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| GM | WORLDWIDE ENGINEERING STANDARDS | Test Procedure | GMW8288 |

# General Specification for Thermal Evaluations Using Thermocouple and Infrared Imaging Methods

## 1 Introduction

**Note:** Nothing in this standard supercedes applicable laws and regulations.

**Note:** In the event of conflict between the English and domestic language, the English language shall take precedence.

**1.1 Purpose.** This standard specifies standard thermocouple and infrared imaging thermal measurement methods for components with electrical/electronic content that shall be used for thermal evaluations, unless otherwise specified.

**1.2 Applicability.** This standard applies to components with Electrical/Electronic (E/E) content to measure thermal properties.

**1.3 Remarks.** This standard defines the following two temperature measurement methods for components with E/E content that are used in a vehicle environment:

- Thermocouple (TC)
- Infrared (IR) imaging

**Note:** Component Technical Specifications (CTS) and/or Subsystem Technical Specifications (SSTS) of E/E content components/systems shall take precedence over this standard.

## 2 References

**Note:** Only the latest approved standards are applicable unless otherwise specified.

**2.1 External Standards/Specifications.**

ISO 9000 ISO/TS 16949

**2.2 GM Standards/Specifications.**

None

**2.3 Additional References.**

- American Society of Nondestructive Testing (ASNT) ASNT-TC-1A Level II Certification
- CG3811 GMW8288 Thermal Evaluations Worksheet
- E/E content components/systems CTS(s) and SSTS(s)

## 3 Resources

**3.1 Facilities.** The test facilities shall have the equipment and personnel expertise required to execute the procedures described within this document. All facilities and test equipment shall be ISO/TS 16949 or ISO 9000 certified.

**3.1.1 Calibration.** The test facilities and equipment shall be in good working order and shall have a valid calibration label.

**3.1.2 Alternatives.** Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

**3.2 Equipment.**

**3.2.1 Calibration.** All equipment that is used for conducting thermal measurements shall have valid calibration labels.

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**3.2.2 Working Condition.** All temperature measurement equipment shall demonstrate proper operation prior to the temperature measurement.

**3.2.3 Parameter Definition and Tolerance.** Unless stated otherwise, Table 1 shall define the test environmental parameters and tolerances to be used.

**Table 1: Environmental Parameters and Tolerances**

| Parameter | Tolerance |
|---|---|
| Temperature | As Specified, ± 3 °C |
| Test Time | As Specified, ± 0.5% |
| Room Ambient Relative Humidity | 30% to 70% |

Unless stated otherwise, Table 2 shall define the measurement equipment tolerances to be used.

**Table 2: Measure Equipment Tolerances**

| Parameter | Tolerance |
|---|---|
| Temperature | ± 0 °C |
| Voltage | As Specified, ± 0.1 V<br>(as measured at the component) |
| Current | As Specified, ± 1% |

**3.2.4 Thermal Test Chamber.** The test chamber shall be capable of a temperature range of -40 °C to +100 °C minimum for evaluations of passenger compartment components. A -40 °C to +160 °C chamber is required for engine compartment components. The chamber shall have access ports for the interface and instrumentation wiring.

**3.2.5 IR-Specific Equipment.**

**3.2.5.1 Calibration of IR Equipment.** If absolute temperature-scale readings are required (as opposed to simple thermal pattern viewing or relative temperature readings), then the IR camera shall be calibrated to the emissivity of the materials being imaged prior to the thermal evaluation procedure.

Calibration shall be performed per the recommended procedures of the camera manufacturer. Separate calibration shall be performed for each combination of filters, lenses, and window materials used in the procedure. Window materials are to be calibrated for each IR camera wavelength range setting used.

It is recommended that the IR camera used in electrical component or printed circuit board thermal assessments be calibrated and filtered for peak performance in the 15 °C to 150 °C range. Better performance in this temperature range is achieved by using a camera that detects in the 8 µm to 14 µm spectral region instead of the 3 µm to 5 µm spectral region. The camera shall be mounted on a tripod or an equivalent fixture to ensure image stability.

**3.2.5.2 Image Display, Capture, and Recording.** The IR camera shall be linked to or include a real-time imaging display. The equipment shall be capable of producing an electronic copy of the IR image(s) to use for evaluation and documentation purposes.

If a dynamic thermal evaluation is required to monitor thermal changes over time or operation conditions, it is recommended that a digital image recording system be used. This allows an entire sequence of a transient event to be captured and allows the procedure to be repeatedly played back after the evaluation for detailed analysis or documentation purposes.

It is recommended that the system microphone, if available, be used by the equipment operator to provide a running narrative during the procedure. The narrative can be used to flag the start of the evaluation, timing of

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condition changes, and document observations or comments. This audio commentary is beneficial when reviewing or analyzing the evaluation.

**3.2.5.3 IR Image Processing Systems.** Infrared image processing systems are recommended for situations involving thermal evaluations of complex components or when highly accurate evaluations or highly detailed report documentation is required.

An IR imaging processing system typically consists of a general-purpose personal computer equipped with an IR camera interface and IR image processing software. These systems allow enhanced analysis of an infrared evaluation in real-time or during recording playback. Typical features of image processing systems include:

- Image zooming.
- Thermal Image color scale adjustments to improve image resolution.
- Automated image comparison and display windows that allow the temperatures of operator-defined points to be displayed and tracked in either text or analog graphics display formats.
- Printouts of selected images complete with captions, scaling, and graphs for report documentation.

The makers of the IR camera typically can provide either camera-compatible complete image processing systems or the appropriate add-on equipment to upgrade a general purpose personal computer into an IR image processing system. IR camera manufacturers can also provide the interface specifications for acquiring an imaging processing system or equipment from third party vendors.

**3.3 Test Vehicle/Test Piece.** The thermal evaluation procedures defined in this document are intended to be flexible and adaptable for use in Development, Design Validation, Product Validation, and current product evaluation. Test samples used for development may range from breadboard or other forms of concept demonstrations to actual production samples. Test samples used for Design Validation shall be production-intent design and materials. Test samples used for Product Validation shall be manufactured on production tooling, with production materials and processes. Test samples used for current product evaluations shall be from normal production lots.

**3.4 Test Time.** Test time will vary based on the number and types of evaluations required, as well as the setup required, for each test. Setup for each evaluation will involve preparations for the measurement instrumentation, simulation of power and loads, and fixturing/orientation of the test sample.

**3.5 Test Required Information.** The test requester shall complete CG3811, GMW8288 Thermal Evaluations Worksheet, and provide this to the test facility. The purpose of the GMW8288 Thermal Evaluations Worksheet is to provide detailed instructions to the test facility regarding the measurement method, data to be collected, fixturing/orientation of the test sample, electrical loading, and other test-specific information to be used during the evaluation. The test requester shall obtain the GMW8288 Thermal Evaluations Worksheet (CG3811) from the GM Global Document Management (GDM) database, the GM Component Validation Engineer (CVE), the GM Environmental Subject Matter Expert (ENV SME), or GM Supply Power. It is also available to suppliers through IHS Global Incorporated.

**3.6 Personnel/Skills.**

**3.6.1 General.** Knowledge of the applicable thermal measurement methods and equipment.

**3.6.2 IR Specific Operator Certification**. It is recommended that the thermographer performing IR imaging shall be trained and certified to at least an ASNT-TC-1A Level II or equivalent.

## 4 Procedure

### 4.1 Preparation.

#### 4.1.1 Preparation (General).

**4.1.1.1 Measurement Method Determination.** Determine which thermal measurement method, i.e., Thermocouple or Infrared Thermography, is needed for the goals of the evaluation.

Thermocouple measurement is used to measure the thermal response of specific circuits, areas, or parts on the circuit board or component. The thermocouple must be attached to that specific point of interest, such that the thermal measurement will be localized at that specific point. Thermocouple measurement is used to determine if the point of interest is self-heating as expected or if it is overheating beyond performance or material

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requirements. Also, this is recommended as a thermal measurement method in instances where areas of interest are not accessible by Infrared Thermography methods.

Infrared Thermography is used to locate, measure, and visualize the thermal gradient response and identify the high stress hot spots of the component as it undergoes various operating conditions. Thermography can be used to assess issues related to current flow and material integrity by means of tracking the heat signature during these conditions. Thermography also provides the ability to detect the following: thermal overstress design issues, faulty or failed parts/components, inadvertent current leakages, and thermal performance changes caused by other overstress, wear out aging mechanisms, or short circuit conditions. Refer to Appendix C: Introduction to IR Thermal Imaging for further information.

**4.1.1.2 Component Test Interface.** The component shall be connected to the actual or simulated vehicle interfaces and loads required to operate the component as per the CTS. The GM Design Release Engineer (DRE) or Product Development Team (PDT) shall define load extremes or variation conditions appropriate to the component at the temperature limits if not defined in the CTS. Adequately sized wiring and fusing to handle the worst-case current load shall be used.

**4.1.1.3 Component Mounting Orientation.** If applicable, the component shall be mounted in an orientation necessary to perform and evaluate any mechanical or visual interface functions. If the component is expected to internally self-heat (> 10 °C or more at the maximum required operating temperature), it shall be mounted in its in-vehicle orientation or, for the situation of multiple vehicle applications, the worst-case thermal orientation.

**Note:** Thermal worst-case orientation is when the heat dissipated from high powered internal parts is allowed to rise, flow over, or be trapped around more thermally sensitive parts.

**4.1.1.4 Operating Performance Measurements.** Appropriate, calibrated instruments shall be used to measure and verify the performance of the component. Sufficient data shall be collected to document proper electrical performance during the thermal evaluations.

For power dissipation and self-heating evaluations, the voltage and current of the power supply, key power outputs, and any input/output needed to calculate component power dissipation shall be measured and documented as defined by the PDT for key activation and loading conditions during the thermal evaluation.

E/E components which also perform mechanical, audio, and/or visual/display functions shall be instrumented/monitored as appropriate for the application to measure, record and verify the operation of these functions in accordance with their CTS requirements, as defined by the PDT.

**4.1.1.5 Functional and Thermal Measurements Implementation.** The supplier or organization responsible for performing the thermal evaluation is responsible for developing the specific test script and the means for performing the functional, electrical, and thermal measurements deemed relevant for the component by the PDT. These procedures are to be approved by General Motors (GM) prior to testing.

**4.1.1.6 Thermal Evaluations Determination and Worksheet.** Refer to the subparagraphs in 4.3 for guidelines to determine which thermal evaluations and methods are required for the component. These paragraphs provide the typical evaluation objective for vehicular E/E components in the Purpose, Background, Applicability, Procedure, and Criteria for each test. Additional requirements may be defined in the CTS of the component to be tested. The GM DRE or PDT shall review these objectives against the requirements and design features of the component.

The GMW8288 Thermal Evaluations Worksheet (CG3811) shall be used to document which thermal evaluations are required for the component. The worksheet is editable such that the test requester shall select, from a pre-determined list, the desired thermal evaluation method to perform, as well as enter additional information to denote each procedure's setup, component configuration, and evaluation objective as selected by the PDT. This worksheet shall be included as part of each test's documentation.

**4.1.2 Preparation for Thermocouple Measurements.**

**4.1.2.1 Thermocouple Measurements Requirements.** Thermal data shall be collected by means of an automated data logger (preferred) or strip chart at a rate of at least three (3) times per minute. The number and types of component internal parts or materials to be temperature-monitored shall be determined by the PDT. Monitoring selections shall be based on the function and criticality of the component and the circuit designer's knowledge of the expected points of high power dissipation. As a minimum, the following thermal measurements are recommended and should be included if deemed appropriate by the PDT:

a. **Chamber Air Temperature** to monitor the temperature of the air surrounding the component.

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b. **Component Internal Air Temperature** for enclosed or partially enclosed components (preferably near the center of the component, microprocessors, or any analog signal circuits of the component).

c. **Part Temperature(s)** of the following as determined by the PDT:

- Microprocessor(s).
- Integrated Circuits (IC).
- High Power Resistors.
- Power driver transistors.
- Insulated Gate Bipolar Transistors (IGBT).
- Other power driver ICs that are capable of high duty cycles, or continuous operation, or dissipate the largest amounts of power.

d. **Optional - Circuit Board Temperature.** Of the expected coolest area of the component/part or circuit board.

e. **Optional - Miscellaneous.** The temperature of other internal parts or features of the component that could produce useful information. (Examples include new ICs, power diodes or ballast resistors, onboard sensors, motors or actuators, boards, nuts and bolts, attachments, etc., as determined by the PDT).

f. **Optional - Controls and Contact Surface Temperatures.** (Of knobs, buttons, switches, or exposed surfaces that could be touched by passengers). Used to ensure that self-heating above room temperature does not raise the contact temperature to a level that is unacceptable to operate. Unless otherwise specified, use > 44 °C (> 111 °F) as a temperature that is uncomfortable to touch and if exposed directly for an extended period of time, can cause potential skin-damage.

**4.1.2.2 Thermal Sensors and Placement.** When locating and attaching thermocouples or sensors it is important to select an attachment configuration that is consistent with the type of thermal information required. Examples:

- When an air temperature measurement is required, it is important that the sensing element is openly exposed to and held in the air space of interest.
- When measuring a surface temperature, it is important that the sensing element has good thermal connectivity with the surface and isolation from the ambient air.
- If the surface is electrically charged, the sensing element shall be electrically insulated from the surface in order to ensure that the measurement is not corrupted and that the sensor does not affect component operation.
- If the component is potted, encapsulated, or coated, the sensing element may be attached prior to potting or coating.
- If the objective of the test is to evaluate heat-trapping effects, the sensing element shall be attached to the component, inside of its housing, or to a simulation of the housing.

When measuring an interior temperature of a design feature, the parts may need to be modified to place the sensing element at the point of interest. For situations where it is not possible to implant an internal sensing element or modify small parts, (such as integrated circuits or transistor packages), consider using a thicker layer of epoxy over the sensing element. This provides additional thermal insulation over the sensing element to provide a measurement that is closer to an interior temperature than a surface temperature. This technique is more effective for situations where the response of a part to environmental temperatures is the point of interest, rather than situations where the part's self-heating is the point of interest.

**4.1.2.3 Attachment of Thermal Sensors.** Sensing elements are preferably attached with epoxies. Taping usually is not strong enough to hold a sensing element for the duration and stresses of the tests, and mechanical fasteners can add a thermal inertia mass that could act as a heat sink and alter the thermal responses.

When using epoxy, it is essential that excessive epoxy does not drip or flow under the Printed Circuit Board (PCB) parts, onto other PCB parts, or across or between different material surfaces. This is critical because thermal expansion of the epoxy could induce stresses between PCB parts or surfaces that could lift or break design features. This could cause the part/component to fail for reasons of incorrect instrumentation setup which would invalidate the evaluation.

**4.1.2.4 Component Orientation.** Since heat rises, and can be affected by air convection, the orientation and airflow around a part/component will impact the temperature of the design features of the component. For

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thermocouple measurements, consider positioning the component on the test surface horizontally, vertically, and/or in-vehicle position, depending on the worst-case heating effects for purpose of the test. Also, consider environmental effects of the ambient air flow in the test facility.

**4.1.3 Preparation for Infrared Imaging.**

**4.1.3.1 Component Orientation.** Since heat rises, and can be affected by air convection, the orientation and airflow around a part/component will impact the temperature of the design features of the component. Each evaluation will need to consider the thermal impact that orientation will have on the component under test and balance this against the need for enabling the IR camera to view the features of primary thermal interest. The characteristics of three typical component orientations are discussed in Table 3. In each of these orientations, the procedure may be conducted either with still air, or with an airflow rate that duplicates in-vehicle conditions.

**Table 3: Component Orientation for Infrared Thermographic Evaluation**

| Component Orientation | Description |
|---|---|
| Horizontal | The component is laid flat on a bench or fixture with the side that generates the most heat pointing up. The IR camera is placed perpendicular to the surface of interest, either directly overhead or offset above the component to capture the effect of open convection.<br>If more than one surface generates heat or is to be scanned, each surface may be imaged separately by rotating the component or by moving the camera. |
| Vertical | The component is positioned or fixtured into a vertical orientation with the camera positioned perpendicularly, in front of the surface of interest.<br>If more than one surface generates heat or is to be scanned, each surface may be imaged separately by rotating the component or by moving the camera. |
| In-Vehicle Orientation | The component shall be fixtured to match the intended in-vehicle orientation.<br>The IR camera is positioned perpendicular to the surface of interest to view the heat generating surfaces(s). |

**4.1.3.2 IR Imaging Guidelines.** Accurate IR imaging requires a visible line of sight between the component/surface of interest and the IR camera. If a direct line of sight is not possible, an IR mirror (a polished shiny reflective metal mirror) may be used to reflect the thermal image to the IR camera. Some evaluations may require the packaging or housing of the component to be opened, removed, or may have a section(s) removed to allow the IR camera to view internal parts. If there is a concern that housing removal/modifications may impact the thermal response, then the housing, section(s) of the housing, or removed sections may be replaced with an IR transparent material. A list of some common IR transparent materials is provided as a reference in Table 4.

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**Table 4: Infrared Transparent Evaluation Material References**

| Material | Useable Temperatures | Description/Application |
|---|---|---|
| Window Insulation Sheeting Film (Type Clean) Non-Ultraviolet (UV)/IR Tinted | up to 40 °C (104 °F) | Indoor Window Insulator Kits are available from 3M (or other manufacturers) in various sizes. These are shrinkable clear plastic films. |
| High Temperature Oven Bags | up to 200 °C (392 °F) | A high temperature flexible plastic bag that can be cut into sheets with high Infrared energy transmissibility. Reference Reynolds Oven Bags products (produced by Reynolds Metals - Consumer Product Division):<br>Large Size: 40.6 cm × 44.5 cm (16 in × 17.5 in)<br>Extra Large Size: 48.3 cm x 59.7 cm (19 in × 23.5 in) |

**4.1.3.3 IR Imaging of Circuit Traces, Leads, and Other Shiny/Polished Metal Surfaces.** Proper emissivity calibration is critical any time accurate infrared imaging of shiny or polished metal objects are required. While shiny metal surfaces are excellent reflectors of IR energy from other sources, metals are also excellent conductors of thermal energy, but, unfortunately they are also poor IR emitters of their own thermal energy. This means that a metal object may get hot and its temperature may be accurately measured by a thermocouple, but that temperature may not be accurately measured by an IR camera. If the temperatures of shiny metal features (such as component leads, uncoated PCB circuit traces, and heat sinks) are significant to the evaluation, a flat black paint dot may be applied to the metal feature of interest. The flat black paint dot will provide adequate emissivity to radiate an accurate thermal image of the temperature it absorbs from any metal object. Matte or flat finish styles of solder mask materials can improve the emissivity of masked PCB traces.

**4.1.3.4 Infrared Imaging Setups.** Typical infrared thermal evaluation setups are discussed in the following. The Thermocouple measurement requirements defined in 4.1.2.1 may be used with these evaluation setups to provide additional information or as a calibration reference point.

**4.1.3.4.1 Shielded Bench Top IR Scanning Setup.** The shielded bench top setup (reference Figure 1) is used for quick IR scans to identify the location of thermal hotspots and to assess general thermal performance patterns under room ambient conditions. This procedure is performed on a bench top at room ambient temperature of 23 °C. The bench shall be isolated from direct air drafts, i.e., doors, windows, or heating/ ventilation ducts, etc.

A thermally insulated support fixture (such as wood or plastic) shall be used to minimize thermal contact between the component and the work surface. The supports shall be positioned to minimize contact with the expected hot spots of the component. Design the setup to allow all sides of interest of the component to be rotated to a position that can be viewed by the IR camera. The camera typically is mounted to either have an overhead or side view of the component.

The component shall be centered in a box or employ some other form of draft barrier to prevent room airflow from cooling the component. The top of the box/draft barrier may be open or an optional cover made of an IR transparent material may be used.

Some evaluations may require the housing to be removed to allow the IR camera to view internal parts. If there is a concern that housing removal/modifications may impact the thermal response, the component may be contained either in its housing modified with IR viewing window over the features of interest or in an IR transparent structure designed to simulate the heat containment characteristics of the housing (reference 4.1.3.2 and 4.1.3.4.4). An IR transparent cover or film shall be used over the viewing window modifications to limit convection heat losses. Reference Table 4.

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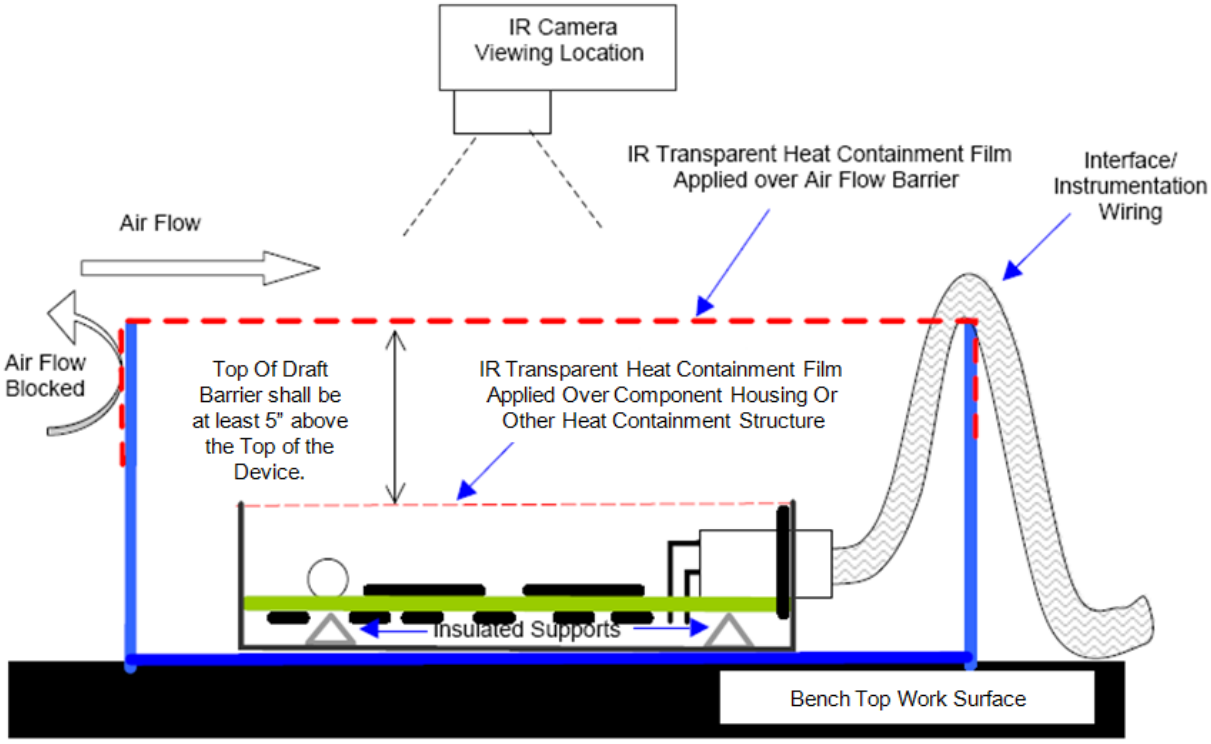


**Figure 1: Diagram of an Overhead View Setup for Bench Top Infrared Imaging that Minimizes Thermal Connectivity and Air Flow Heat Loss Effects**

**4.1.3.4.2 Thermal Chamber IR Imaging Setup.** The Thermal Chamber setup is used for more detailed IR scans to assess the following: hot spots and their worst-case thermal performance patterns, and equilibrium times under extreme thermal conditions.

In this setup, the component is placed or fixtured for viewing in a thermal chamber that is equipped with an IR transparent viewing window or port. This provides an observation point to the IR camera, which is mounted outside the chamber. Reference Figure 2.

**Note:** Most types of glass absorb an amount of IR energy which could cause significant measurement errors. Windows made out of IR transparent materials shall be used or the camera shall be calibrated to adjust for the IR energy loss of a glass window.

Another alternative is to use a chamber with an instrumentation tunnel large enough for the camera lens to view through. A chamber with two access tunnels on opposing sides is preferred as it allows the IR camera to be moved to observe two sides of the component. Therefore, there is no need to stop the test to change the orientation of the component in the chamber.

The viewing window, port, or tunnel may be covered with an IR transparent, high temperature oven bag referenced in Table 4 to maintain chamber heat retention.

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