	See Annex B
Temperature	Chamber control	±2 °C (±3.6 °F)
Air Speed	Across the test item	1.5 to 3.0 m/sec (300 to 600 ft/min)

6. PREPARATION OF TEST FACILITY AND MATERIEL UNDER TEST.

6.1 Test Facility.

Ensure that the optical parts of the facility, lamps, reflectors, and filters, etc., are clean. The level of irradiation over the specified measurement plane must be measured immediately prior to each test. Throughout the test continually monitor any ancillary environmental conditions, and other parameters as specified in the main body of this Method, paragraphs 4.1 and 4.2d.

6.2 Materiel Under Test.

The method of mounting and the orientation of the test item relative to the direction of radiation will have marked influences on the heating effects. The test item will probably be required to be mounted either on raised supports or on a substrate of specified properties, e.g., a layer of concrete of specified thickness or a sand bed of certain thermal conductivity and reflectivity. Include all this and the attitude of the test item in the relevant specification. Special attention must be paid to the surface conditions of the test item to see that its finish is clean or in accordance with the relevant requirements. The heating effect on the test item will be largely affected by the condition of its external surfaces. Care must therefore be exercised in handling the test item, especially in avoiding oil films and in ensuring that the surface finish and its underlay are fully representative of production standards. Attach temperature sensors to the test item as required (but see also paragraph 5.3 of this Annex).

6.3 Ground Reflected Radiation.

In some cases, such as with a white sand or snow ground cover, and the test item in close association with this surface, significant reflected radiation can be applied to the test item. This effect can be measured using a radiometer designed to measure the “albedo” radiation. This sensor is primarily consists of a upward-facing radiometer and a downward facing radiometer. If the test item is to be substantially used in an environment where ground reflected radiation is a concern, consider the albedo radiation in the test design with radiation provided to the lower surface of the test item by auxiliary lighting, or the use of similar reflective material in the test set up.

7. INTERPRETATION OF RESULTS.

The materiel specification should indicate the permitted changes in the external conditions and/or performance of the test item after exposure to the required level of irradiation for certain durations. In addition, the following aspects of interpretation may be considered:

7.1 Comparison with Field Experience.

The effects of exposing material to solar radiation are well documented (see also paragraphs 7.2 and 7.3 below). Investigate any marked differences between the expected effects and the behavior under test conditions, and the basic cause established, i.e., whether caused by the test equipment or procedure, or by some peculiarity in the test item.

7.2 Thermal Effects.

a. The maximum surface and internal temperatures attained by materiel will depend on:

(1) the temperature of the ambient air.

(2) the intensity of radiation.

(3) the air velocity.

(4) the duration of exposure.

(5) the thermal properties of the materiel itself, e.g., surface reflectance, size and shape, thermal conductance, and specific heat.

b. Materiel can attain temperatures in excess of 60 °C (140 °F) if fully exposed to solar radiation in an ambient temperature as low as 35 to 40 °C (95-104 °F). The surface reflectance of an object affects its temperature rise from solar heating to a major extent; changing the finish from a dark color, for example, to a gloss white will effect a considerable reduction in temperature. Conversely, a pristine finish designed to reduce temperature can be expected to deteriorate in time resulting in an increase in temperature. Most materials are selective reflectors, i.e., their spectral reflectance changes with wavelength. For instance, paints, in general, are poor infrared reflectors although they may be very efficient in the visible region. Furthermore, the spectral reflectance of many materials changes sharply in the visible (producing a color sensation to the human eye) and in the near infrared. It is important, therefore, that the spectral energy distribution of the radiation source(s) used in any simulated test should closely duplicate that of natural radiation.

7.3 Degradation of Materials.

The combined effects of solar radiation, atmospheric gases, temperature, humidity changes, etc., are often collectively termed "weathering," and result in the "ageing" and ultimate destruction of most organic materials (e.g., plastics, rubbers, paints, timber, etc.). Many materials that give satisfactory service in temperate regions have been found to be completely unsuitable for use under more adverse conditions. Typical effects are the rapid deterioration and breakdown of paints, the cracking and disintegration of cable sheathing, and the fading of pigments. The breakdown of a material under weathering usually results not from a single reaction, but from several individual reactions of different types occurring simultaneously, often with interacting effects. Although solar radiation, principally the ultraviolet portion, resulting in photodegradation is often the major factor, its effects can seldom be separated, in practice, from those of other weathering factors. An example is the effect of ultraviolet radiation on polyvinyl chloride, where the apparent effects of ultraviolet radiation alone are small, but its susceptibility to thermal breakdown, in which oxygen probably plays a major role, is markedly increased. Unfortunately, artificial tests occasionally produce abnormal defects that do not occur under weathering. This can be often attributed to one or more of the following causes:

a. Many laboratory sources of ultraviolet radiation differ considerably from natural solar radiation in spectral energy distribution.

b. When the intensity of ultraviolet, temperature, humidity, etc., are increased to obtain accelerated effects, the rate of the individual reactions (that occur under normal exposure conditions), are not necessarily increased to the same extent. In some cases, e.g., fluorescent lamps, the infrared energy of the source is significantly less than that of true solar loading, resulting in a surface test temperature that is lower than would be experienced out-of-doors.

c. The artificial tests, in general, do not simulate all the natural weathering factors.

8. HAZARDS AND PERSONNEL SAFETY.

8.1 General.

The complex equipment employed for solar radiation testing purposes will necessarily call for operation and maintenance by a skilled test staff, not only to ensure the prescribed performance of the test, but also because of the various health and safety hazards that have to be considered.

8.2 Ultraviolet Radiation.

The most obvious dangers that have to be guarded against are those associated with the harmful effects of high intensity radiation in the near ultraviolet region. In natural sunlight, the eyes are protected in two ways: the brightness of the sun makes it almost impossible to look directly at it and the ultraviolet radiation is considerably attenuated by the atmosphere. These protections may not apply to artificial sources. Due to the point sources and high UV component of these sources, the eyes must be protected by filtered goggles or viewing apertures, particularly when setting up the equipment. Warn all testing personnel that severe eye damage can result from only short exposure to unfiltered radiation from arc-type lamps. Serious erythema (sunburn) of exposed skin will also occur. Koller (paragraph 6.1, reference c) states the ultraviolet radiation of sunlight is a major causal factor in cancer of the skin in the white population of the US. The use of suitable protective clothing including protection of the head and hands is highly recommended, even when working in test enclosures irradiated by filtered sources.

8.3 Ozone and Harmful Fumes.

Another serious health hazard arising from the use of xenon and other arc lamps is the possible buildup of local toxic concentrations of ozone during the testing period. However, the maximum production of ozone occurs at the initial switching on of the lamp, and thereafter the hot envelope of the lamp tends to degrade the ozone back to oxygen. Where forced-air cooling is employed, this cooling air should be removed from the building and not blown into the lamp housing. In this way, the ozone hazard can be largely eliminated. Suitable detecting and measuring equipment is commercially available. The combined effects of heat and ultraviolet radiation on certain plastics (e.g., melamine laminates) may also produce toxic fumes. Take particular care in the choice of materials used in the construction of a test facility.

8.4 Risk of Lamp Explosions.

The use of high pressure xenon discharge lamps as the primary radiation source can also result in serious accidents unless a well planned code of practice for the handling of these arc discharge tubes has been specified and is adhered to. All such lamps (whether hot or cold, used or new) have a liability to explode violently by reason of the considerable internal pressure (two to three atmospheres when cold, but up to twenty atmospheres when hot). There should be no visible dirt or oil on the envelope, so regular cleaning with detergent and alcohol is necessary using cotton gloves and face protection during such cleaning. When cold lamps are to be stored, the effects of explosion may be limited by two layers of 0.25 mm thick polycarbonate sheet. Particular care must be taken to limit the spread of chain reaction breakdowns in multi-lamp equipment. It is possible to use armor plate glass for the dual purpose of protection against lamp explosions and as a corrective filter. Individual lamp records should be kept as a matter of routine so as to be able to detect abnormal voltage/current behavior.

8.5 Electric Shock.

Normal electric shock preventive measures must, of course, be adopted, particularly in the case of the high voltage igniter systems used with arc lamps. In some xenon lamps, the arc ignition pulse exceeds 60 kV, and an interlock system is therefore essential.

(This page is intentionally blank.)

METHOD 505.7 ANNEX B

INSTRUMENTATION INSTALLATION, PLACEMENT AND GUIDANCE

INSTRUMENTATION.

a. Measurement of Irradiance. The type of instrument considered most suitable for measuring/monitoring the irradiance during test set up and test operation is the pyranometer. The pyranometer is designed for measuring the irradiance (radiant-flux, watts/m^2) on a plane surface that results from direct solar radiation and from the diffuse radiation incident from the hemisphere above. ISO-9060 (paragraph 6.1, reference d), provides additional information regarding definitions, design criteria, and proper use.

b. Pyranometer Classifications.

(1) Referring to ISO-9060, the pyranometer used for testing should be critically selected based on the specific internal requirements for internal tractability/calibration certification, and the ability of the selected pyranometer to meet the requirements of the test and test process (see ISO 9060, Table 1 for classification details, paragraph 4.3.2, "Classification Criteria").

(2) In tests where a direct traceability chain is required, recommend a pyranometer meeting the classification of "secondary standard." For typical test set-up and operation, a classification of "First Class Instrument" is generally sufficient. As a minimum, calibrate all instruments on an annual basis.

c. Pyranometer Use Guidelines.

(1) Pyranometers are used for validating irradiance values during test set-up, for pre-test, during the test, and post test to confirm the specified radiant energy values are maintained. Recommended the interval used for radiant energy level verification during a test be once per day, OR as required based on historical statistical charting showing test compliance for longer periods. For Procedure I, in addition to recording the pretest calibration, it is recommended to record the intensity level at a sufficient interval to verify the proper radiation intensity is achieved throughout the cycle. For Procedure II, in addition to recording the pretest calibration, it is recommended to record the intensity once per-cycle and verify the UVa and UVb portions of the spectrum every seventh cycle.

(2) If pyranometers are continuously exposed to the solar radiation source, consider thermal drift of the radiant energy values provided by the pyranometer. Some pyranometers require a thermal offset value based on temperature, while others have internal offset characteristics that minimize thermal drift.

(3) Periodic calibration certification of pyranometers is required, typically once per-year or as specified by the pyranometer manufacturer. The pyranometer calibration is to be certified in accordance to ISO-9847, paragraph 6.1, reference e, or ASTM E-824, paragraph 6.1, reference f.

(4) Proper mounting, mounting location, and horizontal placement of the pyranometer are critical to achieving proper evaluation of the test item. The testing parties must agree to the mounting of the pyranometer for the test, with mounting location and method recorded as part of the permanent test record.

d. Evaluation of Spectral Power Distribution (SPD). Measuring and monitoring spectral power distribution of the lamp demonstrates compliance with Table 505.7-I. Ensure the SPD measurement system is calibrated and operating properly for accuracy, especially in the ultraviolet range. Instrument accuracy can be found in Table 505.7B-I. Spectral power distribution evaluation guidelines:

(1) SPD measurements are critical for simulated solar testing. The pre and post test results should be documented in the final test report.

(2) Often SPD measurement devices are limited to a maximum range of 800 nm or 1100 nm, and the pyranometer reading is used to algebraically calculate the energy in the infrared range (780 nm-3000 nm).

Table 505.7B-I. Instrument accuracy.

Measurement Instrument	Parameter Measured	Tolerance
Pyranometer/Pyrheliometer	Total irradiation (direct and scattered)	Secondary Standard in accordance with ISO 9060
Spectroradiometer or Filtered Pyranometer	Spectral distribution	±4 percent over the specified radiometric band

NOTE: A filtered pyranometer may not provide a satisfactory resolution in the ultraviolet range.

METHOD 505.7 ANNEX C

GUIDANCE ON TABLES AND FIGURES

The following is a copy of Table 505.7-I in the main body of this Method. Inserting it here facilitates discussion on its use in calculating points on the curve in Figure 505.7-1.

Table 505.7C-I. Spectral energy distribution and permitted tolerance.

Spectral Region	Bandwidth (nm)	Natural Radiation (% of total)	Tolerance (% of total)		Irradiance (W/m^2)	Spectral Region Irradiance (W/m^2)
			Min	Max		
Ultraviolet - B	280-320	0.5	0.3	0.7	5.6	5.6
Ultraviolet - A	320-360	2.4	1.8	3	26.9	62.7
	360-400	3.2	2.4	4.4	35.8	
Visible	400-520	17.9	16.1	19.7	200.5	580.2
	520-640	16.6	14.9	18.3	185.9	
	640-800	17.3	12.8	19	193.8	
Infrared	800-3000	42.1	33.7	50.5	471.5	471.5
Totals					**1120**	**1120**

Compliance to solar radiation requirements covers two main elements, providing the recommended spectral power distribution of the light source, and providing the correct irradiance levels over the specified surface of the test item.

The information in Table 505.7-I is used to determine the capability of the artificial light source to produce a satisfactory spectrum for use in solar simulation testing.

Table 505.7A-I provides guidance for on-sample test level simulated solar radiation intensity and uniformity target values.

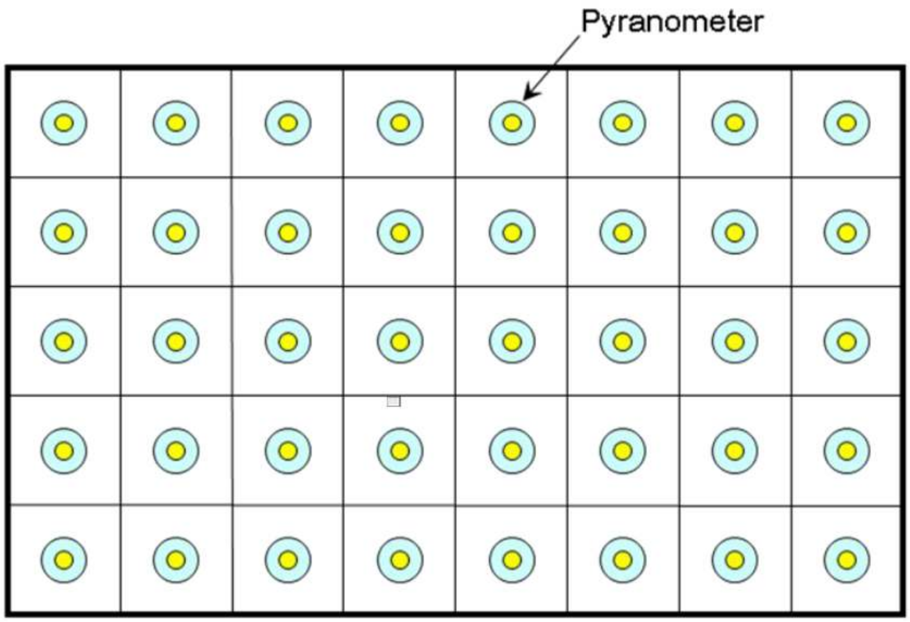
Definition: Spectral Power Distribution: The relative power emitted by a source as a function of wavelength. (See paragraph 6.1, reference g.)

EXAMPLES.

The following examples are to illustrate possible test configurations and instrument placement. As each test is performed to accomplish specific evaluations and address specific system performance criteria, these examples is for illustration only with actual test configuration to be performed according to the test plan and as agreed between the contractual parties.

a. When setting up a solar radiation test the following steps can be employed:

   (1) Establish a ±10 percent uniformity value over an established test plane appropriate for the test item. A grid pattern appropriate for the size of the test item is established, and the solar radiation system is adjusted to provide a uniform exposure over the test plane. During this process, either multiple radiometers or a single radiometer is used and moved to positions required for solar radiation uniformity verification.



Total Irradiance - Sum of energy for all spectral bandwidths at a single measurement point on the diurnal curve ($\pm 4\%$ or $\pm 15 W/m^2$ (whichever is greater) of the target irradiance).

Irradiance Uniformity - Deviation between the measured and target irradiance at all measurement points on the target plane. The number of points shall be adequate to define irradiance variation across the target plane(s) to meet the specific test requirement (+10 percent deviation from the target irradiance).

NOTE: Grid size is typically unique to the chamber dimensions and solar simulator design.

Figure 505.7C-1. Example of establishing target and uniformity levels over surface target plane.

(2) If the test item is available, the test can be run using an established test plane or the actual surface of the test item. The test plane approach is best if the test item surfaces are in a reasonably horizontal plane with minimal height differences.

When the actual test surface is used for test set-up, a grid pattern is applied to the primary surfaces to establish solar radiation uniformity and, if desired, radiometers are placed at reference locations during the test to record and monitor radiation levels during the test.

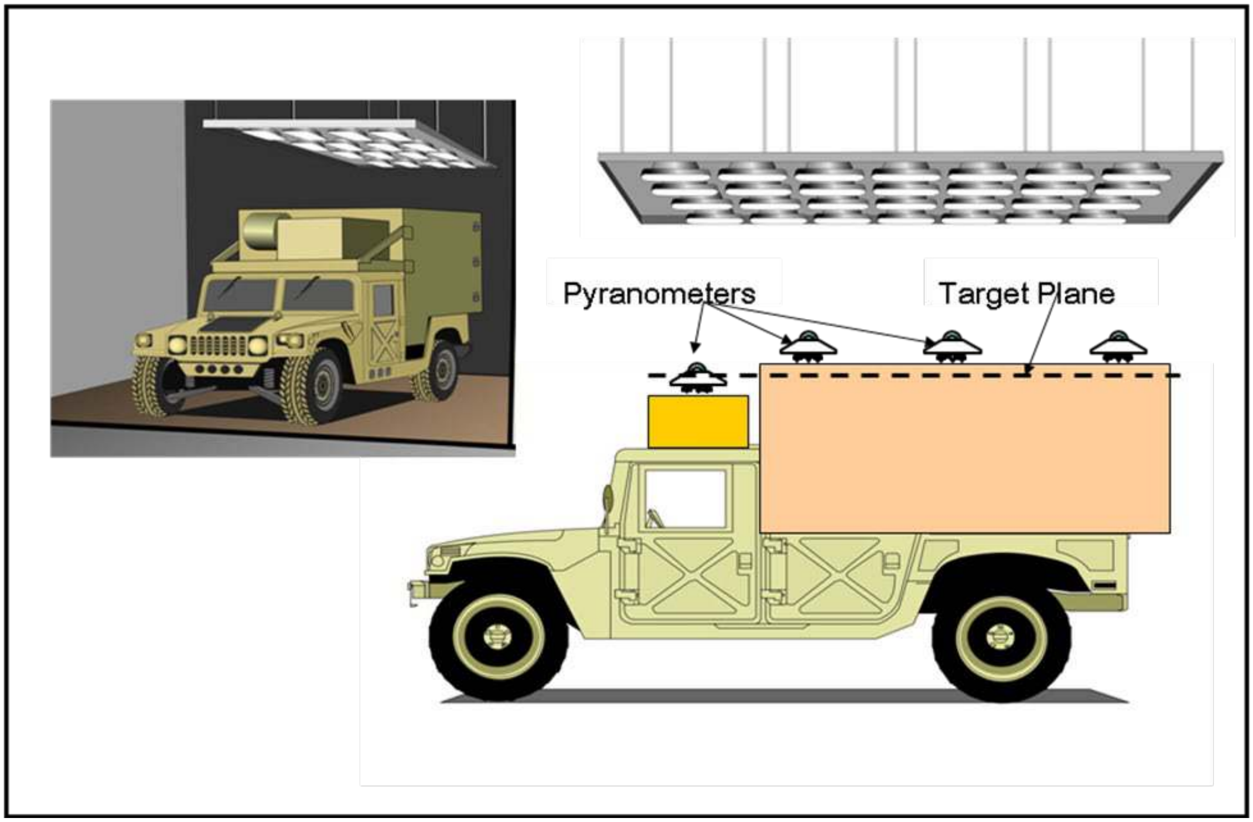


Figure 505.7C-2. Example 1 – Flat surface exposure.

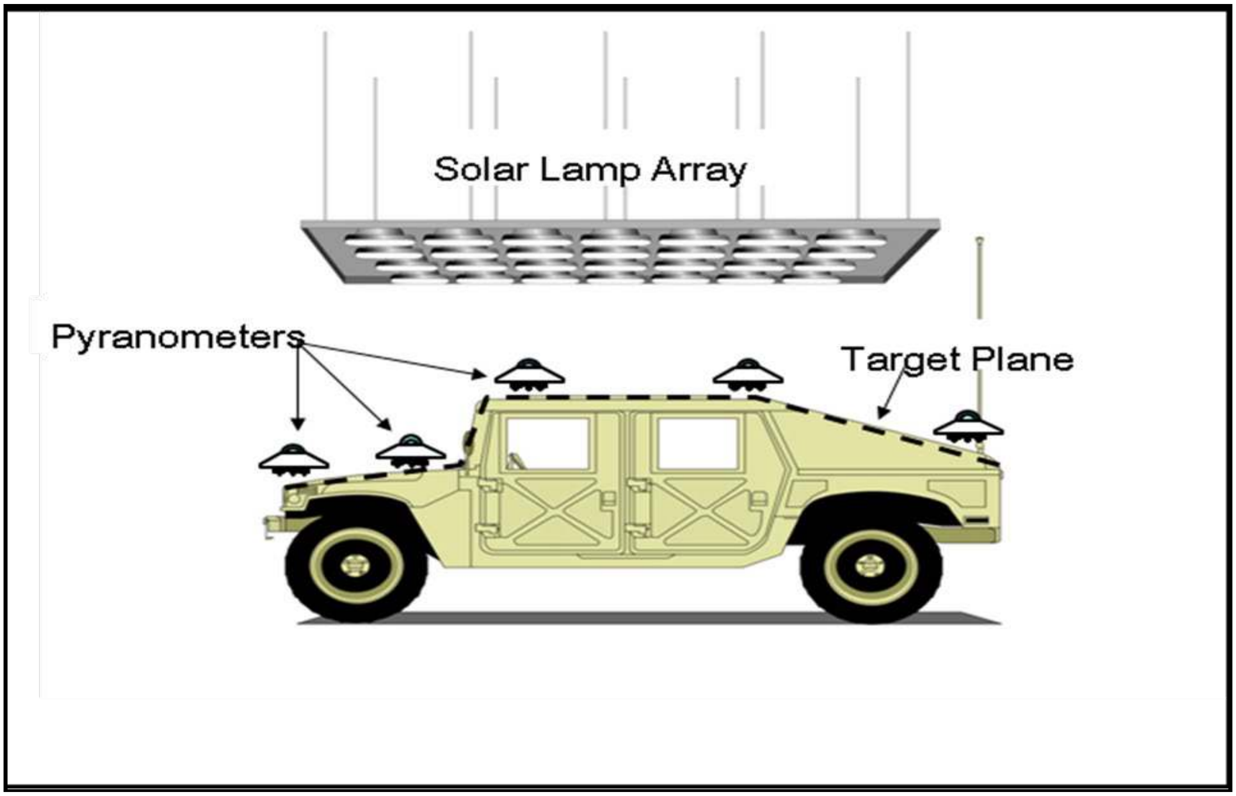


Figure 505.7C-3. Example 2 - Test item surface shape exposure.

(3) Test items with extreme height differences may require multiple test planes. For example, if a system has a raised antenna and an electronics enclosure at a lower height, a multiple test plane configuration would allow the best test results. In this case the upper test plane will receive the proper radiation by the main overhead simulated solar source, and an auxiliary simulated solar source is needed to provide the correct radiation level to the secondary test plane.

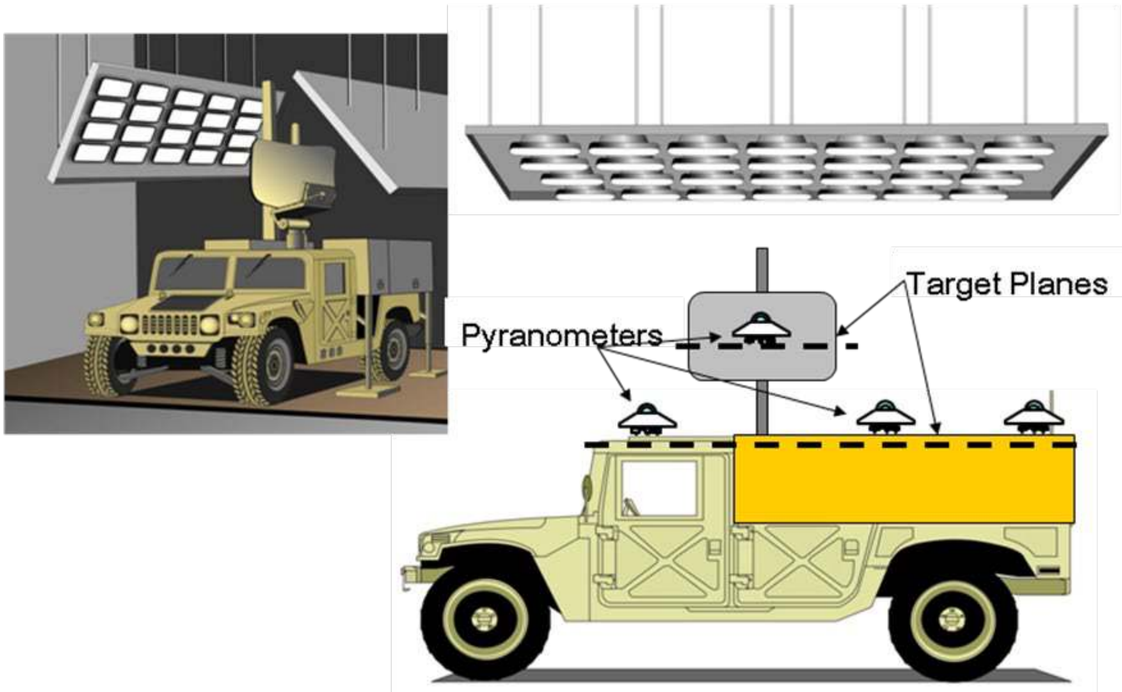


Figure 505.7C-4. Example 3 - Multiple solar surface target planes.

(4) Example of how to calculate the Spectral Power Distribution at a given total irradiance level with reference to Table 505.7-I.

Table 505.7C-II. Example calculation of spectral energy distribution and permitted tolerance.

Spectral Region	Bandwidth (nm)[2]	Natural Radiation (% of total)[2]	Tolerance (% of total)[2]		Calculated Irradiance Tolerances For a Given Total Irradiance (W/m2) → **822.5**[1]				
			Min	Max	Nominal	Min		Max	
Ultraviolet - B	280-320	0.5	0.3	0.7	4.1	2.5	2.5	5.8	5.8
Ultraviolet - A	320-360	2.4	1.8	3	19.7	14.8	34.5	24.7	60.9
	360-400	3.2	2.4	4.4	26.3	19.7		36.2	
Visible	400-520	17.9	16.1	19.7	147.2	132.4	360.3	162	468.8
	520-640	16.6	14.9	18.3	136.5	122.6		150.5	
	640-800	17.3	12.8	19	142.3	105.3		156.3	
Infrared	800-3000	42.1	33.7	50.5	346.3	277.2	277.2	415.4	415.4

Note: 1. The sum of energy in all spectral bands shall not exceed ±4% of total irradiance or ±15 W/m² (whichever is greater)
2. The values in columns 2 through 5 were obtained from CIE-85 and DIN 75220, Table 1.

Spectral compliance is determined by measurement of individual bandwidth energy. The Table 505.7C-II right side provides calculated maximum and minimum bandwidth energy for the fifth step of Figure 505.7C-5 with a total energy of 822.5 W/m2. Individual bandwidth energy may be greater or less than the nominal value, however the irradiance sum must also be within ± 4 % of the total nominal irradiance. Application of the ± 4% tolerance to the target irradiance of 822.5 W/m2 results in the required product between 789.6 to 855.4 W/m2. Spectral compliance must be evaluated based on a single measurement point, not an average or composite of multiple points. The natural radiation energy/bandwidth percentage is the same for each diurnal cycle step as shown by comparison with Table 505.7C-I. The equations below are applicable to calculate energy in a partial bandwidth region for any total irradiance. The individual bandwidth energy minimum and maximum can be used to evaluate lamp degradation or the influence of multiple lamp types on spectral compliance.

For each bandwidth:

$$\text{Nominal Irradiance} = Total\_Irradiance \times \frac{Natural\_Radiation\_(\%\_of\_total)}{100\%}$$

$$\text{Min Irradiance} = Total\_Irradiance \times \frac{Tolerance\_(\%\_of\_total)\_Min}{100\%}$$

$$\text{Max Irradiance} = Total\_Irradiance \times \frac{Tolerance\_(\%\_of\_total)\_Max}{100\%}$$

Therefore, for a total irradiance of 822.5 W/m² the tolerances for the Ultraviolet-B (UVB) band would be:

$$\text{Nominal Irradiance} = 822.5\, {}^{W}\!/_{m^2} \times \frac{0.5\%}{100\%} = 4.1125\, {}^{W}\!/_{m^2} \cong 4.1\, {}^{W}\!/_{m^2}$$

$$\text{Min Irradiance} = 822.5\, {}^{W}\!/_{m^2} \times \frac{0.3\%}{100\%} = 2.4675\, {}^{W}\!/_{m^2} \cong 2.5\, {}^{W}\!/_{m^2}$$

$$\text{Max Irradiance} = 822.5\, {}^{W}\!/_{m^2} \times \frac{0.7\%}{100\%} = 5.7575\, {}^{W}\!/_{m^2} \cong 5.8\, {}^{W}\!/_{m^2}$$

The second criteria is a uniform irradiance across a test item surface area (target plane). Method 505 uses the term "uniformity", other documents may reference "non-uniformity". Both terms define a deviation between measured and desired irradiance across positions on a measurement grid. A test item may have multiple grids or intensity requirements, but the basic evaluation is the same. The uniformity evaluation can be performed with an imaginary surface prior to placement of the test item in the chamber. Alternatively, measurements can be performed on the test item if pre-test irradiance exposure is acceptable. In either case, documentation of measurement grid points and irradiance is required to validate the test setup uniformity.

The central 3 x 4 target plane in Figure 505.7C-1 represents the Figure 505.7C-2 vehicle top surface. Each pyranometer represents one portion of the target plane area, additional pyranometers are distributed around the target plane. Figures 505.7C-3 and 505.7C-4 illustrate additional test configurations and target planes. Accurate uniformity for the vehicle antenna and lower electronics enclosure is best represented by a multiple target plane configuration. The upper plane receives irradiance from the main overhead array, and an auxiliary array is needed to provide irradiance to the lower plane. Screen mesh or other material above higher components can also be used to attenuate irradiance. The test configurations are for illustration only, actual testing must to be performed according to the test plan and as agreed between the contractual parties.

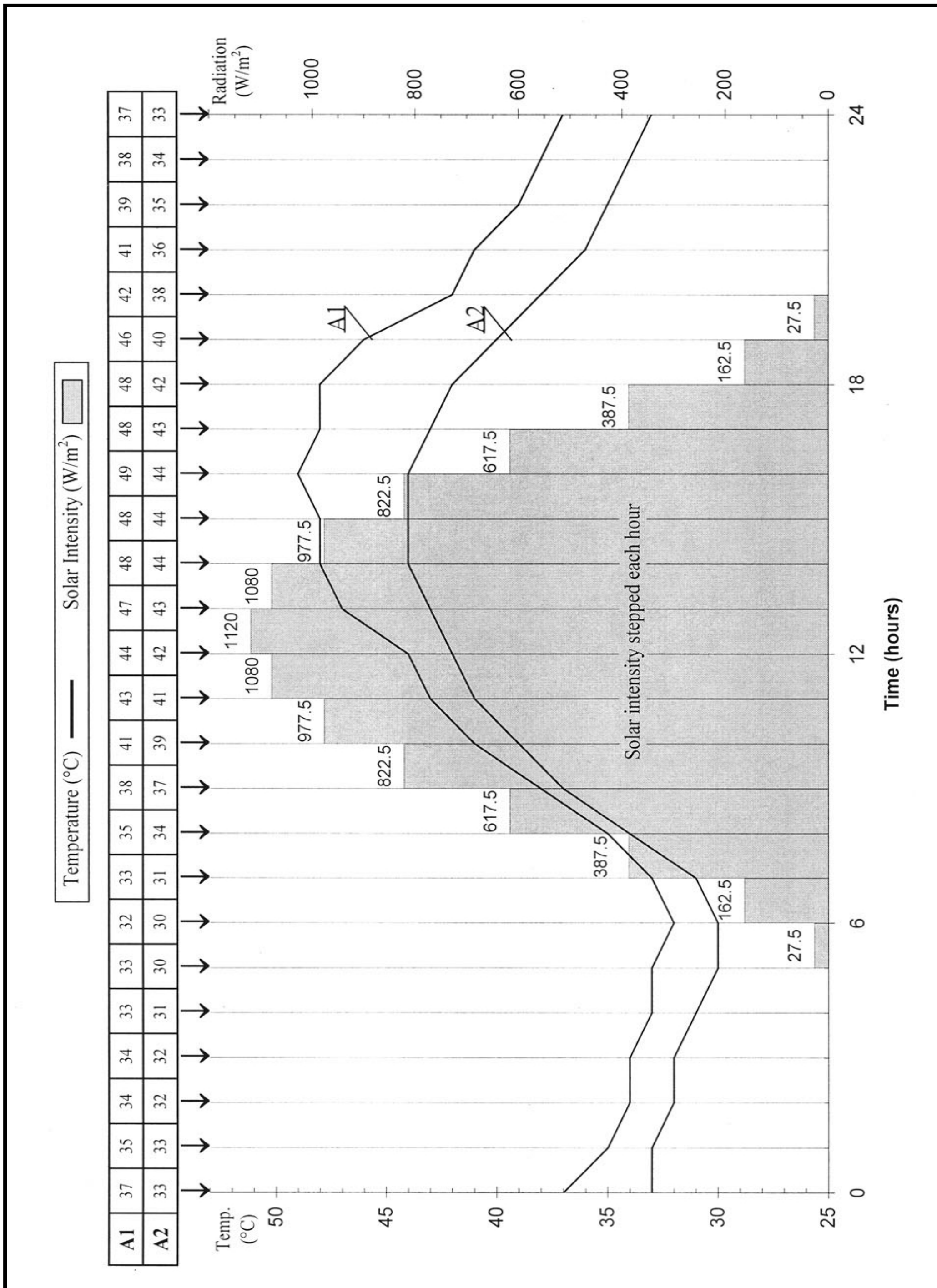


Figure 505.7C-5. Method for conducting Procedure I with solar radiation controlled in one-hour steps.

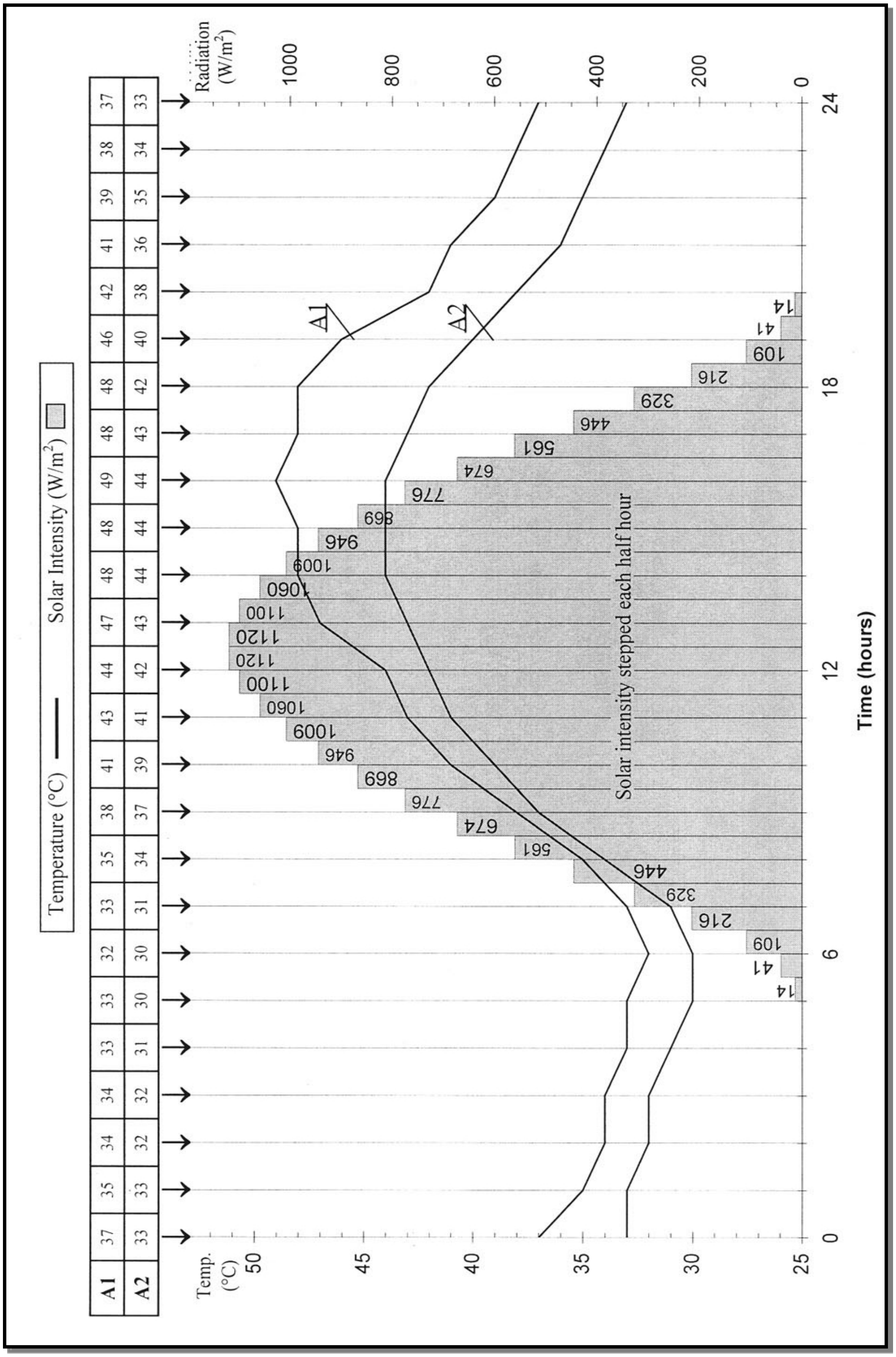


Figure 505.7C-6. Method for conducting Procedure I with solar radiation controlled in half-hour steps.