Designation: C 1484 – 01

Standard Specification for Vacuum Insulation Panels[1]

This standard is issued under the fixed designation C 1484; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers the general requirements for Vacuum Insulation Panels (VIP). These panels have been used wherever high thermal resistance is desired in confined space applications, such as transportation, equipment, and appliances.

1.2 Vacuum panels typically exhibit an edge effect due to differences between core and barrier thermal properties. This specification applies to composite panels whose center-of-panel apparent thermal resistivities (sec. 3.2.4) typically range from 87 to 870 m·K/W (12.5 to 125 hr·ft^2·°F/Btu·in) at 24°C (75°F) mean, and whose intended service temperature boundaries range from –70 to 480°C (–94 to 900°F).

1.3 The specification applies to panels encompassing evacuated space with: some means of preventing panel collapse due to atmospheric pressure, some means of reducing radiation heat transfer, and some means of reducing the mean free path of the remaining gas molecules.

1.4 *Limitations*

1.4.1 The specification is intended for evacuated planar composites; it does not apply to non-planar evacuated self-supporting structures, such as containers or bottles with evacuated walls. The complexity of describing the performance of the planar products is considered sufficiently challenging for this initial specification, although other shapes will be considered at a future time.

1.4.2 The specification describes the thermal performance considerations in the use of these insulations. Because this market is still developing, discrete classes of products have not yet been defined and standard performance values are not yet available.

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

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health specifications and determine the applicability of regulatory limitations prior to use.* For specific safety considerations see Annex A1.

2. Referenced Documents

2.1 *ASTM Standards:*

C 165 Test Method for Measuring Compressive Properties of Thermal Insulations[2]

C 168 Terminology Relating to Thermal Insulating Materials[2]

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[2]

C 203 Test Methods for Breaking Load and Flexural Properties of Block-Type Thermal Insulation[2]

C 480 Test Method for Flexure Creep of Sandwich Constructions[3]

C 518 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[2]

C 740 Practice for Use of Evacuated Reflective Insulation in Cryogenic Service[2]

C 1045 Practice for the Calculation of Thermal Transmission Properties from Steady-State Heat Flux Measurements[2]

C 1055 Guide for Heated System Surface Conditions that Produce Contact Burn Injuries[2]

C 1058 Practice for Selecting Temperatures for Reporting and Evaluating Thermal Properties of Thermal Insulations[2]

C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[2]

C 1136 Specification for Flexible, Low Permeance Vapor Retarders for Thermal Insulation[2]

C 1363 Test Method for the Thermal Performance of Building Assemblies by Means of a Hot Box Apparatus[2]

D 999 Methods for Vibration Testing of Shipping Containers[4]

D 1434 Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting[5]

D 2221 Test Method for Creep Properties of Package Cushioning Materials[4]

[1] This specification is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.22 on Organic and Nonhomogeneous Inorganic Thermal Insulations.

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[2] *Annual Book of ASTM Standards*, Vol 04.06.

[3] *Annual Book of ASTM Standards*, Vol 15.03.

[4] *Annual Book of ASTM Standards*, Vol 15.09.

[5] *Annual Book of ASTM Standards*, Vol 08.01.

D 2126 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging[5]

D 3103 Test Method for Thermal Insulation Quality of Packages[4]

D 3763 Test Method for High Speed Puncture Properties of Plastics Using Load and Displacement Sensors[6]

D 4169 Practice for Performance Testing of Shipping Containers and Systems[4]

E 493 Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Inside-Out Testing Mode[6]

F 88 Test Method for Seal Strength of Flexible Barrier Materials[4]

2.2 *Other Standards:*

ISO 8318 Packaging - Complete, Filled Transport Packages - Vibration Tests Using a Sinusoidal Variable Frequency[7]

IEC68-2-6, Part 2, Test F, Vibration, Basic Environmental Testing Procedures[8]

TAPPI T803 Puncture Test of Containerboard[9]

3. Terminology

3.1 *Definitions*—Terminology C 168 applies to terms used in this specification.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adsorbent*—a component of some VIP designs, comprising a chemical or physical scavenger for gas molecules.

3.2.2 *barrier*—the material used to separate the evacuated volume from the environment.

3.2.3 *center-of-panel*—a small area located at the center of the largest planar surface of the panel, equidistant from each pair of opposite edges of that surface.

3.2.4 *center-of-panel apparent thermal resistivity*—the thermal performance of vacuum panels includes an edge effect due to some heat flow through the barrier material and this shunting of heat around the panel becomes more prevalent with greater barrier thermal conductivity, as shown in Fig. 1. For panels larger than a minimum size (as described in 11.4.1 and Appendix X1), the center-of-panel apparent thermal resistivity is the intrinsic core thermal resistivity of the VIP. This center-of-panel measurement is used for quality control, compliance verification, and to calculate the effective thermal performance of a panel. The effective thermal performance of a panel will vary with the size and shape of the panel.

3.2.4.1 *Discussion*—Thermal resistivity, the inverse of thermal conductivity, is used when discussing the center-of-panel thermal behavior and this value is independent of the panel thickness.

3.2.5 *core*—the material placed within the evacuated volume. This material may perform any or all of the following functions: prevent panel collapse due to atmospheric pressure, reduce radiation heat transfer, and reduce the mean free path of the remaining gas molecules. The thermal conductivity of the core, or λ_{core}, is defined as the thermal conductivity of the core material under the same vacuum that would occur within a panel, but without the barrier material. This is the thermal conductivity that would be measured in the center of an infinitely large panel.

[6] *Annual Book of ASTM Standards*, Vol 03.03.

[7] International Organization for Standardization, Case Postale 56, Geneva CH-1211, Switzerland.

[8] International Electrotechnical Commission, 3 Rue De Varembe; PO Box 131, Geneva CH-1211, Switzerland.

[9] TAPPI, 15 Technology Parkway S., Norcross, GA 30092.

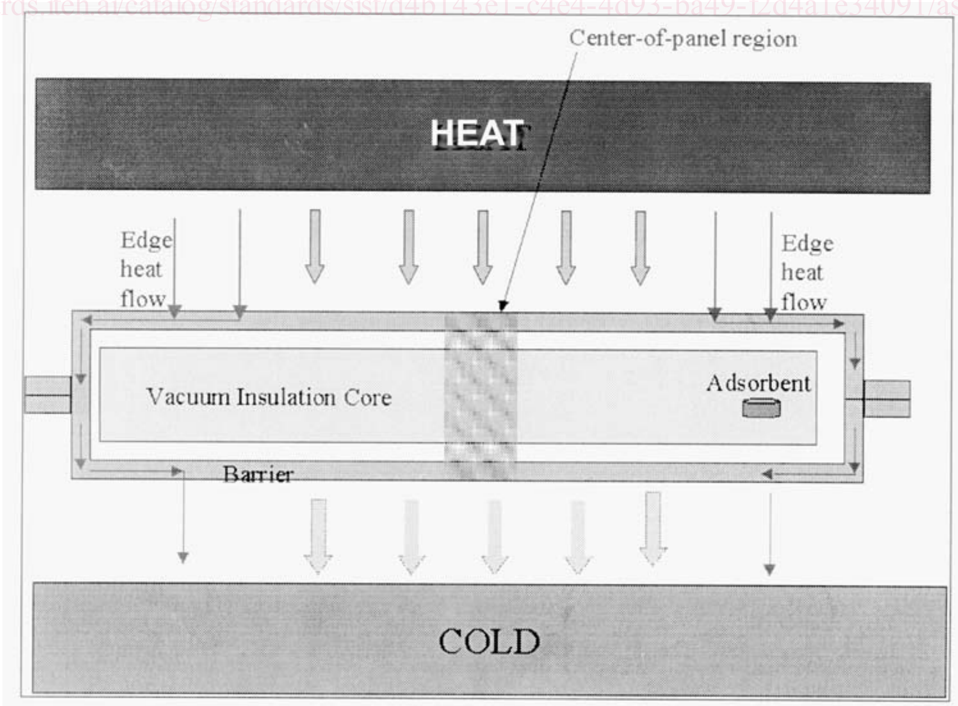

FIG. 1 Side View of a Vacuum Insulation Panel Showing Edge Heat Flow and the Center-of-Panel Region

3.2.6 *effective thermal resistance (Effective R-value)*—this value reflects the total panel resistance to heat flow, considering heat flow through the evacuated region and through the barrier material. Depending on the thermal conductivity of the barrier material and the size of the panel, the effective thermal resistance may be significantly less than the product of the center-of-panel apparent thermal resistivity and the panel thickness. The effective thermal resistance is based on the edge-to-edge area covered by the VIP, that is, the entire VIP. Note that the effective thermal resistance will also vary with the panel mean temperature.

3.2.6.1 *Discussion*—Thermal resistance, the inverse of thermal conductance, is used when discussing the effective thermal performance of the panel. This value includes the effect of the actual panel dimensions, including the panel thickness.

3.2.7 *effective thermal resistance after puncture*—this value represents the effective thermal resistance of the panel in the event of a total barrier failure (complete loss of vacuum). The edge effect is still present after a puncture.

3.2.8 *evacuated or vacuum insulations*—insulation systems whose gas phase thermal conductivity portion of the overall apparent thermal conductivity has been significantly reduced by reduction of the internal gas pressure. The level of vacuum will depend on properties of the composite panel materials, and the desired effective thermal conductivity.[10]

3.2.9 *seal*—any joint between two pieces of barrier material.

3.2.10 *service life*—the thermal resistance of a VIP may degrade with time due to residual outgassing of VIP materials and gas diffusion through the barrier and seals. Both of these processes are affected by the VIP's service environment, most importantly by the service temperature and humidity in the surrounding air. The service life is the period of time over which the center-of-panel thermal conductivity meets the definition of a superinsulator. A standard-condition service life is defined as that period of time over which the center-of-panel thermal conductivity meets the definition of a superinsulator under standard conditions of 24°C (75°F) and 50 % relative humidity. This standard-condition service life must be reported by the manufacturer, along with their basis for determining this value. The basis may be either actual, based on measured panel performance, or a combination of measured performance data and a predictive calculation model as described in Appendix X2. The user must recognise that the service life in hotter or more humid conditions may be shorter; conversely drier or colder environmental conditions can extend the life of the panel.

3.2.11 *superinsulation*—insulation systems whose center-of-panel thermal resistivity exceeds 87 m · K/W (12.5 h·ft^2·°F/BTU · in.) measured at 24°C (75°F) mean.

3.3 *Symbols and Units*—The symbols used in this test method have the following significance:

3.3.1 A = area, m^2.

3.3.2 B = outgassing coefficient of panel barrier, Pa·l/(h$^{(1-\beta)}$).

3.3.3 C = outgassing coefficient of panel filler, Pa·l/(h$^{(1-\alpha)}$).

3.3.4 d_o = density of the gas at standard temperature and pressure, kg/m^3.

3.3.5 g = outgassing rate, Pa·l/h.

3.3.6 G = adsorbent capacity, Pa·m^3.

3.3.7 k = gas permeation rate, m^3/h.

3.3.8 M = molecular weight, kg/mole.

3.3.9 P = pressure, Pa.

3.3.10 p = gas permeance, m/h·Pa.

3.3.11 q = heat flux, W/m^2.

3.3.12 Q = heat flow, W.

3.3.13 R = ideal gas constant, 8.315 J/g-mole · K.

3.3.14 T = temperature, K.

3.3.15 V = internal VIP free volume, m^3.

3.3.16 Z_{edge} = ratio of simplified heat flow through barrier material to simplified heat flow through VIP core.

3.3.17 α = outgassing exponent of filler.

3.3.18 β = outgassing exponent of barrier.

3.3.19 λ = thermal conductivity.

3.3.20 τ = time, h.

3.3.21 *Subscripts*:

3.3.21.1 a = ambient.

3.3.21.2 e = environmental.

3.3.21.3 f = flange.

3.3.21.4 i = refers to a specific gas, that is, P_i is the partial pressure of the ith gas.

3.3.21.5 *init* = initial.

3.3.21.6 s = surface.

4. Ordering Information

4.1 Orders shall include the following information:

4.1.1 Title, designation, and year of issue of this specification,

4.1.2 Product name,

4.1.3 Panel size and effective R-value required,

4.1.4 Service environmental parameters: maximum temperature, average temperature, maximum relative humidity, average relative humidity,

4.1.5 Required service life,

4.1.6 Tolerance if other than specified,

4.1.7 Quantity of material,

4.1.8 Special requirements for inspection or testing, or both,

4.1.9 If packaging is other than specified,

4.1.10 If marking is other than specified,

4.1.11 Special installation instructions if applicable,

4.1.12 Required compressive resistance,

4.1.13 Required effective thermal resistance after puncture,

4.1.14 Any required fire characteristics,

4.1.15 Required creep characteristics,

4.1.16 Required seal strength, and

4.1.17 Required dimensional stability at service environmental conditions.

5. Materials and Manufacture

5.1 *Panel Composite Design*—The panel shall consist of a gas barrier layer(s), as described in 5.2, and an evacuated core material or system as described in 5.3. See Fig. 1. An engineered quantity of gas adsorbent may be included. It is not

[10] For further discussion on heat flow mechanisms in evacuated insulations, see Practice C 740 on Evacuated Reflective Insulation in Cryogenic Service.

necessary that the panel design be symmetrical, depending upon end-use requirements.

5.2 *Panel Barrier Composition*—The barrier may consist of one or more layers of materials whose primary functions are to control gas diffusion to the core, and to provide mechanical protection. The barrier may be metallic, organic, inorganic or a combination thereof depending on the level of vacuum required, the desired service life, and the intended service temperature regimes. Barrier materials are selected to prevent outgassing, or at least to give off only those gases or vapors which can be conveniently adsorbed.

5.3 *Panel Core Composition*—The core shall comprise a system of cells, microspheres, powders, fibers, aerogels, or laminates, whose chemical composition may be organic, inorganic, metallic, or both. The reticular nature of the core may include subsystems such as honeycomb or integral wall systems. The function of the core composition or system is typically twofold: it reduces the radiative, solid, and gaseous heat transfer contributions to overall heat transfer, and it can provide a structural complement to the barriers. Core systems or densities may therefore vary for different anticipated end-uses and service temperature regimes.

6. Physical and Mechanical Properties

6.1 *Compressive Resistance*—The required compressive resistance should be specified by the purchaser according to the application.

6.2 *Effective Thermal Resistance (effective R-value)*—Because the effective thermal resistance is affected by many variables, Table 1 defines standard conditions and information that must be reported with the effective thermal resistance. Manufacturers may also provide thermal resistance data at other conditions. In addition to temperature, temperature gradient, and thickness effects, size and shape may have a significant impact on the effective thermal resistance of super-insulation panels, depending on the thermal conductivity of the barrier relative to that of the core. Fig. 2 shows the influence of panel size and barrier thickness on the effective R-value. The effective thermal resistance can also be affected by temporary temperature excursions that could occur during panel installation, as discussed further in Appendix X3.

6.3 *Effective Thermal Resistance After Puncture*—This value represents the effective thermal resistance of the panel in the event of a barrier failure (that is, after the panel internal volume has reached ambient pressure) and should be reported by the supplier.

6.4 *Fire Characteristics*—Vacuum panel products may contain materials that are not flame-resistant. The fire performance of the material should be addressed through fire test requirements that are specific to the end use.

TABLE 1 Standard Effective Thermal Resistance Report Conditions and Related Information Requirements for New Vacuum Insulation Panels

Panel Dimensions
Maximum use temperature
Maximum use humidity at 24°C (75°F)
Projected standard-condition service life
Initial effective thermal resistance at 24°C (75°F) and 50 % relative humidity

6.5 *Creep Characteristics*—The creep properties of a VIP will determine its shape and thickness in an application where the VIP is subjected to an externally applied constant stress. This stress can be caused by the environmental temperature as well as by a mechanical load. The creep properties are important because the shape and thickness of the VIP directly affect its thermal performance. The required creep properties should be specified by the purchaser according to the application.

6.6 *Barrier Permeance*—The barrier permeance is required for the VIP Service Life calculations. Note that the barrier permeance must be measured and reported for individual gases of interest. Note that the barrier permeance may also be affected by the service environment.

6.7 *Dimensional Stability at Service Conditions*—The maximum allowable change in panel dimensions caused by the change from ambient to service environmental conditions should be specified by the purchaser.

7. Dimensions and Tolerances

7.1 *Dimensions*—The dimensions shall be as agreed upon by the purchaser and supplier.

7.2 *Tolerances*—Tolerances shall be as agreed upon by the purchaser and supplier.

8. Workmanship and Finish

8.1 The insulation shall have no defects that adversely affect its service qualities and ability to be installed.

9. Sampling

9.1 Quality control records, maintained by the manufacturer, will usually suffice in the relationship between the purchaser and the manufacturer. If they mutually agree to accept lots on the basis of quality control records, no further sampling is required.

9.2 If the above procedure is not acceptable, an alternate sampling procedure shall be agreed upon between the purchaser and the manufacturer.

10. Qualification Requirements

10.1 For the purpose of initial material or product qualification, insulation shall meet the physical and mechanical properties of Section 6.

10.2 Acceptance qualification for lots and shipments of qualified product should be agreed upon by purchaser and supplier.

11. Test Methods

11.1 Properties of the insulation shall be determined in accordance with the following methods.

11.2 *Compressive Resistance*—Test Method C 165 or another method acceptable to both the purchaser and supplier should be used.

11.3 *Barrier Permeance*—The barrier permeance should be measured using Test Method D 1434, the method described in Appendix X4, or another method acceptable to both the purchaser and supplier. Note that the barrier permeance must be measured for individual gases of interest. The effects of

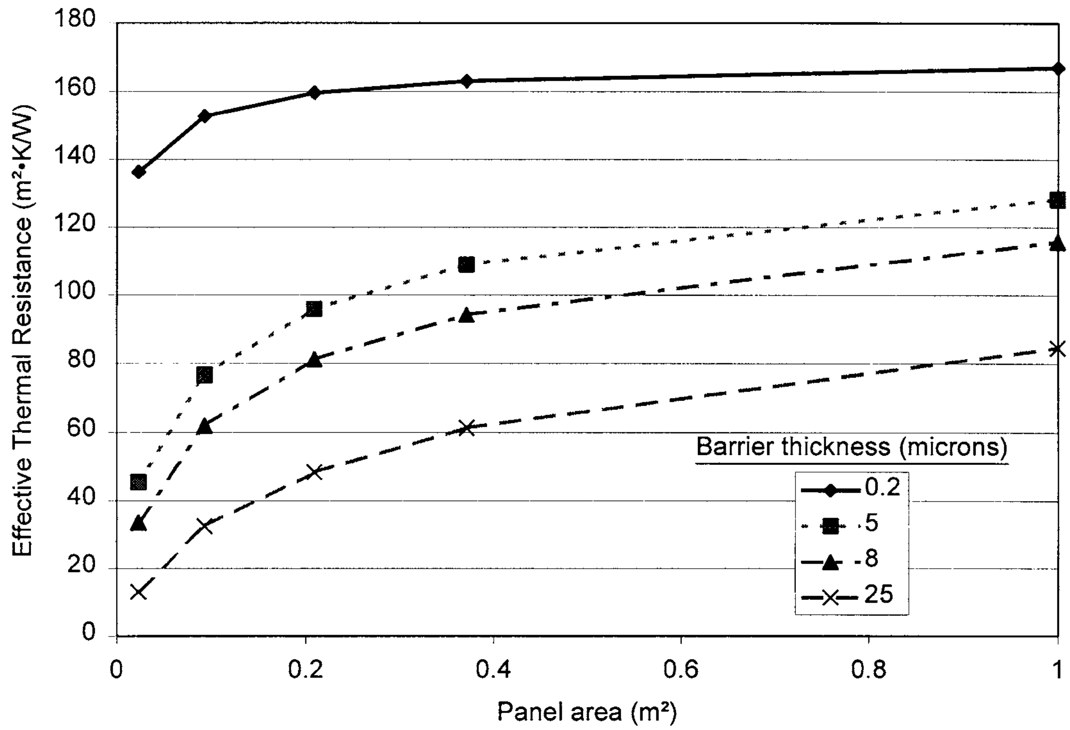

FIG. 2 Effective Thermal Resistance Changes with Panel Size and Barrier Thickness; All Other Panel Characteristics (Materials and Thickness) Held Constant

service temperature and humidity, any temperature excursion(s), and the chemical environment on the barrier permeance must be considered.

11.4 *Thermal Performance*:

11.4.1 *Center-of-Panel Thermal Resistivity*—The center-of-panel thermal resistivity is a measured value that is used to approximate the thermal resistivity of the evacuated core region. The center-of-panel thermal resistivity may be used, along with information about the barrier material and panel geometry, to calculate the effective panel thermal resistance. Use Test Methods C 177, C 518, or C 1114 in conjunction with Practice C 1045 to evaluate center-of-panel heat transfer properties. In the event of dispute, Test Method C 177 shall be the referee method. See Notes 1 and 2. Temperature differences shall be selected from Practice C 1058. The mean test temperature shall be selected according to the standard reporting temperatures shown in Table 1. It is often necessary to separate the panel barrier from the isothermal plates in a Test Method C 518 apparatus as shown in Fig. 3. When this configuration is used, thermocouples should be positioned to directly report the temperature on the center of the top and bottom faces of the

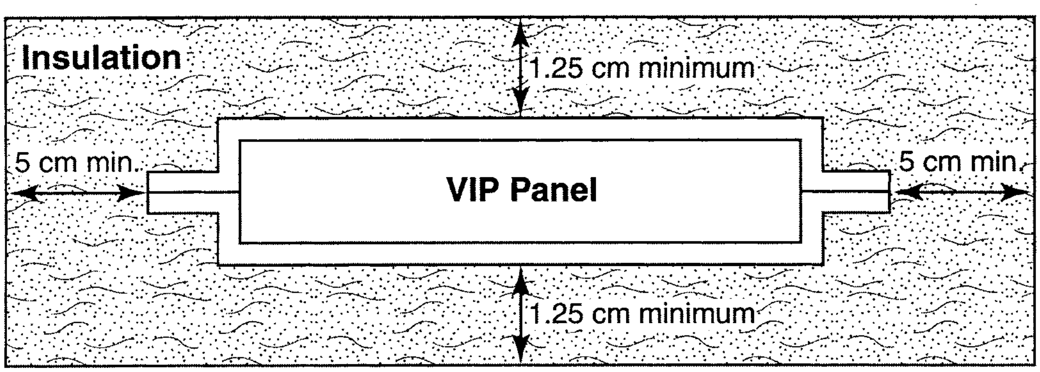

FIG. 3 Side View of the Standard Configuration Used to Measure the Effective Thermal Resistance of a Vacuum Insulation Panel

panel. The mean thermal resistivity of the center-of-panel tested shall not be less than the manufacturer's stated values.

11.4.1.1 The minimum panel size for this test is determined by the thermal conductivity of the barrier, the thickness of the barrier, the thermal conductivity of the core, and the size of the heat flux transducer or guarded hot plate surface used to make the measurement. Appendix X1 provides a fuller discussion of the relationship between these factors. See Note 3.

11.4.1.2 Another method to determine the core conductivity uses an array of heat flux transducers in the heat flow meter apparatus. These measurements can be analysed using a thermal modelling program to calculate the thermal resistivity of the filler or the magnitude of the thermal bridging through the barrier **(1)**.[11]

11.4.1.3 If Test Method C 1363 is used to measure the effective panel thermal resistance of the full size panel, the center-of-panel thermal resistivity measurement is not required. However, if numerical models are used to predict the effective thermal performance for panels of other sizes, the center-of-panel thermal resistivity must be measured.

11.4.1.4 The center-of-panel measurement can be used for quality control purposes. If panels are tested two weeks after manufacture as part of a quality-control program, this measurement will expose any panels with gross leaks.

NOTE 1—Due to the low thermal diffusivity of some superinsulators, it may be necessary to increase the time required to reach steady-state heat flow in the thermal resistance tests.

NOTE 2—Precision and bias are not yet available for these tests for these materials. Round-robin tests are planned to provide this information.

NOTE 3—For a sufficiently large panel, the flow through the panel's barrier will be a relatively small portion of the flow measured at the center of panel, so that thermal conductivity measurements made at the center of the panel will represent the conductivity of the panel's core region within an adequate margin of error.

11.4.2 *Effective Thermal Resistance*:

11.4.2.1 The effective thermal resistance differs significantly from the product of the center-of-panel resistivity and the thickness, and this system characteristic must take into account the details of the overall VIP design as well as its installation. The effective thermal resistance will vary over long periods of time. Therefore standard reporting conditions have been specified in Table 1. This issue is discussed further in 11.6.

11.4.2.2 The effective thermal resistance of a full-size panel can be measured using a calorimetric technique as described in Ref. **(2)**, or Test Method C 1363. In both cases the appropriate modeling corrections described in Ref. **(3)** must be applied. The test temperatures should shall be selected from Practice C 1058. The mean test temperature shall be selected according to the standard reporting temperatures shown in Table 1.

11.4.2.3 The effective thermal resistance of a full-size panel may be calculated by the use of finite element analysis, as described in Ref **(1)**. For this analysis, the center-of-panel (or core) thermal conductivity and that of the barrier material must be known.

11.4.2.4 A round-robin test is planned to examine the consistency of the various mathematical models used to calculate effective thermal resistance.

11.5 *Effective Thermal Performance after Puncture*—The panel barrier must be punctured with a hole at least 6 mm (0.25 in.) in diameter and the panel interior must be exposed to atmospheric pressure for at least seven days. Then the effective thermal resistance must be measured as described in 11.4.2. The mean thermal resistance of the material tested shall not be less than the manufacturer's stated values.

11.6 *Service Life*—The actual service life of a vacuum insulation panel is determined in large part by: the panel design and materials, the service environment, and the minimum acceptable thermal resistance. The standard-condition service life is defined as the period of time for which the panel will provide superinsulation performance in an environment of 24°C (75°F) and 50 % relative humidity. In making this determination, the manufacturer must consider, at the stated standard environmental conditions, the following: the outgassing of the filler material, the outgassing and permeability of the barrier material, the permeability of the seals, and the performance of any adsorbent materials contained within the panel. Then the expected decrease in thermal resistance that occurs as the vacuum insulation panel ages can be measured or computed from the relationship between thermal resistance and internal VIP pressure (for the appropriate mixture of gasses). The actual service life of a vacuum insulation panel can be shorter or longer than the standard-condition service life, depending on the service environment and the minimum required thermal resistance. Appendix X2 contains useful information about this complex issue.

11.7 *Creep Properties*—Test Methods C 480 or D 2221 or another method acceptable to both the purchaser and supplier should be used.

11.8 *Dimensional Stability at Service Conditions*—Test Method D 2126 should be used.

11.9 *Other Tests*—Depending upon the application, other tests may also be appropriate. This is discussed further in Appendix X4.

12. Inspection

12.1 Unless otherwise specified, Test Method C 390 shall govern the sampling and acceptance of material for conformance to inspection requirements. Exceptions to these requirements shall be stated in the purchase agreement.

13. Rejection and Resubmittal

13.1 Failure to conform to the requirements in this specification shall constitute cause for rejection. Rejection should be reported to the manufacturer or supplier promptly and in writing.

13.2 In case of shipment rejection, the manufacturer shall have the right to reinspect shipment and resubmit the lot after removal of that portion not conforming to requirements.

14. Packaging and Marking

14.1 *Packaging*—Unless otherwise specified, the insulation shall be supplied in the manufacturer's standard commercial packages to assure contents are undamaged at delivery.

[11] The boldface numbers given in parentheses refer to a list of references at the end of the text.