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14. ABSTRACT
This Test Operations Procedure (TOP) describes the general methodology for characterization of Solar Test Equipment that is used for Military Standard (MIL-STD)-810 Change Notice (CN) 1, Method 505 Solar Radiation Procedure I – Cycling (Heating). Experience has shown that large facility-to-facility variations can exist in the solar test equipment, procedures, and ultimately the heating imparted to the test item. The methods described herein also support characterization and reduction to variation at a test facility over time due to degradation of the system, maintenance, and facility modifications. This TOP defines a standard set of guidelines for instrumentation and procedures for characterizing the applied environment in a solar test chamber.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 01-2-826 23 August 2022
DTIC AD No.

CHARACTERIZATION OF SOLAR TEST EQUIPMENT FOR HEATING EFFECTS TESTING

* Distribution Statement A. Approved for public release; distribution is unlimited.

1. SCOPE.

1.1 Purpose.

This Test Operations Procedure (TOP) describes the general methodology for characterization of Solar Test Equipment/Chamber that is used for Military Standard (MIL-STD)-810H Change Notice (CN) 1[1**], Method 505 Solar Radiation Procedure I - Cycling (Heating). Experience has shown that large facility-to-facility variation exists in the solar test equipment, procedures and ultimately the thermal heating of the test item. The methods described herein also support characterization and reduction to variation at a test facility over time due to degradation of the system, maintenance, and facility modifications. This TOP defines a standard set of guidelines for instrumentation and procedures for characterizing the applied environment in a solar test chamber to reduce facility-to-facility variation.

1.2 Background.

MIL-STD-810H CN1, Method 505 Solar Radiation Procedure I is used to evaluate the combined effects solar and high ambient temperatures on Department of Defense (DoD) materiel. This Method is performed on DoD materiel to ensure it will perform properly when fielded in a hot dry environment.

1.3 Limitations.

a. This TOP does not address Procedure II of MIL-STD-810H CN1 Method 505 Steady State (actinic effects).

** Superscript numbers correspond to Appendix B, References.

b. This TOP does not supersede any guidance from the latest revision of MIL-STD-810.

c. The TOP guidance is applicable to small and large chambers, however characteristics of individual chambers and irradiance simulation equipment may require tailoring of TOP guidelines and test objectives.

d. The TOP irradiance discussion is applicable for ambient natural solar conditions (one sun) and excludes multi-sun accelerated test procedures.

2. TEST PROCESS.

2.1 Introduction.

The characterization procedures are typically used for the following purposes. These procedures are not intended to be performed as a pre-test check.

a. New equipment: performed to characterize a new chamber or solar test equipment to ensure it provides the simulated solar environment specified in MIL-STD-810H CN1.

b. Following a major maintenance or repair activity. Changes in lamps, air handling systems, chamber controls can affect the operation of the test equipment and may require chamber characterization.

c. Periodic Characterization. This is intended to ensure that degradation over time is not significantly impacting the environment applied by the chamber. Each solar test chamber has unique design aspects that may affect performance. Consult with the manufacturer to understand the key components that may degrade over time and to determine the best interval for performing the chamber characterization. If no guidance is provided by the manufacturer, it is recommended that the characterization be performed every two years. Chamber characterization procedures include the following.

(1) Air Temperature (Section 4).

(2) Air Flow (Section 5).

(3) Irradiance (Section 6).

(4) Spectral Energy (Section 7).

(5) Combined Heating Effects (Section 8).

d. Each section is written as a standalone procedure. However, it is highly encouraged to tailor the approach to perform these in the most efficient manner for the facility and the test purpose. These procedures may be performed in parallel or series. For certain test purposes it may be deemed only necessary to perform a selected subset of the procedures (e.g., the bulbs are replaced so the Spectral Energy procedure is performed).

e. Whilst the TOP methodology provides a framework to understand and control a solar chamber operational parameters, a laboratory test may not produce response temperatures found in the natural environment due to other conditions. When tailoring to a specific natural environment, the measurement of natural environment response at one or more conditions is recommended to confirm the laboratory response accuracy.

f. Documentation of all chamber equipment, control parameters, instrumentation, and procedures is required to effectively utilize this TOP.

2.2 Test Volume and Measurement Grid.

a. One important aspect for the Air Temperature, Air Flow and Irradiance procedures is to define the test volume. This test volume is the area where the simulated solar environment generated is within the requirements of MIL-STD-810H CN1. It is the volume of the chamber where test items are placed. Effectively, it defines the useable space in the chamber. The test volume grid is typically defined relative to the floor and the center of the chamber.

b. For characterization of Air Temperature, Air Flow and Irradiance, measurements are taken over a horizontal grid spacing that is determined by the chamber size and lamp configuration. In general, the following is recommended for a measurement grid size: 0.25 meters for small reach-in chambers, 0.5 meters for walk-in chambers, for large drive-in chambers, this spacing may be increased to 1 meter. The grid points should be selected to provide a representative sample of measurements taken in different locations relative to the lamps (e.g., directly under and at boundaries between lamps). This is used to verify uniformity for a specific solar simulator design. The horizontal grid measurements should be taken at multiple vertical heights. For general characterization with a horizontal lamp array, it is recommended that sufficient vertical measurements be made to determine the volume where the uniformity requirements are maintained for each measurement type (irradiance, temperature, air flow) (see Figure 1). Consider test item and instrumentation physical size, lamp position(s), and control accuracy requirements to define the grid pattern. Cartesian, polar, or other coordinate systems in evenly or irregular spacing are all acceptable based on test specific requirements.

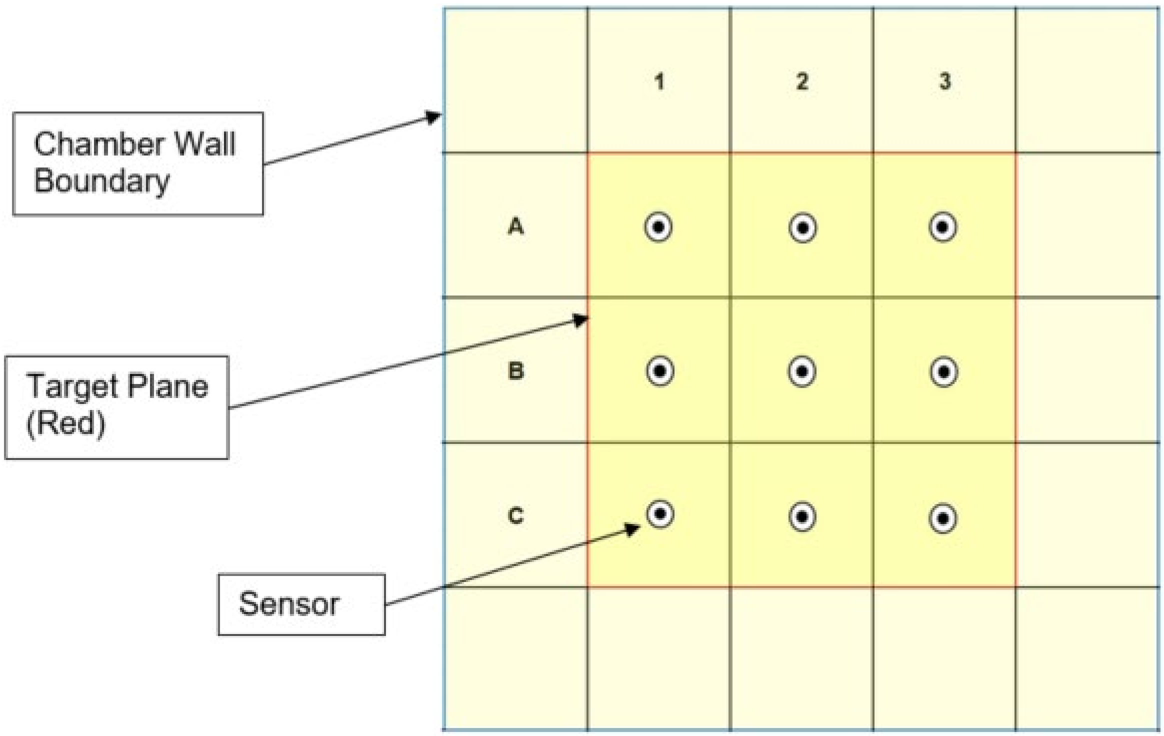

Figure 1. Example horizontal target plane with rectangular grid pattern.

c. Simultaneous measurement from multiple sensors, to include but not limited to, temperature, airflow, and radiation irradiance is recommended to reduce data acquisition labor. A typical acquisition procedure establishes uniform grid on the chamber floor. An adjustable height stand can be used to support the sensor(s) vertically above each grid point.

2.3 Thermal Static Load.

Where applicable, it may be appropriate to perform the solar test equipment characterization with a static load or representative test item in the chamber. This is appropriate when a chamber is dedicated to testing a specific product, but is not required. Typical pre-test checkouts as described in MIL-STD-810H CN1 are used to adjust chamber control parameters when there are large variations in test item size.

2.4 Modeling.

To the extent possible, the testing performed to characterize the chamber should be coupled with a model of the chamber. This is especially appropriate for the irradiance parameter. Ray tracing software, used for irradiance modeling, typically provided by the solar test equipment manufacturer, can provide an estimate of the test volume and the variation in solar irradiance across test item(s). The modeling software will provide understanding of the lamp irradiance overlap and its impact on uniformity.

2.5 Standard Ambient Conditions.

When the term "Standard Ambient" is specified in this document, the values shown below apply. If the term is not used, and no specific values are called out in this document, tests (e.g., pretest, during, and posttest) will be conducted at these standard ambient conditions. Standard ambient, for the purpose of this test plan, will be used unless otherwise stated.

a. Temperature: 25 °Celsius (°C) ± 10 °C (77 °Fahrenheit (°F) ± 18 °F).

b. Relative Humidity (RH): 20 to 80 percent.

c. Atmospheric Pressure: site pressure.

3. INSTRUMENTATION.

Table 1 provides a summary of the measurement requirements for this TOP. These values are derived from information in Method 505, and Part One Section 5.3, of MIL-STD-810H CN1.

TABLE 1. SUMMARY OF MEASUREMENT REQUIREMENTS

MEASUREMENTS	DEVICE MEASUREMENT RANGE[a]	CONTROL TOLERANCE	MEASUREMENT ACCURACY[c]
Air Temperature	-18 to 60 °C (0 to 140 °F)	±2.0 °C[b] or ±2.8 °C[b] (±3.6 °F[b] or ±5 °F[b])	±0.67 °C (±1.2 °F)
Air Speed	0-5 meters per second (m/s)	±10% of the specified value OR the range of 1.5-3.0 m/s	±3.3%
Solar Irradiance	0-1250 watts per meter squared (W/m^2)	±4% or ±15 W/m^2 whichever is less	Class A pyranometer per ISO 9060:2018[2]
Relative Humidity	0-100% RH	±5%, if required	±2% RH
Spectral Energy Distribution	*See Section 3.4*		
Surface Temperature	-18 to 99 °C (0 to 210 °F)	N/A	±0.67 °C (±1.2 °F)

[a] Values are intended to encompass meteorological test conditions with margin. Adjust the measurement span if required.
[b] For test volumes containing test items larger than 5 m^3 the allowable tolerance is ±2.8 °C (±5 °F).
[c] Evaluation of complete instrumentation/data acquisition system accuracy is recommended.

3.1 Air Temperature.

a. Use of a chamber temperature control sensor(s) near the test item is recommended to best simulate the combined solar load and ambient heat transfer. It is critical this temperature sensor(s) be shielded and aspirated due to the radiation intensity. It is recommended than an aspirated shielded enclosure designed for outdoor measurement be used. The temperature sensor used is typically a higher accuracy thermocouple or a Resistance Temperature Detector (RTD). There is not a specific requirement for response time, however the time constant should be evaluated or determined by the user to ensure an adequate temperature stabilization between measurements. See Table 1 for range, control tolerance, and accuracy requirements.

b. Ultrasonic anemometers can provide a temperature measurement, however the accuracy is much less than that which is measured by a shielded and aspirated temperature sensor. Due to this, it may be used as a backup, but is not recommended as a replacement to the shielded aspirated thermocouple or RTD.

3.2 Air Flow.

a. In typical chambers, the flow direction is not unidirectional with airflow often flowing downward toward the floor of the chamber. For these air flow measurements in the chamber a three-dimensional (3D) ultrasonic measurement is recommended to ensure the full velocity vector is measured. The 3D anemometer may also have limitations in one axis (typically azimuth). Ensure the measurement device is positioned to allow for capturing the full velocity.

b. There is not a specific requirement for response time, however the time constant should be evaluated or determined by the user to ensure an adequate velocity stabilization. The sampling rate for wind speed measurements will be a minimum of 4 samples per second. The air speeds should be the average the measurements over a minimum of 10 seconds with the chamber equipment controls held constant. If the flow conditions in the chamber are highly variable measurements over a longer duration than 10 seconds may be necessary. See Table 1 for range, control tolerance, and accuracy requirements.

3.3 Solar Irradiance.

a. Solar irradiance for the purposes of this procedure is the global horizontal irradiance, the hemispherical solar radiation received by a horizontal plane surface. This is measured with a pyranometer. The pyranometer used should comply with the Class A requirements defined in International Organization for Standardization (ISO) 9060:2018. Class A roughly corresponds to the Secondary Standard from ISO 9060:1990[3]. The required 95 percent response time for a Class A radiometer is less than 10 seconds. Ensure the pyranometer complies with the cosine angle (directional response) requirement of ISO 9060:2018.

b. The MIL-STD-810H CN1 spectral range of interest is 280 nanometers (nm) to 3000 nm. However, most Class A pyranometers do not measure this full range, and they typically have a spectral range of 285 to 2800 nm (50 percent amplitude response points). Depending on the bulb output spectrum, the energy not measured by the pyranometer may be negligible. However, this should be assessed, and as required, accounted for in measurements.

c. When using a pyranometer, it is important to ensure adequate airflow around the instrument to minimize measurement error caused by temperature gradients across the instrument. The pyranometer should also include temperature compensation. Follow manufacturer's recommendations for installation and operation of the pyranometer.

3.4 Spectral Energy Distribution.

a. Several radiometers and spectrometers exist to measure a solar test system spectral distribution or total energy per band. Evaluation of the 280 to 3000 nm bandwidth may require several instruments and simultaneous measurements. Techniques are still in the development stages and this document will be updated after methods have been validated in the chamber. Precise and repeatable measurements require adequate instrumentation knowledge and understanding of spectrum measurement techniques. A spectrum measurement could be performed using one of the methods in this section, or combination of methods.

b. Several device designs currently exist to measure the spectral power distribution (SPD) providing the energy level per-wavelength band of a solar radiation source. To measure the natural solar spectral band a measurement range of 280 nm to 3000 nm is required.

c. The ability to compare the SPD output of an artificial radiation source against the requirements defined in the specification (Table 2) can be accomplished in several ways using a variety of techniques and required instrumentation. In most cases a combination of instruments is used to accomplish the measurement.

TABLE 2. MIL-STD-810H CN1 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

(1) Pyranometer with Bandpass Filter Domes. While not currently in production, historically spectral cut-on filters were used to block specific ranges of radiation (400 nm and below as an example) allowing only portions of the spectrum to reach the pyranometer. While this technique can be used to develop general energy levels over specific ranges, it is not commonly used and provides only energy over specific spectral range levels. Use of this technology does not provide wavelength specific information.

(2) Solarimeter (reference cell) Systems. Solarimeter designs are available to measure solar and artificial light sources over a specific spectral range, however these units must be specifically calibrated to the actual radiation source in use. These instruments are typically designed for measurement and control related to specific solar measurement applications. Use of this technology does not provide wavelength specific information. The two common radiometer technologies used for wavelength specific SPD measurements currently employ Monochromator optical design or Charge Coupled Device (CCD) optical design.

(3) Monochromator Optical Design. A Monochromator instrument can provide accurate measurements covering the spectral range of 250 to 3000 nm (depending on configuration). However, as Monochromator based devices are complex, difficult to operate, requires complex/costly calibration instrumentation, and prohibitively expensive to purchase they are not often used in the industrial chamber environment. These are often used for the spectral characterization of light sources in a controlled laboratory environment.

(4) Charge Coupled Device (CCD) Spectrometers. Unlike the Monochromator type instruments, spectrometer devices using CCD technology are compact, relatively inexpensive devices providing an easy user interface and a straight-forward calibration process. However, these devices are limited to the spectral range of 280 to 800 nm, or depending on configuration, 280 to 1100 nm. As the range of primary concern for thermal heating effects is 400 to 3000 nm, the spectrometer is used to validate the spectrum over the 400 to 800 nm range. These data can then be coupled with the pyranometer radiometer data and the ultraviolet (UV) data to provide the 800 to 3000 nm energy through subtraction.

d. In all cases (Monochromator or CCD instrument type) the accurate measurement in the UV range is difficult and if not performed properly may lead to significant measurement errors. As such the specifics of using these instruments for accurate and reliable measurements is not discussed or required as part of this document. However if performed properly these can be used to determine the UV content in the light source for UV subtraction of the Total Solar Radiation value provided by the pyranometer.

e. Spectral radiometers should have an American Society for Testing and Materials (ASTM) G138-12[4] compliant calibration. Calibration may require multiple calibrated light sources to cover the spectrum of interest. Due to the variation and sophistication of the available spectral radiometers, it’s highly encouraged to perform measurements in accordance with ASTM G138-12 to check the calibration.

f. Consult with the spectral radiometer manufacturer or radiometry specialist to select the most appropriate input optics to produce accurate measurements when used in conjunction with the pyranometer.

3.5 Combined Heating Effects.

a. The instrumentation outlined in this section seeks to provide a sampling of potential test item temperature responses. It currently includes standard painted panels, but in future revisions after methodology studies have been completed, test item temperature sensor installation techniques and under glass surface temperature measurements will be added. Alternate surface temperature distribution evaluation methods include thermally reactive paint and infrared (IR) camera systems. These methods can be less accurate, but may be useful for preliminary comparisons.

b. To ensure consistency and correlation with the natural environment the panel type recommended for the procedures are ASTM G179[5] panels. These are thin metal panels, and the ASTM defines the thermocouple installation and paint finish for black and white panels. If the chamber is used often for standard coating systems, it is recommended that these coating systems be applied to unpainted ASTM G179 panels for comparison purposes. The use of both backed and unbacked panels is recommended. The unbacked panels provide a quick response to the changes in conditions allowing for characterization of the temporal variability of the conditions. The backed panels provide a closer simulation to a test item and typically result in higher temperatures at similar conditions to the unbacked panels.

4. AIR TEMPERATURE CHARACTERIZATION.

4.1 Overview.

Air temperature characterization is performed to measure the air temperature (average and uniformity) in the test volume of the solar chamber. These measurements will aid in defining the useable volume of the chamber for the typical chamber configuration and confirm compliance with the test parameter tolerances in Table 505.7-II, in Method 505.7, of MIL-STD-810H CN1.

4.2 Test Criteria.

a. Air temperature measurement at three solar diuranl cycle set-points is recommended to evaluate the chamber spatial temperature variation. For the A1 Hot Dry Natural Cycle, it is recommended to use 162 W/m^2 at 33 °C, 617 W/m^2 at 38 °C, and 1120 W/m^2 at 47 °C. These values are included in the procedure below, but they can be tailored as necessary for other planned test profiles. In general, characterization using A1 provides sufficient information to verify proper chamber operation and useable volume for other profiles. Measurement grid spacing is described in Section 2.2.

b. MIL-STD-810H CN1 provides the following guidance on test section air temperature uniformity in Part One, Section 5.1.a. This guidance should be used for determining the portion of the chamber that is in compliance.

> *"Surround the test item totally by an envelope of air (except at necessary support points), considering boundary effects. Keep the air temperature uniform in the immediate vicinity of the item. To ensure the test item is bathed in the required air temperature, place verification sensors at representative points around the entire item and as close to the test item as possible, but not so the airstream temperature is affected by the test item temperature. Keep these temperatures within ± 2 °C (3.6 °F) of the required test temperature. Ensure the air temperature gradient across the item does not exceed 1 °C (2 °F) per meter or a maximum of 2.2 °C (4 °F) total (test item non-operating). Wider temperature tolerances are acceptable in situations such as:*
>
> *(1) For large items with a volume greater than 5m^3 (6.5 yd^3), the temperature tolerance can be ± 3 °C (± 5 °F). Justify any larger tolerance and obtain approval for its use from the procuring activity.*
>
> *(2) For required temperatures greater than 100 °C (212 °F), the temperature tolerance can be ± 5 °C (± 9 °F). Specify the actual tolerance achieved."*

c. Based on this guidance, all of the measurements should be within ± 2 °C (± 3.6 °F) or ± 3 °C (± 5 °F) based on the size of the test item. The variation in the temperature should be within 1 °C (2 °F) per meter. Using knowledge of the planned test item sizes, the user may also want to set limits based on the maximum of 2.2 °C (4 °F) total across the test item.

4.3 Procedure.

a. Pretest/Setup.

Step 1. Install and checkout instrumentation that complies with Section 3.1. Ensure aspirated radiation shield fan is operating properly.

Step 2. Inspect the chamber and solar test equipment. Ensure any required preventative maintenance has been performed. Photograph the chamber configuration.

> Note: See guidance on measurement grid spacing in Section 2.2. Multiple aspirated radiation shields with temperature sensor may be used to reduce the time to perform measurements.

b. Air Temperature Measurements.

Step 1. Ramp the chamber temperature to the temperature for the first measurement point (typically the highest intensity and temperature) and stabilize the air temperature.

Step 2. Adjust the lamps to provide irradiance specified for the first measurement point. Record control settings of the chamber and solar test equipment.

Step 3. Perform air temperature measurements across the horizontal grid on the planned target plane. Ensure the measurement device stabilizes at each point.

Step 4. Analyze the measurements and adjust the chamber settings as necessary to meet the chamber air temperature uniformity requirement. If adjustments are necessary, repeat Step 2.

Step 5. With the air temperature measurements confirmed, perform measurements on additional horizontal planes to determine the volume where the air temperature control tolerance measurements are met. Document the chamber settings.

Step 6. Repeat steps 1-5 for the additional test points.

4.4 Analysis of Results.

a. Using the criteria presented in Section 4.2, determine the useable test volume. Depending on the chamber size, the test volume may be defined for both large and small test items.

b. Present the results visually to easily determine areas of compliance relative to the chamber volume and test criteria. It is typical to present the data with the center of the chamber as a reference. Table 3 provides an example presentation of air temperature data. The characterization report should include the test chamber configuration and settings.

TABLE 3. PRESENTATION OF AIR TEMPERATURE DATA
(Target of 33 °C and 162 W/m^2)

Height of Target Plane: 1 Meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	31.7	32.3	32.7	33.0	32.3	32.2	**30.8**
	-1m	32.3	32.3	33.1	33.3	32.7	32.7	32.7
	-0.5m	32.7	32.0	32.7	33.7	32.2	32.0	32.3
	Center	32.3	32.2	32.5	33.3	32.7	32.7	32.8
Forward	+0.5m	33.0	33.3	33.0	33.1	33.0	33.0	33.3
	+1m	32.7	33.7	33.3	33.3	33.3	33.2	33.5
	+1.5m	**30.4**	**31.2**	33.0	33.7	33.0	33.0	33.0
		Out of Tolerance				*Temperatures in °C*		

Height of Target Plane: 1.5 Meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	32.0	32.6	33.0	33.3	32.6	32.5	32.3
	-1m	32.6	32.6	33.4	33.6	33.0	33.0	33.0
	-0.5m	33.0	32.3	33.0	34.0	32.5	32.3	32.6
	Center	32.6	32.5	32.8	33.6	33.0	33.0	33.1
Forward	+0.5m	33.3	33.6	33.3	33.4	33.3	33.3	33.6
	+1m	33.0	34.0	33.6	33.6	33.6	33.5	33.8
	+1.5m	**30.6**	**31.2**	33.3	34.0	33.3	33.3	33.3
		Out of Tolerance				*Temperatures in °C*		

Height of Target Plane: 2 Meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	33.0	33.3	33.7	34.0	33.3	33.2	**31.7**
	-1m	33.3	33.3	34.1	34.3	33.7	33.7	33.7
	-0.5m	33.7	33.0	33.7	34.7	33.2	33.0	33.3
	Center	33.3	33.2	33.5	34.3	33.7	33.7	33.8
Forward	+0.5m	34.0	34.3	34.0	34.1	34.0	34.0	34.3
	+1m	33.7	34.7	34.3	34.3	34.3	34.2	34.5
	+1.5m	**31.3**	**31.2**	34.0	**35.4**	34.0	34.0	34.0
		Out of Tolerance				*Temperatures in °C*		

5. AIR FLOW CHARACTERIZATION.

5.1 Overview.

a. Air flow characterization is performed to measure the air speed (average and uniformity) in the test volume of the solar chamber. These measurements will aid in defining the useable volume of the chamber for the typical chamber configuration and confirm compliance with the test parameter tolerances in Table 505.7-II, in Method 505.7, of MIL-STD-810H CN1.

b. Measurements are generally taken at standard ambient temperatures. However, ensure that the chamber is configured and operating with the same air flow and obstructions as it would during the solar test. Measurement grid spacing is described in Section 2.2.

5.2 Test Criteria.

a. MIL-STD-810H CN1 provides the following guidance on test section air flow:

> *"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."*

b. As the primary objective of this TOP is for the characterization of Solar Test Equipment/Chamber for the default conditions prescribed by Procedure I, the test criteria are that useable test volume have airspeeds between 1.5 to 3.0 m/s. Tailor as needed for the typical test requirements of the facility.

5.3 Procedure.

a. Pretest/Setup.

Step 1. Install and checkout instrumentation that complies with Section 3.3. Ensure the chamber is configured with the solar test equipment as this may alter the airflow. Any obstructions in the planned test volume should be removed.

Step 2. Inspect the chamber and solar test equipment. Ensure any required preventative maintenance has been performed. Photograph the chamber configuration.

> Note: See guidance on measurement grid spacing in Section 2.2. Multiple anemometers may be used to reduce the time to perform measurements.

b. Flow Measurements.

Step 1. With the chamber at a stable temperature within standard ambient conditions, bring all airflow generation (chamber circulation fan and supplementary fans) to the planned settings. Record control settings.

Step 2. Perform air flow measurements across the horizontal grid on the planned target plane. Ensure the sufficient data is recorded to allow for measurement device stabilization and a minimum of 10 seconds of data for determining the average air speed at that location.

Step 3. Analyze the measurements and adjust the fan settings as necessary to ensure all measurements are within the required range. If adjustments are necessary, repeat Step 2.

Step 4. With the air flow measurements confirmed to be within the allowable range, perform measurements on additional horizontal planes to determine the volume where the air flow requirements are met.

c. Analysis of Results.

(1) Using the criteria presented in Section 5.2 determine the useable test volume. Depending on the chamber size, the test volume may be defined for both large and small test items.

(2) Present the results visually to easily determine areas of compliance relative to the chamber volume and test criteria. It is typical to present the data with the center of the chamber as a reference. The characterization report should include the test chamber configuration and settings (see Table 4).

TABLE 4. PRESENTATION OF AIR FLOW DATA
(Specified Range of 1.5 to 3.0 m/s)

Height of Target Plane: 1 meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	1.7	1.9	1.7	1.8	1.9	1.7	**1.1**
	-1m	1.5	1.7	2.0	1.5	1.9	1.5	1.5
	-0.5m	2.1	2.5	2.2	2.1	2.3	2.1	2.1
	Center	2.1	2.7	2.5	2.6	2.4	2.4	2.1
Forward	+0.5m	2.5	2.1	2.5	2.1	2.5	2.5	2.5
	+1m	1.5	1.6	2.1	2.5	1.6	1.5	1.5
	+1.5m	**1.3**	1.8	1.5	1.5	1.8	**1.3**	1.7
		Out of Tolerance				*Air Speed in m/s*		

Height of Target Plane: 1.5 meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	1.9	2.1	1.9	2.0	2.1	1.9	**1.3**
	-1m	1.7	1.9	2.2	1.7	2.1	1.7	1.7
	-0.5m	2.4	2.8	2.5	2.4	2.6	2.4	2.4
	Center	2.4	3.0	2.8	2.9	2.7	2.7	2.4
Forward	+0.5m	2.8	2.4	2.8	2.4	2.8	2.8	2.8
	+1m	1.5	1.6	2.4	2.8	1.6	1.5	1.5
	+1.5m	1.6	2.0	1.7	1.7	2.0	1.6	1.9
		Out of Tolerance				*Air Speed in m/s*		

Height of Target Plane: 2 meter								
		Left				*Right*		
		-1.5m	-1m	-0.5m	Center	+0.5m	+1m	+1.5m
Aft	-1.5m	1.9	2.1	1.9	2.0	2.1	1.9	**1.3**
	-1m	1.7	1.9	2.2	1.7	2.1	1.7	1.7
	-0.5m	2.3	2.7	2.4	2.3	2.5	2.3	2.3
	Center	2.3	2.9	2.7	2.8	2.6	2.6	2.3
Forward	+0.5m	2.7	2.3	2.7	2.3	2.7	2.7	2.7
	+1m	1.5	1.6	2.3	2.7	1.6	1.5	1.5
	+1.5m	1.5	2.0	1.7	1.7	2.0	1.5	1.9
		Out of Tolerance				*Air Speed in m/s*		

6. IRRADIANCE CHARACTERIZATION (INTENSITY AND UNIFORMITY).

6.1 Overview.

Irradiance characterization is performed to measure the intensity and uniformity in the test volume of the solar chamber. These measurements will define the useable volume of the chamber for the typical chamber configuration and confirm compliance with the test parameter tolerances in Table 505.7-II, in Method 505.7, of MIL-STD-810H CN1.

6.2 Test Criteria.

a. It is recommended that measurements are taken at three points in the planned profile. For the A1 Hot Dry Natural Cycle, it is recommended to use 162 W/m^2 at 33 °C, 617 W/m^2 at 38 °C, and 1120 W/m^2 at 47 °C. These values are included in the procedure below, but these can be tailored as necessary for other planned test profiles. In general, characterization using the recommended A1 provides sufficient information to verify proper chamber operation and useable volume for other profiles. Measurement grid spacing is described in Section 2.2.

b. MIL-STD-810H CN1, Method 505.7, Table 505.7-II provides the uniformity requirement of ± 10 percent deviation between the measured and target irradiance at all measurement points.

c. MIL-STD-810H CN1, Method 505.7, Table 505.7-II also provides a control tolerance requirement for the total irradiance to be within ± 4 percent or ± 15 W/m^2 (whichever is greater) of the target irradiance. For the purposes of this TOP, this is also applied to the average of the irradiance measurements taken over the useable grid. This tolerance, while not explicitly stated in MIL-STD-810H CN1, is a prudent check to ensure the test chamber can adequately apply the environment.

6.3 Procedure.

a. Pretest/Setup.

Step 1. Install and checkout instrumentation that complies with Section 3.3. Ensure the pyranometers are configured correctly, per the manufacturer's instructions. In addition to standard calibration procedures, it is recommended to ensure a zero output is measured with the pyranometer(s) when placed in a fully dark location.

Step 2. Inspect the chamber and solar test equipment. Ensure any required preventative maintenance has been performed. Photograph the chamber configuration.

Note: See guidance on measurement grid spacing in Section 2.2. Multiple pyranometers may be used to reduce the time to perform measurements. When using multiple pyranometers, it is recommended to compare results from the pyranometers at various intensities prior to performing measurements to ensure variations in measurements due to the pyranometer accuracy is understood.

b. Irradiance Measurements.

Step 1. Ramp the chamber temperature to the temperature for the first measurement point (typically the highest intensity and temperature) and stabilize the air temperature.

Step 2. Adjust the lamps to provide irradiance specified for the first measurement point. Record control settings of the chamber and solar test equipment.

Step 3. Perform irradiance measurements across the horizontal grid on the planned target plane. Ensure the device measurement stabilizes at each point.

Step 4. Analyze the measurements and adjust the solar irradiance as necessary to meet the total irradiance tolerance. If adjustments are necessary, repeat Step 2.

Step 5. With the irradiance measurements confirmed, perform measurements on additional horizontal planes at different heights to determine the volume where the total irradiance and uniformity requirements are met. Document the chamber settings.

Step 6. Repeat steps 1-5 for the additional test points (e.g., low, medium).

6.4 Analysis of Results.

Comparison to test criteria.

a. Using the criteria presented in Section 6.2 determine the useable test volume.

b. Analysis of the measurements determines compliance with the total irradiance and uniformity requirements. An example analysis follows.

c. Figure 1 describes the measurement locations on the target plane. Table 5 summarizes an example of target plane irradiance measurements following final lamp position and power adjustment to achieve an 1120 W/m^2 on a 3 x 3 measurement grid target plane. The table on the right side of the table indicates linear percentage deviation at each measurement point. The Method 505.7 uniformity requirement is a maximum of ± 10 percent deviation between the measured and desired irradiance at all measurement points, as indicated in the Equation 1.

At each measurement grid point: $((I_{MEASURED} - I_{TARGET}) / I_{TARGET}) * 100 \leq 10\ \%$ *(Equation 1)*

TABLE 5. UNIFORMITY CALCULATION

Measured Irradiance, W/m^2					Point Error, % ($I_{MEASURED} - I_{TARGET}$)			
Row/ Column	1	2	3		Row/ Column	1	2	3
A	1068	1123	1110		A	- 4.6	0.3	- 0.9
B	1061	1125	1105		B	- 5.3	0.4	-1.3
C	1064	1115	1101		C	- 5.0	- 0.4	-1.7
Irradiance Minimum (B1), W/m^2			1061		Maximum % Above Target (B2), %			0.4
Irradiance Maximum (B2), W/m^2			1125		Maximum % Below Target (B1), %			-5.3
Irradiance Average, W/m^2			1095.5		Irradiance Uniformity, %			5.3

(1) For an 1120 W/m^2 target irradiance, the allowable measurement range for uniformity is 1008 to 1232 W/m^2. Position B1 has the largest deviation; the overall measurement uniformity is 5.3 percent. The maximum point to point deviation is location B1 to B2, 5.7 percent, however the maximum uniformity is still 5.3 percent.

(2) The second criterion is the evaluation of average irradiance compared to the target irradiance. For an 1120 W/m^2 target irradiance, the allowable range for the average irradiance is 1075.2 to 1164 W/m^2 based on the ± 4 percent tolerance. The average value measured in this example is 1095.5 W/m^2 and within the allowable range. For target values below 375 W/m^2 the tolerance is ± 15 W/m^2.

d. Comparison to Previous Chamber Characterization. Irradiance measurements and test equipment control settings should also be compared to previous test results to ensure repeatable test conditions and to evaluate degradation of the system to identify the need for preventative maintenance.

7. SPECTRAL ENERGY CHARACTERIZATION.

7.1 Overview.

a. The purpose of this measurement is to verify the spectral radiant energy of the solar simulator is providing a reasonable spectral match to sunlight. When a reasonable spectral match to sunlight is provided it is assumed the heating effects of radiant energy during the chamber test is similar to the natural outdoor environment with similar boundary conditions (airflow, ground density etc). Measurement of test item or panel response temperatures in the natural environment is recommended prior to chamber testing for validation of the chamber simulation.

b. There are multiple proposed methods for measuring the spectral energy distribution. For this procedure, a spectrometer and pyranometer are used as discussed in paragraph 3.4, option 3.

7.2 Test Criteria.

a. The spectrum requirements are defined by MIL-STD-810H CN1. The spectral energy distribution requirement from MIL-STD-810H CN1 is shown in Table 2.

b. MIL-STD-810H CN1, Section 4.2.1, provides additional details on determining the specific spectral requirement for performing Procedure I on planned test items. This procedure will focus on determining compliance with the visible and infrared portions of the spectrum. Test items that incorporate attenuating coatings, glazing, or other systems that may affect spectral reflection/absorption may require additional analysis and/or increased accuracy replicating the solar spectral energy distribution to ensure the proper amount of radiative heat transfer occurs during the testing.

c. The location of the spectral measurement points is at the same surface plane as used in Section 6, however fewer points are required. For single lamp systems in a small reach-in chamber one location may be needed, for walk-in chambers two, four, or six may be required. For large drive-in chambers, eight locations will typically provide the spectral detail needed. Use as many points as needed to provide reasonable analysis of overall spectral uniformity. The points selected should be co-located with a subset of the irradiance measurement points, see Section 2.2. Document measurement location information for future reference.

d. If preparing for a specific shape test object, spectral measurement locations can be based on the solar exposure surfaces of concern.

e. It is recommended that spectral measurements are performed for the following total radiation levels. Ideally, the chamber temperature conditions are at the same maximum temperature on the diurnal cycle profile when the irradiance level occurs, however instrumentation limitations may require the measurements to be performed at standard ambient temperatures.

(1) 55 W/m^2.

(2) 505 W/m^2.

(3) 915 W/m^2.

(4) 1120 W/m^2.

7.3 Procedure.

a. Pretest/Setup.

Step 1. Review calibration records and operating manuals of instrumentation to ensure accurate measurements are created.

Step 2. Establish the measurement points based on the exposure area of the chamber or top surface area of the test object. See Section 7.2.

Step 3. Plan the measurement for electrical/optical cable routing and if needed blocking of solar radiation or extreme temperatures to thermally sensitive measurement instrumentation.

b. Spectral Energy Measurements.

Step 1. Ramp the chamber temperature to the temperature for the first measurement point (typically the highest intensity and temperature) and stabilize the air temperature.

Step 2. Adjust the lamps to provide irradiance specified for the first measurement point. Record control settings of the chamber and solar test equipment.

Step 3. For each measurement location perform a measurement using the Spectral Measurement Device (SMD) followed by placing the pyranometer at the same location.

Step 4. Record the file/data measurements for each location. The spectrometer data are typically saved to a file. The pyranometer data are typically recorded manually.

Step 5. Perform the analysis as described in Section 7.4. If results are unacceptable, make adjustments to the lamp configuration or settings to achieve the desired spectrum and repeat steps 1-4.

Step 6. Repeat steps 1-5 for the additional test points.

7.4 Analysis of Results.

a. This TOP is addressing Procedure I only, and it assumes test items do not have special glazing or coating systems. Due to this, the focus of the analysis is determining compliance with the visible and infrared portions of the spectrum (400 to 3000 nm). The UV region energy is included in the total, however the UV region tolerances are excluded from the analysis.

b. If the spectral radiometer data are output in spreadsheet/text format, manual addition of the tabular data will need to be performed. The spectral radiometer data are used to determine the irradiance in each band of the visible portion of the spectrum (400 to 800 nm). These data are entered in the yellow cells in Table 6.

TABLE 6. SPECTRAL MEASUREMENT ANALYSIS AND REPORTING EXAMPLE

Spectral Region	Bandwidth (nm)	Measured Irradiance Value (W/m^2)	Measured Percent of Total Irradiance	Minimum Allowable (% of total)	Maximum Allowable (% of total)
UV-A / UV-B	280-400	60	5.4%	N/A	N/A
Visible	400-520	210	18.7%	16.1%	19.7%
	520-640	180	16.1%	14.9%	18.3%
	640-800	190	16.9%	12.8%	19.0%
Infrared	800-3000	481	42.9%	33.7%	50.5%
Total		1121			
Legend:					
Section 7.4b.	Section 7.4d.	Section 7.4e.	Section 7.4f.	Section 7.4g.	MIL-STD-810H CN1

c. Ensure the measured data are reported $W/m^2/nm$. Adjust output values as needed (for example if data are collected at 2 nm intervals the data will need to be divided by two, if measured at every 0.5 nm, the data are multiplied by two). If the data from the measurement device are not linear, ensure that proper weighting is applied. Trapezoidal integration should be used when calculating the energy content in each spectral region or band.

d. The total irradiance, or data from the pyranometer are entered as the total irradiance value in the orange cell in Table 6.

e. The pyranometer data includes energy in the ultraviolet range (280nm-400nm). To account for this energy the pyranometer values are reduced by the UV portion. This can be measured using a calibrated spectral radiometer or utilize data from the solar test equipment manufacturer. Ensure that the UV data were measured from the solar radiation simulator to include optical covers or filters, electrical dimming, and/or mechanical attenuation. A measurement of the bulb only may not provide accurate data. Enter the UV irradiance value in the blue cell in Table 6.

f. The infrared portion of the spectrum is calculated by subtracting the visible (yellow cells) and UV (blue cell) from the total irradiance (orange cell) (see Equation 2). Enter the IR irradiance value in the red cell in Table 6.

$$\text{Infrared Portion} = \text{Total} - (\text{Visible} + \text{UV}) \qquad \textit{(Equation 2)}$$

g. The percent of total irradiance is calculated for each band by dividing the energy for that band by the total energy and multiplying by 100. These values are shown in the purple cells of Table 6.

h. Compare measured data verifying the "Percent of Total" values for each visible and infrared band are within the allowable minimum and maximum values stated in MIL-STD-810H CN1.

i. Record and save data for future comparison and analysis.

8. COMBINED HEATING EFFECTS CHARACTERIZATION.

8.1 Overview.

Combined heating effects characterization is performed to provide an indication of the effects of radiative and convective heat on a representative sample. The radiative heat load is assessed individually in the Irradiance and Spectral Energy characterization procedures. The convective heat load is assessed in the Air Temperature and Air Flow characterization procedures. This characterization procedure uses ASTM G179 standard black and white panels to assess the combined heating effects. The use of both backed and unbacked panels is recommended. Further work is planned to evaluate other options for combined effects sensors and test criteria.

8.2 Test Criteria.

a. Specific test criteria for combined effects measurements are not defined in MIL-STD-810H CN1. Future work is planned to determine recommended values for panel temperature measurements. The measurements recorded here are for characterization and comparison purposes only to provide an understanding of the heating effect variation within a chamber and when compared to other chambers.

b. Measurements are recommended to be taken at the same test points (temperature and irradiance levels) as those used in Section 4 for the Air Temperature characterization.

c. For measurement grid spacing the following steps are recommended:

Step 1. Perform measurements at each location on the grid spacing.

Step 2. Perform at a smaller grid (similar to Spectrum Measurements).

Step 3. Perform at a subset of nominal and off-nominal locations based on the temperature, irradiance and airflow measurements.

8.3 Procedure.

a. Pretest/Setup.

Step 1. Install and checkout white and black panel instrumentation. Ensure the panels are clean and no dust or grime is present that may affect the temperature response of the panel. Confirm that the spectral reflectance of the panel is within the requirements in ASTM G179.

Step 2. Inspect the chamber and solar test equipment. Ensure any required preventative maintenance has been performed. Photograph the chamber configuration.

b. Panel Measurements.

Step 1. Ramp the chamber temperature to the temperature for the first measurement point (typically the highest intensity and temperature) and stabilize the air temperature.

Step 2. Adjust the lamps to provide irradiance specified for the first measurement point. Record control settings of the chamber and solar test equipment.

Step 3. Perform black and white panel temperature measurements across the horizontal grid on the planned target plane. Ensure the device measurement stabilizes at each point.

Step 4. Repeat steps 1-3 for the additional test points (e.g., low, medium).

8.4 Analysis of Results.

a. Given that test criteria have not yet been developed, it is recommended that the data collected be assessed to evaluate the heating effect variation within a chamber and when compared to other chambers.

b. Data should be presented in the same manner as the air temperature, shown in Section 4.4.

APPENDIX A. ABBREVIATIONS AND ACRONYMS.

3D	three-dimensional
ASTM	American Society for Testing and Materials
°C	degrees Celsius
CCD	charge coupled device
CN	Change Notice
DoD	Department of Defense
°F	degrees Fahrenheit
ft/min	feet per minute
IR	infrared
ISO	International Organization for Standardization
m	meter
m/s	meters per second
MIL-STD	Military Standard
nm	nanometer
RH	relative humidity
RTC	U.S. Army Redstone Test Center
RTD	Resistance Temperature Detector
SMD	Spectral Measurement Device
SPD	spectral power distribution
TOP	Test Operations Procedure
UV	ultraviolet
W/m^2	watts per meter squared

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APPENDIX B. REFERENCES.

1. MIL-STD-810H CN1, Department of Defense Test Method Standard, Environmental Engineering Considerations and Laboratory Tests, 18 May 2022.

2. ISO 9060:2018, Solar Energy - Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation, 13 November 2018.

3. ISO 9060:1990, Solar Energy - Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiation, 24 October 1990 (superseded by ISO 9060:2018).

4. ASTM G138-12, Standard Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance, 20 July 2020.

5. ASTM G179, Standard Specification for Metal Black Panel and White Panel Temperature Devices for Natural Weathering Tests, 1 January 2004.

For information only (related publications).

Military Handbook-310, Department of Defense Handbook, Global Climatic Data for Developing Military Products, 23 June 1997.

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APPENDIX C. APPROVAL AUTHORITY.

CSTE-CI 23 August 2022

MEMORANDUM FOR

Commander, U.S. Army White Sands Missile Range
Executive Director, U.S. Army Evaluation Center
Commander, U.S. Army Operational Test Command
Commander, U.S. Army Yuma Proving Ground
Commander, U.S. Army Dugway Proving Ground
Commanders, U.S. ATEC Test Centers
Director, U.S. ATEC Tropic Regions Test Center
Director, U.S. ATEC West Desert Test Center

SUBJECT: Test Operations Procedure 01-2-826 Characterization of Solar Test Equipment for Heating Effects Testing

1. Test Operations Procedure (TOP) 01-2-826 Characterization of Solar Test Equipment for Heating Effects Testing, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.

2. Scope of the document. This TOP describes the general methodology for characterization of Solar Test Equipment that is used for Military Standard 810H Change Notice 1, Method 505 Solar Radiation Procedure I – Cycling (Heating). The methods described herein support characterization and reduction to variation at a test facility over time due to degradation of the system, maintenance, and facility modifications. This TOP defines a standard set of guidelines for instrumentation and procedures for characterizing the applied environment in a solar test chamber.

3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

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MICHAEL J. ZWIEBEL
Director, Directorate for Capabilities Integration (DCI)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-CI-P), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: U.S. Army Redstone Test Center (RTC), Climatic Test Division (TERT-ECC), 7250 Briar Road, Redstone Arsenal, AL 35898. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.