Designation: E235/E235M – 12

Standard Specification for Type K and Type N Mineral-Insulated, Metal-Sheathed Thermocouples for Nuclear or for Other High-Reliability Applications[1]

This standard is issued under the fixed designation E235/E235M; 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 requirements for simplex, compacted mineral-insulated, metal-sheathed (MIMS), Type K and N thermocouples for nuclear or other high reliability service. Depending on size, these thermocouples are normally suitable for operating temperatures to 1652°F [900°C]; special conditions of environment and life expectancy may permit their use at temperatures in excess of 2012°F [1100°C]. This specification was prepared to detail requirements for this type of MIMS thermocouple for use in nuclear environments, but they can also be used for laboratory or general commercial applications where the environmental conditions exceed normal service requirements. The intended use of a MIMS thermocouple in a specific nuclear application will require evaluation of the compatibility of the thermocouple, including the effect of the temperature, atmosphere, and integrated neutron flux on the materials and accuracy of the thermoelements in the proposed application by the purchaser.

1.2 This specification does not attempt to include all possible specifications, standards, etc., for materials that may be used as sheathing, insulation, and thermocouple wires for sheathed-type construction. The requirements of this specification include only the austenitic stainless steels and other alloys as allowed by Specification E585/E585M for sheathing, magnesium oxide or aluminum oxide as insulation, and Type K and N thermocouple wires for thermoelements (see Note 1).

1.3 *General Design*—Nominal sizes of the finished thermocouples shall be 0.0400 in., 0.0625 in., 0.125 in., 0.1875 in., or 0.250 in. [1.000 mm, 1.500 mm, 3.000 mm, 4.500 mm, or 6.000 mm]. Sheath dimensions and tolerances for each nominal size shall be in accordance with Table 1 and Figs. 1 and 2. The measuring junction styles for thermocouples covered by this specification are as follows:

1.3.1 *Style G*[2] *(grounded)*—The measuring junction is electrically connected to its conductive sheath, and

1.3.2 *Style U*[2] *(ungrounded)*—The measuring junction is electrically isolated from its conductive sheath and from reference ground.

1.4 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system are not exact equivalents or conversions; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *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 practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

A262 Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels

E3 Guide for Preparation of Metallographic Specimens

E45 Test Methods for Determining the Inclusion Content of Steel

E112 Test Methods for Determining Average Grain Size

E165 Practice for Liquid Penetrant Examination for General Industry

E220 Test Method for Calibration of Thermocouples By Comparison Techniques

E230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

E344 Terminology Relating to Thermometry and Hydrometry

[1] This specification is under the jurisdiction of ASTM Committee E20 on Temperature Measurement and is the direct responsibility of Subcommittee E20.04 on Thermocouples.

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[2] Style G and Style U measuring junctions were previously termed Class 1 and Class 2 measuring junctions respectively.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

TABLE 1 Dimensions for Style G and U Measuring Junctions

Sheath Outside Diameter, *A*			Minimum Sheath Wall, *B*	Minimum Insulation Thickness, *C*	Minimum Wire Diameter, *D*	*E*, Tolerance		*F*, Tolerance	
Nominal	Tolerance					min	max	min	max
	min	max							
Inches									
0.0400	0.0390	0.0415	0.006	0.004	0.005	0.006	0.020	0.004	0.021
0.0625	0.0615	0.0640	0.009	0.005	0.010	0.009	0.032	0.005	0.032
0.1250	0.1240	0.1265	0.012	0.012	0.020	0.012	0.062	0.012	0.063
0.1875	0.1865	0.1890	0.020	0.022	0.031	0.020	0.093	0.022	0.095
0.2500	0.2480	0.2520	0.030	0.024	0.040	0.030	0.125	0.024	0.125
[Millimetres]									
[1.000]	[0.975]	[1.038]	[0.15]	[0.10]	[0.13]	[0.15]	[0.51]	[0.10]	[0.53]
[1.500]	[1.475]	[1.538]	[0.23]	[0.13]	[0.25]	[0.23]	[0.81]	[0.13]	[0.81]
[3.000]	[2.975]	[3.038]	[0.30]	[0.30]	[0.51]	[0.30]	[1.57]	[0.30]	[1.60]
[4.500]	[4.475]	[4.538]	[0.51]	[0.56]	[0.79]	[0.51]	[2.36]	[0.56]	[2.41]
[6.000]	[5.950]	[6.050]	[0.76]	[0.61]	[1.02]	[0.76]	[3.18]	[0.61]	[3.18]

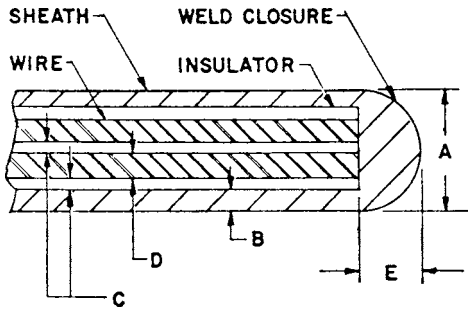

FIG. 1 Grounded Measuring Junction, Style G

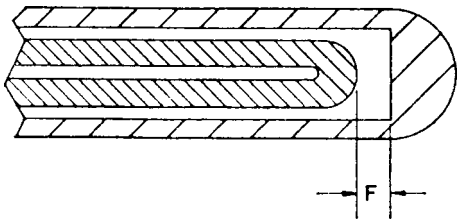

FIG. 2 Ungrounded Measuring Junction, Style U

E585/E585M Specification for Compacted Mineral-Insulated, Metal-Sheathed, Base Metal Thermocouple Cable

E780 Test Method for Measuring the Insulation Resistance of Mineral-Insulated, Metal-Sheathed Thermocouples and Thermocouple Cable at Room Temperature

E839 Test Methods for Sheathed Thermocouples and Sheathed Thermocouple Cable

E883 Guide for Reflected–Light Photomicrography

E1652 Specification for Magnesium Oxide and Aluminum Oxide Powder and Crushable Insulators Used in the Manufacture of Metal-Sheathed Platinum Resistance Thermometers, Base Metal Thermocouples, and Noble Metal Thermocouples

2.2 *ANSI Standard:*

B46.1 Surface Texture[4]

2.3 *American Welding Society Standard:*

A5.9 Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel-Welding Rods and Bare Electrodes[5]

3. Terminology

3.1 The definitions given in Terminology E344 shall apply to this specification.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *lot, n*—a quantity of finished MIMS thermocouples manufactured from the same lot of MIMS cable, then assembled and processed at the same time under the same controlled production conditions to their required final configuration.

4. Ordering Information and Basis of Purchase

4.1 The purchase order documents shall specify the following information:

4.1.1 The quantity, length, and nominal diameter of the MIMS thermocouple,

4.1.2 The thermocouple type and tolerance on the initial values of emf versus temperature per Table 2, if other than standard,

4.1.3 The type of ceramic insulation required, either alumina (Al_2O_3) or magnesia (MgO),

4.1.4 The type of sheath material and other information required (see 5.1.1),

4.1.5 The style of thermocouple measuring junction (see 1.2),

4.1.6 The type of dye-penetrant inspection procedure to be used, and

4.1.7 Any deviations from this specification or the referenced specifications.

5. Materials and Manufacture

5.1 All materials used shall be in accordance with the following requirements:

5.1.1 *Sheath Materials*—The sheath material used for the thermocouples described in this specification shall meet the

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] Available from American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126, http://www.aws.org.

TABLE 2 Tolerances on Initial Values of EMF versus Temperature for MIMS Thermocouples

NOTE 1—Tolerances in this table apply to new MIMS thermocouples.

NOTE 2—Tolerances apply to new material as produced and do not allow for changes in thermoelectric characteristics of the materials during use. The magnitude of such changes depends upon such factors as sheath and thermoelement size, temperature, time of exposure, and the environment.

NOTE 3—Where tolerances are given in percent, the percentage applies to the temperature being measured when expressed in degrees Celsius.

NOTE 4—To determine the tolerance in degrees Fahrenheit, multiply the tolerance in degrees Celsius by 9/5.

Thermocouple Type	Temperature Range °F	Temperature Range [°C]	Tolerances—Reference Junction 32°F [0°C] Standard Tolerances °F	Standard Tolerances [°C]	Special Tolerances °F	Special Tolerances [°C]
K or N	32 to 2300	[0 to 1260]	Note 4	[The greater of ±2.2°C or ±0.75 %]	Note 4	[The greater of ±1.1°C or ±0.4 %]
K[A]	–328 to 32	[–200 to 0]		[The greater of ±2.2°C or ±2 %]		[B]

[A] MIMS the thermocouples are normally supplied to meet the tolerances specified in the table for temperatures above 0°C. The same materials, however, may not fall within the sub-zero tolerances given in the second section of the table. If materials are required to meet the sub-zero limits, the purchase order shall so state. Selection of materials shall be required.

[B] Little information is available to justify establishing special tolerances for sub-zero temperatures. Such special sub-zero tolerances, if required, shall be agreed upon between the purchaser and the producer.

requirements of Specification E585/E585M. The purchaser of the thermocouples shall specify only the name of the material (seamless or welded), grade, optional requirements, test report required, and ASTM designation.

5.1.1.1 The inclusion level of the sheath shall be determined by mounting a 1-in. minimum length of a longitudinal section of the sheath using Test Methods E45, Microscopical Method A, for examination. The inclusion level shall be less than 3 A through D, thin or heavy.

5.1.1.2 The grain size of the sheath shall be determined by a specimen taken in accordance with Test Methods E112. Grain size shall be as specified in Table 3, or finer, as determined by the Comparison Procedure of Test Methods E112.

5.1.1.3 Each lot of sheath material used shall be sampled using Practices A262 as follows. Samples shall be tested by Practice A, and further tested as outlined by Table 1 in Practices A262, where screening tests so indicate. Acceptance levels for these tests shall be agreed upon between the purchaser and the producer.

5.1.2 *Thermoelement*—Thermoelements referred to in this specification shall be Type K or Type N with a standard tolerance on initial values of emf versus temperature as specified in Table 2 unless otherwise specified by the purchaser.

NOTE 1—The purchaser may specify an alternative type of thermoelement as designated in Specification E230 by indicating this deviation in the ordering documents. The supplier and the purchaser shall then agree upon a tolerance.

5.1.3 *Insulation*—The insulating material shall be either magnesia (MgO) or alumina (Al_2O_3) and shall comply with Specification E1652 Type 1 material requirements:

TABLE 3 Maximum Grain Sizes

Sheath Outside Diameter, in. [mm]	Maximum
0.0400 [1.000]	6
0.0625 [1.500]	5
0.1250 [3.000]	
0.1875 [4.500]	
0.2500 [6.000]	

5.1.3.1 A certified analysis of the composition of the insulating material as supplied to the thermocouple manufacturer shall be furnished to the purchaser. The thermocouple manufacturer shall be responsible for maintaining the purity in the finished product within the specified limits.

5.1.4 *Welding Rod*—Filler rod material used for welding on the sheath or for welding the end of the thermocouple closed shall comply with the requirements of AWS Specification A5.9 for the sheath material specified on the ordering documents.

5.2 *Processing:*

5.2.1 *Cleanliness*—The outer surface of the completed thermocouples at the time of delivery shall be free of residues containing nuclear poisons (such as boron and cadmium compounds) or foreign substances (such as chlorine compounds, strong acids or bases, oils, greases, or dust) that could become the source of corrosion or chemistry changes in a primary coolant or heat-transfer medium. The use of compounds containing halogens for final cleaning is prohibited. Alcohol, or methyl isobutyl ketone may be used unless otherwise specified.

5.2.2 *Annealing*—The sheath of the finished thermocouple shall be solution annealed and shall not be sensitized.

6. Inspection and Test Methods

6.1 *General Procedure*—Inspect and approve all thermocouples in accordance with the sampling procedures specified in this section and with inspection requirements stated herein and in referenced specifications. Acceptance of the sample inspection results does not relieve the thermocouple manufacturer of the responsibility that all thermocouples shall conform to all requirements of this specification and the latest issue of the referenced specifications.

6.1.1 Acceptance of thermocouples manufactured in accordance with this specification requires the satisfactory completion of the general tests specified for all thermocouples and three additional tests on selected sample thermocouples.

6.1.2 Select one sample thermocouple at random from each group of not more than 15 thermocouples from the same lot. Use sections of those sample thermocouples for the tests required in 6.7, 6.10.2, and 6.1.1. For the test in 6.10.2,

fabricate a measuring junction of the same style as that in the original group. Inspection and testing of this measuring junction, such as that in 6.3, is not required.

6.2 *Insulation Resistance*—Measure the insulation resistance between the thermocouple circuit and the sheath of each Style U thermocouple with a sheath length not exceeding 50 ft [15 m] in accordance with Test Method E780 using the voltage specified in Table 4 applied in both direct and reversed polarity. The insulation resistance measured shall exceed that in Table 4. This requirement can also be applied to completed Style U thermocouples in that the purchaser may select a sample thermocouple from each lot and remove the measuring junction to perform this test. Exercise due caution to prevent moisture pickup. If the thermocouple fails this test, the lot of thermocouples shall be rejected.

6.3 *Dimensional Inspection:*

6.3.1 Measure the outside diameter of each thermocouple's sheath per Test Methods E839 to verify that it is in conformance with Table 1.

6.3.2 Using the section of each sample thermocouple taken in 6.1.2, measure the sheath wall, insulation thickness, and wire diameters per Test Methods E839 to verify that they are in conformance with Table 1.

6.3.3 Using the radiographic inspection techniques described in Test Methods E839, examine each fabricated thermocouple including its measuring junction, weld closure, and a minimum of 4 in. [100 mm] of sheath extending from the thermocouple's tip to verify that the weld closure thickness "E" and measuring junction position "F" if an ungrounded junction are in conformance with Table 1; to confirm that the sheath wall, insulation thickness, and wire diameters remain consistent with those measurements made in 6.3.2; and to verify that any defects do not exceed the requirements in 6.3.3.1 and 6.3.3.2:

6.3.3.1 Cracks, voids, or inclusions in the sheath wall greater than 15 % of the sheath wall thickness, or 0.002 in. [0.05 mm], whichever is greater,

6.3.3.2 Cracks, voids, inclusions, discontinuities, or localized reduction of the thermoelements, insulation, or sheath diameter in or near the measuring junction greater than 0.002 in. [0.05 mm].

6.3.3.3 Supply the radiograph to the purchaser with appropriate means to identify the thermocouple with its radiograph.

6.4 *Sheath Integrity:*

6.4.1 Verify the thermocouple's sheath integrity in accordance with Test Methods E839, Sheath Integrity-Mass Spectrometer Method.

6.5 *Surface Finish*—The sheath surface of all completed thermocouples shall have a bright appearance with a finish no rougher than 32 rms µin. Make a visual comparison with roughness standards in accordance with ANSI B46.1.

6.6 *Surface Defects*—There shall be no cracks, seams, holes, or other defects on the surface of the sheath of the finished thermocouples when examined in accordance with Procedure A2 or B3 of Test Method E165. Any indication of cracks, seams, holes, or other defects shall be cause for rejection.

6.7 *Metallurgical Structure of the Sheath:*

6.7.1 Conduct tests of the sheath on the section of the sample thermocouple selected in 6.1.2. Tightly wind the selected section of the sheath three full turns around a mandrel twice the sheath diameter. Cut the center turn from that section and mount for metallographic examination. Prepare the metallographic specimen in accordance with Guide E3. The sheath material at the mounted specimen shall not contain any evidence of cracks or localized wall thinning when longitudinally sectioned and examined by normal metallographic practice at a magnification of 200 to 500 times in accordance with Guide E883.

6.7.2 Mount a transverse section from an unbent portion of the sample thermocouple's sheath and examine it for grain size, defects, and grain boundary attack. Grain size shall not exceed the maximum specified in Table 3 as determined by the Comparison Procedure of Test Methods E112. Defects or grain boundary attack shall not penetrate the wall in excess of 10 % of the wall thickness or 0.002 in. [0.05 mm], which ever is smaller.

6.7.3 Mount a longitudinal section from an unbent portion of the sample thermocouple's sheath and determine the inclusion level by Method A of Test Methods E45. The inclusion level shall be less than 3 A through D, thin or heavy. Defects or grain boundary attack shall not penetrate the wall in excess of 10 % of the wall thickness or 0.002 in. [0.05 mm], whichever is smaller.

NOTE 2—If specified by the purchaser of the thermocouples, the embrittlement test specified in Practices A262 can be performed on the sample thermocouple as a check for intergranular attack or excessive carbide precipitation. Acceptance levels shall be agreed upon between the purchaser and the producer.

6.8 *Thermal Cycling of Measuring Junction*—Verify the continuity of the thermocouple circuit of each finished thermocouple using a voltage not to exceed 6 V ac (rms) or 6 V dc, after five consecutive thermal cycles as follows:

6.8.1 The testing medium shall be noncorrosive, and shall be maintained at a temperature of 775 ± 25°F [413 ± 14°C] during the test.

6.8.2 Cycle by immersing the measuring junction end of the thermocouple in the testing medium at a minimum depth of 3

TABLE 4 Insulation Resistance

Sheath Outside Diameter, in. [mm]	Applied D-C Voltage (Both Direct and Reversed Polarity)	Required Minimum Insulation Resistance at Room Temperature, MΩ
0.040 to 0.058 [1.0 to 1.48]	50	1000
0.059 to 0.250 [1.49 to 6.00]	500	5000

in. [75 mm] and hold for 2 to 5 min. Remove from the testing medium and cool by quenching in room temperature water within 5 s. The total elapsed time at room temperature shall be no less than 1 min before recycling.

6.9 *Insulation Resistance After Thermal Cycling*—All Style U thermocouples shall be retested and shall meet the requirements of 6.2.

6.10 *Calibration:*

6.10.1 *Calibration After Conducting Thermal Cycling Tests*—Calibrate all finished thermocouple at 212°F [100°C], 450°F [232°C], and 787°F [419°C] in accordance with the general procedure outlined in Test Method E220 to demonstrate that, when compared to the emf versus temperature relationship defined in Specification E230 for the same thermocouple type, the temperature differences are initially within the required tolerances defined in Table 2. Perform the calibration in a furnace or bath using an immersion depth greater than the immersion depth used when performing the thermal cycling in 6.8. The actual temperature of the heat source used for calibration may deviate up to ±25°F [±14°C] from the calibration temperature specified.

6.10.2 *Calibration of the Sample Thermocouple at Higher Temperatures*—Calibrate the section of the sample thermocouple selected in accordance with 6.1.2 that has a measuring junction at 1000°F [538°C], 1350°F [732°C], and 1650°F [900°C] in accordance with the general procedures outlined in Test Method E220 to demonstrate that, when compared to the emf versus temperature relationship defined in Specification E230 for the same thermocouple type, the temperature differences are initially with the required tolerances defined in Table 2. The actual temperature of the heat source used for calibration may deviated up to ±25°F [±14°C] from the calibration temperature specified.

6.11 *Minimum Insulation Density*—Unless otherwise agreed upon between the purchaser and the producer, measure the insulation density of a section of the sample thermocouple selected in 6.1.2 using the methods specified in Test Methods E839. The minimum density of the compacted electrical insulation shall be 70 % of the theoretical maximum density. The theoretical maximum density of MgO is 0.129 lb/in.^{3} [3580 mg/cm^3] and the 70 % minimum density required computes to .090 lb/in^3 [2506 mg/cm^3]. The theoretical maximum density of Al_2O_3 (alpha alumina) is 0.143 lb/in.^{3} [3970 mg/cm^3] and the 70 % minimum density required computes to .100 lb/in.^{3} [2779 mg/cm^3].

NOTE 3—These values are taken from the *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co.

7. Certification and Test Reports

7.1 Submit copies of the following certifications and test and inspection reports to the purchaser:

7.1.1 Certification that the thermoelements used in the manufacture of the thermocouples are in accordance with the purchaser's ordering documents for the designated material described in 5.1.2,

7.1.2 Chemical analysis of the sheath material, and

7.1.3 Certified compositional analysis of the insulation (see 5.1.3).

7.2 Submit copies of the following general test:

7.2.1 Measurement results of the insulation resistance tests (see 6.2),

7.2.2 Results of the dimensional and radiographic inspection (see 6.3),

7.2.3 Test results of sheath integrity tests (see 6.4),

7.2.4 Results of liquid penetrant inspection (see 6.6), and

7.2.5 Results from thermal cycle tests (see 6.8).

7.3 Submit copies of the following sample tests.

7.3.1 Test results on metallurgical structure (see 6.7) and

7.3.2 Calibration results (see 6.10.1 and 6.10.2)

8. Packaging, Marking, Shipping, and Preservation

8.1 *Sealing*—Seal-weld all open ends of each thermocouple prior to shipment. To distinguish the sealed end from the measuring junction end of each thermocouple, the sealed end shall have a weld bead at least twice the sheath diameter.

8.2 *Thermocouple Identification*—Individually identify each thermocouple by two corrosion-resistant metal tags, each approximately 0.75 in. [20 mm] by 2 in. [50 mm] affixed to the thermocouple using plastic-coated or corrosion-resistant wire. Locate the tags approximately 6 in. [150 mm] from each end. The tags shall bear the thermocouple manufacturer's name and serialized identification number for easy cross-reference to all records on sheath, insulation, conduct or wires, and radiographs for each thermocouple. Also indicate the buyer's purchase order.

8.3 *Packaging and Shipping*—Clean the thermocouple sheaths to ensure that they are free of grease, oil, finger marks, dirt, scale, and other foreign matter before packaging. Ship thermocouples in straight lengths if under 10 ft [3.0 m] in length or if greater than 0.1250 in. [3.000 mm] in diameter, or in coils of a diameter not less than 200 times the sheath diameter or 18 in. [460 mm] in coil diameter, whichever is greater. Protect the thermocouples in a dust-tight container. It shall be the responsibility of the manufacturer to construct the container in such a manner as to prevent the thermocouples from being damaged during shipment and handling.

8.4 *Marking*—Plainly mark each shipping container with the address of the purchaser, purchase order number, and the name of the manufacturer.

9. Keywords

9.1 grounded junction; high-reliability thermocouple; metal-sheathed; mineral insulated; thermocouple ; ungrounded junction