



Standard Guide for Thermal Performance Testing of Cryogenic Insulation Systems¹

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1. Scope

1.1 This guide provides information for the laboratory measurement of the steady-state thermal transmission properties and heat flux of thermal insulation systems under cryogenic conditions. Thermal insulation systems may be composed of one or more materials that may be homogeneous or non-homogeneous; flat, cylindrical, or spherical; at boundary conditions from near absolute zero or 4 K up to 400 K; and in environments from high vacuum to an ambient pressure of air or residual gas. The testing approaches presented as part of this guide are distinct from, and yet complementary to, other ASTM thermal test methods including C177, C518, and C335. A key aspect of this guide is the notion of an insulation system, not an insulation material. Under the practical use environment of most cryogenic applications even a single-material system can still be a complex insulation system (1-3).² To determine the inherent thermal properties of insulation materials, the standard test methods as cited in this guide should be consulted.

1.2 The function of most cryogenic thermal insulation systems used in these applications is to maintain large temperature differences thereby providing high levels of thermal insulating performance. The combination of warm and cold boundary temperatures can be any two temperatures in the range of near 0 K to 400 K. Cold boundary temperatures typically range from 4 K to 100 K, but can be much higher such as 300 K. Warm boundary temperatures typically range from 250 K to 400 K, but can be much lower such as 40 K. Large temperature differences up to 300 K are typical. Testing for thermal performance at large temperature differences with one boundary at cryogenic temperature is typical and representative of most applications. Thermal performance as a function of temperature can also be evaluated or calculated in

accordance with Practices C1058 or C1045 when sufficient information on the temperature profile and physical modeling are available.

1.3 The range of residual gas pressures for this Guide is from 10^{-7} torr to 10^{+3} torr (1.33^{-5} Pa to 133 kPa) with different purge gases as required. Corresponding to the applications in cryogenic systems, three sub-ranges of vacuum are also defined: High Vacuum (HV) from $<10^{-6}$ torr to 10^{-3} torr (1.333^{-4} Pa to 0.133 Pa) [free molecular regime], Soft Vacuum (SV) from 10^{-2} torr to 10 torr (from 1.33 Pa to 1,333 Pa) [transition regime], No Vacuum (NV) from 100 torr to 1000 torr (13.3 kPa to 133 kPa) [continuum regime].

1.4 Thermal performance can vary by four orders of magnitude over the entire vacuum pressure range. Effective thermal conductivities can range from 0.010 mW/m-K to 100 mW/m-K. The primary governing factor in thermal performance is the pressure of the test environment. High vacuum insulation systems are often in the range from 0.05 mW/m-K to 2 mW/m-K while non-vacuum systems are typically in the range from 10 mW/m-K to 30 mW/m-K. Soft vacuum systems are generally between these two extremes (4). Of particular demand is the very low thermal conductivity (very high thermal resistance) range in sub-ambient temperature environments. For example, careful delineation of test results in the range of 0.01 mW/m-K to 1 mW/m-K (from R-value 14,400 to R-value 144) is required as a matter of normal engineering applications for many cryogenic insulation systems (5-7). The application of effective thermal conductivity values to multilayer insulation (MLI) systems and other combinations of diverse materials, because they are highly anisotropic and specialized, must be done with due caution and full provision of supporting technical information (8). The use of heat flux (W/m^2) is, in general, more suitable for reporting the thermal performance of MLI systems (9-11).

1.5 This guide covers different approaches for thermal performance measurement in sub-ambient temperature environments. The test apparatuses (apparatus) are divided into two categories: boiloff calorimetry and electrical power. Both absolute and comparative apparatuses are included.

1.6 This guide sets forth the general design requirements necessary to construct and operate a satisfactory test apparatus.

¹ This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.