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Standard Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes With Integral Fins¹

This standard is issued under the fixed designation B 359/B 359M; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope*

1.1 This specification² establishes the requirements for seamless copper and copper alloy tubing on which the external or internal surface, or both, has been modified by a cold-forming process to produce an integral enhanced surface for improved heat transfer.

1.2 *Units*—The values stated in either in-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems could result in nonconformance with the specification.

1.3 The tubes are typically used in surface condensers, evaporators, and heat exchangers.

1.4 The product shall be produced of the following coppers or copper alloys, as specified in the ordering information.

| Copper or Copper Alloy UNS No. | Type of Metal |
|-----------------------------------|---|
| C10100 | Oxygen-free electronic |
| C10200 | Oxygen-free without residual deoxidants |
| C10300 | Oxygen-free, extra low phosphorus |
| C10800 | Oxygen-free, low phosphorus |
| C12000 | DLP Phosphorized, low residual phosphorus (See Note 1) |
| C12200 | DHP, Phosphorized, high residual phosphorus (See Note 1) |
| C14200 | DPA Phosphorized arsenical (See Note 1) |
| C19200 | Phosphorized, 1 % iron |
| C23000 | Red Brass |
| C44300 | Admiralty Metal Types B, C, and |
| C44400 | D |
| C44550 | Aluminum Bronze |
| C60800 | Aluminum Brass Type B |
| C68700 | 95-5 Copper-Nickel |
| C70400 | 90-10 Copper-Nickel |
| C70600 | 90-10 Copper-Nickel (Modified for Welding) |
| C70620 | 80-20 Copper-Nickel Type A |
| C71000 | 70-30 Copper-Nickel |
| C71500 | 70-30 Copper-Nickel (Modified for Welding) |
| C71520 | Copper-Nickel |
| C72200 | |

NOTE 1—Designations listed in Classification B 224.

1.5 The following safety hazard caveat pertains only to the test methods described in this specification. *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.*

1.6 Product produced in accordance with the Supplementary Requirements section for military applications shall be produced only to the inch-pound system of this specification.

¹ This specification is under the jurisdiction of ASTM Committee B05 on Copper and Copper Alloys and is the direct responsibility of Subcommittee B05.04 on Pipe and Tube.

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² For ASME Boiler and Pressure Vessel Code applications see related Specification SB-359 in Section II of that Code.

*A Summary of Changes section appears at the end of this standard.

2. Referenced Documents

2.1 ASTM Standards:³

- B 153 Test Method for Expansion (Pin Test) of Copper and Copper-Alloy Pipe and Tubing
- B 154 Test Method for Mercurous Nitrate Test for Copper and Copper-Alloys
- B 170 Specification for Oxygen-Free Electrolytic Copper—Refinery Shapes
- B 224 Classification of Coppers
- B 601 Classification for Temper Designations for Copper and Copper Alloys—Wrought and Cast
- B 846 Terminology for Copper and Copper Alloys
- B 858 ~~Test Method for Determination of Susceptibility to Stress Corrosion Cracking in Copper Alloys Using the Ammonia Vapor Test~~³ Test Method for Ammonia Vapor Test for Determining Susceptibility to Stress Corrosion Cracking in Copper Alloys
- B 900 ~~Practice for Packaging of Copper and Copper-Alloy Mill Products for U. S. Government Agencies~~³ Practice for Packaging of Copper and Copper Alloy Mill Products for U.S. Government Agencies
- D 4727/D 4727M Specification for Corrugated and Solid Fiberboard Sheet Stock (Container Grade) and Cut Shapes
- E 3 ~~Test Methods of Preparation of Metallographic Specimens~~ Guide for Preparation of Metallographic Specimens
- E 8 Test Methods for Tension Testing of Metallic Materials
- E 8M Test Methods for Tension Testing of Metallic Materials (Metric)⁴[Metric]
- E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E 53 Test Method for Determination of Copper in Unalloyed Copper by Gravimetry
- E 62 Test Methods for Chemical Analysis of Copper and Copper Alloys (Photometric Methods)
- E 112 Test Methods for Determining Average Grain Size
- E 118 Test Methods for Chemical Analysis of Copper-Chromium Alloys
- E 243 Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes
- E 255 Practice for Sampling Copper and Copper Alloys for the Determination of Chemical Composition
- E 478 Test Methods for Chemical Analysis of Copper Alloys

3. General Requirements

3.1 Product described by this specification shall typically be furnished with unenhanced ends, but may be furnished with enhanced ends or stripped ends from which the O.D. enhancement has been removed by machining.

3.1.1 The enhanced sections of the tube in the as-fabricated temper are in the cold-worked condition produced by the enhancing operation.

3.1.2 The unenhanced sections of the tube shall be in the annealed or light drawn temper, and shall be suitable for rolling-in operations.

4. Terminology

4.1 For the definitions of terms related to copper and copper alloys, refer to Terminology B 846.

4.2 Definitions:

4.2.1 *flattening, v*—this term shall be interpreted as that condition which allows a micrometer caliper, set at three times the wall thickness, to pass over the tube freely throughout the flattened part, except at the points where the change in element of flattening takes place.

4.3 Definitions of Terms Specific to This Standard:

4.3.1 *tube condenser, n*—see *tube, heat exchanger* in Terminology B 846.

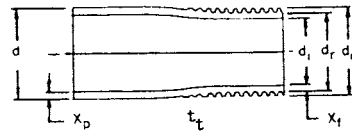
5. Ordering Information

5.1 Include the following information when placing orders under this specification:

- 5.1.1 ASTM designation and year of issue,
- 5.1.2 Copper or Copper Alloy UNS No. designation (see 1.4 and Section 7),
- 5.1.3 Temper (see Section 8),
- 5.1.4 Dimensions: diameter, wall thickness, length and location of unenhanced surfaces and total tube length. Configuration of enhanced surfaces shall be as agreed upon between the manufacturer and the purchaser. (See Figs. 1-3).
- 5.1.5 Whether the product is to be subsequently welded for UNS Alloy C72200, UNS Alloys C 70620 and C71520 are welding grades of C70600 and C71500,
- 5.1.6 Quantity, and
- 5.1.7 If product is for the U.S. government.

³ Annual Book of ASTM Standards, Vol 02.01.

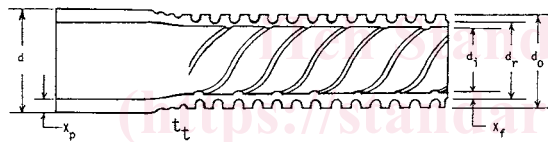
³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.



- d - Outside Diameter of Unenhanced Section
- d_o - Outside Diameter of the Enhanced Section
- d_r - Root Diameter of the Enhanced Section
- d_i - Inside Diameter of the Enhanced Section
- x_p - Wall Thickness of the Unenhanced Section
- x_r - Wall Thickness of the Unenhanced Section
- t_t - Transition Taper

NOTE—The outside diameter over the enhanced section will not normally exceed the outside diameter of the unenhanced section.

FIG. 1 Outside Diameter Enhanced Tube Nomenclature



- d - Outside Diameter of Unenhanced Section
- d_o - Outside Diameter over the Enhanced Section
- d_r - Root diameter of the Enhanced Section
- d_i - Inside Diameter of the Enhanced Section
- x_p - Wall Thickness of the Unenhanced Section
- x_f - Wall Thickness of the Enhanced Section
- t_t - Transition Taper

FIG. 2 Outside Diameter and Inside Diameter Enhanced Tube Nomenclature

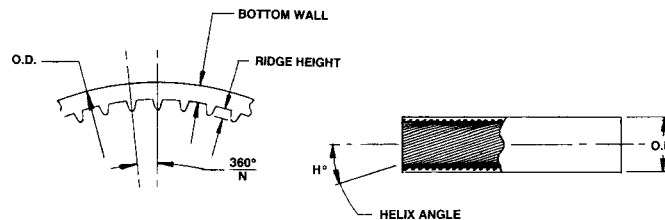


FIG. 3 Inside Diameter Enhanced Tube Nomenclature

5.2 The following options are available and shall be specified at the time of placing the order, when required:

5.2.1 When heat identification or traceability is required,

5.2.2 When tubes are for Boiler and Pressure Vessel code application, which should then be ordered according to ASME SB 359,

5.2.3 Flattening test (see 11.2),

5.2.4 Certification (see Section 22), when required,

5.2.5 Mill test report (see Section 23), when required, and

5.2.6 Stress relief annealing (see 9.4), when required.

5.3 In addition, when material is purchased for agencies of the U.S. government, it shall conform to the requirements specified in the Supplementary Requirements section, when specified in the contract or purchase order.

6. Materials and Manufacture

6.1 Materials:

6.1.1 The material of manufacture shall be of such quality and purity that the finished product shall have the properties and characteristics prescribed in this specification for the applicable alloy and temper.

6.2 *Manufacture:*

6.2.1 The seamless copper and copper alloy tubing shall have the internal or external surface, or both, modified by a cold forming process to produce an integral enhanced surface for improved heat transfer.

6.2.2 The cut ends of the tubes shall be deburred.

6.2.3 Due to the discontinuous nature of the processing of castings into wrought products, it is not practical to identify specific casting analysis with a specific quantity of finished material.

6.2.4 When heat identification is required, the purchaser shall specify the details desired in the purchase order or contract.

7. Chemical Composition

7.1 The tubes shall conform to the chemical requirements specified in Table 1 for copper or copper alloy specified in the ordering information.

7.2 These specification limits do not preclude the presence of unnamed elements. By agreement between the manufacturer, or supplier and purchaser, analysis may be required and limits established for elements not specified.

7.2.1 *Copper Alloy C19200*—Copper may be taken as the difference between the sum of results for all specified elements and 100 %. When all elements specified, including copper, are determined, their sum shall be 99.8 % minimum.

7.2.2 For alloys in which copper is specified as the remainder, copper may be taken as the difference between the sum of the results for all specified elements and 100 % for the particular alloy.

7.2.2.1 When analyzed, copper plus the sum of results for specified elements shall conform with the requirements shown in the following table:

TABLE 1 Chemical Requirements

| Copper or Copper Alloy UNS No. | Composition, % | | | | | | | | | | | | Other Named Elements |
|--------------------------------|----------------------------|------------|----------|---------------------|-----------|------------|------------|-------------|------------|------------|-------------|-----------|--------------------------|
| | Copper | Tin | Aluminum | Nickel, incl Cobalt | Lead, max | Iron | Zinc | Manganese | Arsenic | Antimony | Phosphorus | Chromium | |
| C10100 | 99.99 min ^{A,B} | 0.0002 max | ... | 0.0010 max | 0.0005 | 0.0010 max | 0.0001 max | 0.00005 max | 0.0005 max | 0.0004 max | 0.0003 max | ... | Te 0.0002 |
| C10200 | 99.95 min ^{C,D,E} | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| C10300 | 99.95 min ^{C,F} | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.001–0.005 | ... | ... |
| C10800 | 99.95 min ^{C,F} | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.005–0.012 | ... | ... |
| C12000 | 99.90 min ^C | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.004–0.012 | ... | ... |
| C12200 | 99.9 min ^C | ... | ... | ... | ... | ... | ... | ... | ... | ... | 0.015–0.040 | ... | ... |
| C14200 | 99.4 min ^C | ... | ... | ... | ... | ... | ... | ... | 0.15–0.50 | ... | 0.015–0.040 | ... | ... |
| C19200 | 98.5 min ^G | ... | ... | ... | ... | 0.8–1.2 | 0.20 max | ... | ... | ... | 0.01–0.04 | ... | ... |
| C23000 | 84.0–86.0 ^G | ... | ... | ... | 0.05 | 0.05 max | remainder | ... | ... | ... | ... | ... | ... |
| C44300 | 70.0–73.0 ^H | 0.9–1.2 | ... | ... | 0.07 | 0.06 max | remainder | ... | 0.02–0.06 | ... | ... | ... | ... |
| C44400 | 70.0–73.0 ^H | 0.9–1.2 | ... | ... | 0.07 | 0.06 max | remainder | ... | ... | 0.02–0.10 | ... | ... | ... |
| C44500 | 70.0–73.0 ^H | 0.9–1.2 | ... | ... | 0.07 | 0.06 max | remainder | ... | ... | ... | 0.02–0.10 | ... | ... |
| C60800 | remainder ^{C,I} | ... | 5.0–6.5 | ... | 0.10 | 0.10 max | ... | ... | 0.02–0.35 | ... | ... | ... | ... |
| C68700 | 76.0–79.0 ^{C,I} | ... | 1.8–2.5 | ... | 0.07 | 0.06 max | remainder | ... | 0.02–0.06 | ... | ... | ... | ... |
| C70400 | remainder ^{C,I} | ... | ... | 4.8–6.2 | 0.05 | 1.3–1.7 | 1.0 max | 0.30–0.8 | ... | ... | ... | ... | ... |
| C70600 | remainder ^{C,I} | ... | ... | 9.0–11.0 | 0.05 | 1.0–1.8 | 1.0 max | 1.0 max | ... | ... | ... | ... | ... |
| C70620 | 86.5 min ^{C,I} | ... | ... | 9.0–11.0 | 0.02 | 1.0–1.8 | 0.5 max | 1.0 max | ... | ... | 0.02 max | ... | 0.05 C max 0.02 S max |
| C71000 | remainder ^{C,I,J} | ... | ... | 19.0–23.0 | 0.05 | 1.0 max | 1.0 max | 1.0 max | ... | ... | ... | ... | ... |
| C71500 | remainder ^{C,I} | ... | ... | 29.0–33.0 | 0.05 | 0.40–1.0 | 1.0 max | 1.0 max | ... | ... | ... | ... | ... |
| C71520 | 65.0 min | ... | ... | 29.0–33.0 | 0.02 | 0.40–1.0 | 0.50 max | 1.0 max | ... | ... | 0.02 max | ... | 0.05 C max 0.02 S max |
| C72200 | remainder ^{C,G,J} | ... | ... | 15.0–18.0 | 0.05 | 0.50–1.0 | 1.0 max | 1.0 max | ... | ... | ... | 0.30–0.70 | 0.03 Si 0.03 Ti |

^A This value is exclusive of silver and shall be determined by difference of "impurity total" from 100 %. "Impurity total" is defined as the sum of sulfur, silver, lead, tin, bismuth, arsenic, antimony, iron, nickel, zinc, phosphorus, selenium, tellurium, manganese, cadmium, and oxygen present in the sample.

^B Other impurity maximums for C10100 shall be: bismuth and cadmium 0.0001 each, oxygen 0.0005, selenium 0.0003, silver 0.0025, and sulfur 0.0015.

^C Copper (including silver).

^D Oxygen in C10200 shall be 0.0010 max.

^E Cu is determined by the difference in the impurity total and 100 %.

^F Copper plus sum of named elements shall be 99.95 % min.

^G Cu + Sum of Named Elements, 99.8 % min.

^H Cu + Sum of Named Elements, 99.6 % min.

^I Cu + Sum of Named Elements, 99.5 % min.

^J When the product is for subsequent welding applications, and so specified in the contract or purchase order, zinc shall be 0.50 % max, lead 0.02 % max, phosphorus 0.02 % max, sulfur 0.02 % max, and carbon 0.05 % max.

| Copper Alloy UNS No. | Copper Plus Named Elements, % min |
|----------------------|-----------------------------------|
| C60800 | 99.5 |
| C70400 | 99.5 |
| C70600 | 99.5 |
| C70620 | 99.5 |
| C71000 | 99.5 |
| C71500 | 99.5 |
| C71520 | 99.5 |
| C72200 | 99.8 |

7.2.3 For alloys in which zinc is specified as the remainder, either copper or zinc may be taken as the difference between the sum of the results of specified elements analyzed and 100 %.

7.2.3.1 When all specified elements are determined, the sum of results plus copper shall be as follows:

| Copper Alloy UNS No. | Copper Plus Named Elements, % min |
|------------------------|-----------------------------------|
| C23000 | 99.8 |
| C44300, C44400, C44500 | 99.6 |
| C68700 | 99.5 |

8. Temper

8.1 Tempers, as defined in Classification B 601 and this document, are as follows:

8.1.1 The tube, after enhancing, shall be supplied, as specified, in the annealed (O61) or as-fabricated temper.

8.1.1.1 The enhanced sections of tubes in the as-fabricated temper are in the cold-worked condition produced by the fabricating operation.

8.1.1.2 The unenhanced sections of tubes in the as-fabricated temper are in the temper of the tube prior to enhancing, annealed (O61), or light drawn (H55), and suitable for rolling-in operations.

8.1.1.3 Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700, furnished in the as-fabricated temper, shall be stress relief annealed after enhancing and be capable of meeting the requirements of the stress-corrosion susceptibility requirement in Section 12. Stress-relief annealing of the copper and other copper alloys described by this specification is not required.

9. Grain Size of Annealed Temper

9.1 Samples of annealed-temper (O61) tubes selected for test shall be subjected to microscopical examination at a magnification of 75 diameters and shall show uniform and complete recrystallation.

9.2 Average grain size shall be within limits agreed upon between the manufacturer and purchaser, when measured in the wall of the tube outside of the enhanced area.

9.3 The requirements of this section do not apply to product shipped in the as-fabricated temper.

9.4 Some annealed tubes, when subjected to aggressive environments, may be subject to stress-corrosion cracking failure because of the residual tensile stresses developed in straightening. For such applications, it is recommended that tubes of Copper Alloy UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700 be subjected to a stress relieving thermal treatment subsequent to straightening. When required, this must be specified on the purchase order or contract. Tolerance for roundness and length, and the condition for straightness, for tube so ordered, shall be to the requirements agreed upon between the manufacturer and purchaser.

10. Mechanical Property Requirements

10.1 *Tensile Property Requirements* :

10.1.1 Prior to the enhancing operation, the tube shall conform to the requirements for tensile properties prescribed in Table 2.

11. Performance Requirements

11.1 *Expansion Test*— The unenhanced sections of all tubes selected for test shall conform to the requirements prescribed in Table 3 when tested in accordance with Test Method B 153. The expanded tube shall show no cracking or rupture visible to the unaided eye.

11.2 *Flattening Test*:

11.2.1 When specified in the contract or purchase order, the flattening test described in the test method section in 18.4 shall be performed.

11.2.1.1 During inspection, the flattened areas of the test-specimen shall be free of defects, but blemishes of a nature that do not interfere with the intended application are acceptable.

12. Other Requirements

12.1 *Mercurous Nitrate Test or Ammonia Vapor Test*:

12.1.1 The mercurous nitrate or ammonia vapor test is required only for Copper Alloys UNS Nos. C23000, C44300, C44400, C44500, C60800, and C68700. (**Warning**—Mercury is a definite health hazard and therefore equipment for the detection and

TABLE 2 Tensile Requirements

| Copper or Copper Alloy UNS No. | Temper Designation | | Tensile Strength, min | Yield Strength, ^A min |
|--|--------------------|-------------|------------------------|----------------------------------|
| | Standard | Former | ksi ^B [MPa] | ksi ^B [MPa] |
| C10100, C10200, C10300, C10800, C12000, C12200, C14200 | O61 | annealed | 30 [205] | 9 [62] ^C |
| C10100, C10200, C10300, C10800, C12000, C12200, C14200 | H55 | light-drawn | 36 [250] | 30 [205] |
| | O61 | annealed | 38 [260] | 12 [85] |
| | O61 | annealed | 40 [275] | 12 [85] |
| C44300, C44400, C44500 | O61 | annealed | 45 [310] | 15 [105] |
| | O61 | annealed | 50 [345] | 19 [130] |
| | O61 | annealed | 50 [345] | 18 [125] |
| | O61 | annealed | 38 [260] | 12 [85] |
| | O61 | annealed | 40 [275] | 15 [105] |
| | O61 | annealed | 40 [275] | 15 [105] |
| | O61 | annealed | 45 [310] | 16 [110] |
| | O61 | annealed | 52 [360] | 18 [125] |
| | O61 | annealed | 52 [360] | 18 [125] |
| | O61 | annealed | 45 [310] | 16 [110] |

^A At 0.5 % extension under load.

^B ksi = 1000 psi.

^C Light straightening operation is permitted.

TABLE 3 Expansion Requirements

| Temper Designation | | Copper or Copper Alloy UNS No. | Expansion of Tube Outside Diameter in Percent of Original Outside Diameter |
|--------------------|-------------|--|--|
| Standard | Former | | |
| O61 | annealed | C10100, C10200, C10300, C10800, C12000, C12200, C14200 | 30 |
| H55 | light-drawn | C10100, C10200, C10300, C10800, C12000, C12200, C14200 | 20 |
| O61 | annealed | C19200 | 30 |
| O61 | annealed | C23000 | 20 |
| O61 | annealed | C44300, C44400, C44500 | 20 |
| O61 | annealed | C60800 | 20 |
| O61 | annealed | C68700 | 20 |
| O61 | annealed | C70400 | 30 |
| O61 | annealed | C70600, C70620 | 30 |
| O61 | annealed | C71000 | 30 |
| O61 | annealed | C71500, C71520 | 30 |
| O61 | annealed | C72200 | 30 |

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<https://standards.iteh.ai/catalog/standards/sist/e46f887b-c348-4cfb-aadb-7dcba9fd4133/astm-b359-b359m-022006>
 removal of mercury vapor produced in volatilization is recommended. The use of rubber gloves in testing is advisable.)

12.1.2 The test specimens, cut 6 in. [150 mm] in length from the enhanced section shall withstand, without cracking, an immersion in the standard mercurous nitrate solution in Test Method B 154 or immersion in the ammonia vapor solution as defined in Test Method B 858.

12.1.3 Unless otherwise agreed upon between the manufacturer, or supplier, and the purchaser, the manufacturer shall have the option of using either the mercurous nitrate test or the ammonia vapor test. If agreement cannot be reached, the mercurous nitrate test standard shall be utilized.

12.1.4 If the ammonia vapor test is selected, the appropriate risk level pH value for the test solution shall be agreed upon by the manufacturer and purchaser, or alternately, if the purchaser defers to the manufacturer's expertise for the selection of the test pH value, the minimum value selected shall be 9.8.

12.2 Non-Destructive Testing:

12.2.1 Each tube shall be subjected to a non-destructive test. Tubes shall normally be tested in the as-fabricated temper but, at the option of the manufacturer, may be tested in the annealed temper. Unless otherwise specified, the manufacturer shall have the option of testing the tubes by one of the following test methods:

12.2.1.1 Non-Destructive Examination for Defects:

(1) The tubes shall be passed through an eddy-current testing unit adjusted per the requirements of 18.3.3 to provide information on the suitability of the tube for the intended application.

(2) Tubes causing irrelevant signals because of moisture, soil, and like effects may be reconditioned and retested. Such tubes shall be considered to conform, should they not cause output signals beyond the acceptable limits.

(3) Tubes causing irrelevant signals because of visible and identifiable handling marks may be retested by the hydrostatic test prescribed in 12.2.1.2 or the pneumatic test prescribed in 12.2.1.3.

(4) Unless otherwise agreed, tubes meeting the requirements of either test shall be considered to conform if the tube dimensions are within the prescribed limits.

12.2.1.2 Hydrostatic Test—Each tube, without showing evidence of leakage, shall withstand an internal hydrostatic pressure