



Designation: G189 – 07 (Reapproved 2021)^{e1}

Standard Guide for Laboratory Simulation of Corrosion Under Insulation¹

This standard is issued under the fixed designation G189; 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.

^{e1} NOTE—Replaced Terminology G15 with Terminology G193, and other editorial changes made throughout in Jan. 2021.

1. Scope

1.1 This guide covers the simulation of corrosion under insulation (CUI), including both general and localized attack, on insulated specimens cut from pipe sections exposed to a corrosive environment usually at elevated temperature. It describes a CUI exposure apparatus (hereinafter referred to as a CUI-Cell), preparation of specimens, simulation procedures for isothermal or cyclic temperature, or both, and wet/dry conditions, which are parameters that need to be monitored during the simulation and the classification of simulation type.

1.2 The application of this guide is broad and can incorporate a range of materials, environments and conditions that are beyond the scope of a single test method. The apparatus and procedures contained herein are principally directed at establishing acceptable procedures for CUI simulation for the purposes of evaluating the corrosivity of CUI environments on carbon and low alloy pipe steels, and may possibly be applicable to other materials as well. However, the same or similar procedures can also be utilized for the evaluation of (1) CUI on other metals or alloys, (2) anti-corrosive treatments on metal surfaces, and (3) the potential contribution of thermal insulation and its constituents on CUI. The only requirements are that they can be machined, formed or incorporated into the CUI-Cell pipe configuration as described herein.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

¹ This guide is under the jurisdiction of ASTM Committee G01 on Corrosion of Metals and is the direct responsibility of Subcommittee G01.11 on Electrochemical Measurements in Corrosion Testing.

Current edition approved Jan. 1, 2021. Published January 2021. Originally approved in 2007. Last previous edition approved in 2013 as G189 – 07 (2013). DOI: 10.1520/G0189-07R21E01.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

A106/A106M Specification for Seamless Carbon Steel Pipe for High-Temperature Service

C552 Specification for Cellular Glass Thermal Insulation

C871 Test Methods for Chemical Analysis of Thermal Insulation Materials for Leachable Chloride, Fluoride, Silicate, and Sodium Ions

D1193 Specification for Reagent Water

G1 Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens

G3 Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing

G5 Reference Test Method for Making Potentiodynamic Anodic Polarization Measurements

G31 Guide for Laboratory Immersion Corrosion Testing of Metals

G46 Guide for Examination and Evaluation of Pitting Corrosion

G59 Test Method for Conducting Potentiodynamic Polarization Resistance Measurements

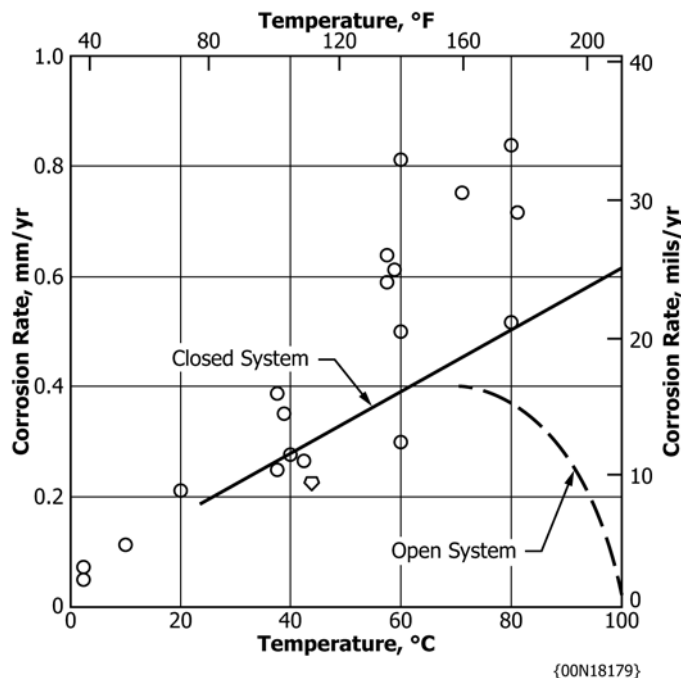
G102 Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements

G193 Terminology and Acronyms Relating to Corrosion

3. Terminology

3.1 The terminology used herein, if not specifically defined otherwise, shall be construed to be in accordance with Terminology G193.

² 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.



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NOTE 1—The actual CUI corrosion rates can be in excess of the those obtain in conventional laboratory immersion exposures.
FIG. 1 Comparison of Actual Plant CUI Corrosion Rates Measurements (Open Data Points Shown is for Plant CUI) with Laboratory Corrosion Data Obtained in Open and Closed Systems

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *corrosion under insulation (CUI), n*—the corrosion of steel or other materials under thermal insulation due to the presence of water, oxygen or other corrodants, or combinations thereof.

3.2.2 *control condition, n*—an exposure condition using a pre-selected environment without the inclusion of inhibitors, protective treatments, or additives to the thermal insulation or exposure environment. It is selected to provide baseline data to which data from other exposure conditions can be compared.

3.2.3 *protection ratio, n*—ratio of the corrosion rate with the surface treatment or particular insulative material, or both, with that obtained for the control condition.

4. Summary of Guide

4.1 The CUI-Cell consists of three to six ring specimens separated by non-conductive spacers and held together by two blind flanged pipe sections, one on each end. Thermal insulation is placed around one-half of the evaluation section of the cell and sealed providing an annular space to retain a corrosive environment. The other half of the insulation is put in place to have proper heat transfer conditions as a typical insulated pipe section with internal heating. Provisions are given herein to use the specimens as corrosion coupons or electrodes in two separate electrochemical cells. One half of the CUI-Cell can be used to perform a CUI simulation under the control condition while the other can be used to evaluate inhibitors, protective coatings or insulative materials.

4.2 Corrosion measurements can be made using either mass loss data (Procedure A) or electrochemical dynamic polarization resistance methods (Procedure B), or both. This apparatus

can be used to conduct laboratory evaluations under isothermal or cyclic temperature and under wet or wet/dry conditions simulating desired conditions in service. Comparison of the measured corrosion rates from exposures conducted with various surface treatments on steel and/or with various insulative materials with corrosion rates obtained with bare steel under the control condition provides the basis for assessment of protection efficiency. A value of protection efficiency of less than 1.0 indicates reduction in the severity of corrosion relative to the control condition whereas a value greater than 1.0 indicates an increase in the severity of corrosion relative to the control condition.

5. Significance and Use

5.1 The corrosion observed on steel and other materials under thermal insulation is of great concern for many industries including chemical processing, petroleum refining and electric power generation. In most cases, insulation is utilized on piping and vessels to maintain the temperatures of the operating systems for process stabilization and energy conservation. However, these situations can also provide the prerequisites for the occurrence of general or localized corrosion, or both, and in stainless steels, stress corrosion cracking. For example, combined with elevated temperatures, CUI can sometimes result in aqueous corrosion rates for steel that are greater than those found in conventional immersion tests conducted in either open or closed systems (see Fig. 1).³ This figure shows actual CUI

³ Ashbaugh, W. G., "Corrosion of Metals Under Insulation," *Process Industries Corrosion*, Ed. B. J. Moniz and W. I. Pollock, ASTM STP 880, West Conshohocken, PA, 1986.

data determined in the field compared with the corrosion data from fully immersed corrosion coupons tests.

5.2 This guide provides a technical basis for laboratory simulation of many of the manifestations of CUI. This is an area where there has been a need for better simulation techniques, but until recently, has eluded many investigators. Much of the available experimental data is based on field and in-plant measurements of remaining wall thickness. Laboratory studies have generally been limited to simple immersion tests for the corrosivity of leachants from thermal insulation on corrosion coupons using techniques similar to those given in Guide G31. The field and inplant tests give an indication of corrosion after the fact and can not be easily utilized for experimental purposes. The use of coupons in laboratory immersion tests can give a general indication of corrosion tendencies. However, in some cases, these procedures are useful in ranking insulative materials in terms of their tendencies to leach corrosive species. However, this immersion technique does not always present an accurate representation of the actual CUI tendencies experienced in the service due to differences in exposure geometry, temperature, cyclic temperatures, or wet/dry conditions in the plant and field environments.

5.3 One of the special aspects of the apparatus and methodologies contained herein are their capabilities to accommodate several aspects critical to successful simulation of the CUI exposure condition. These are: (1) an idealized annular geometry between piping and surrounding thermal insulation, (2) internal heating to produce a hot-wall surface on which CUI can be quantified, (3) introduction of ionic solutions into the annular cavity between the piping and thermal insulation, (4) control of the temperature to produce either isothermal or cyclic temperature conditions, and (5) control of the delivery of the control or solution to produce wet or wet-dry conditions. Other simpler methods can be used to run corrosion evaluations on specimens immersed in various solutions and leachants from thermal insulation. In some cases, these procedures may be acceptable for evaluation of the contribution of various factors on corrosion. However, they do not provide accommodation of the above mentioned factors that may be needed for CUI simulation.

5.4 With the CUI-Cell, the pipe material, insulation and environment can be selected for the desired simulation needed. Therefore, no single standard exposure condition can be defined. The guide is designed to assist in the laboratory simulation of (1) the influence of different insulation materials on CUI that, in some cases, may contain materials or additives, or both, that can accelerate corrosion, (2) the effect of applied or otherwise incorporated inhibitors or protective coatings on reducing the extent and severity of CUI. This guide provides information on CUI in a relatively short time (approximately 72 h) as well as providing a means of assessing variation of corrosion rate with time and environmental conditions.

6. Apparatus

6.1 The CUI-Cell⁴ can simulate the severity and modality of corrosion that has been described to occur under thermal insulation.^{3,5} Initially this cell was developed for the evaluation of various surface treatments to be applied on the external surface of pipe to remediate CUI problems. However, subsequently, this same apparatus has been used successfully to evaluate the influence of various types of thermal insulation on CUI. In the cell, corrosion is intended to occur on the outer surface of ring specimens machined from a selected material. Fig. 2 shows a schematic representation of the CUI-Cell. The components of the cell include the following:

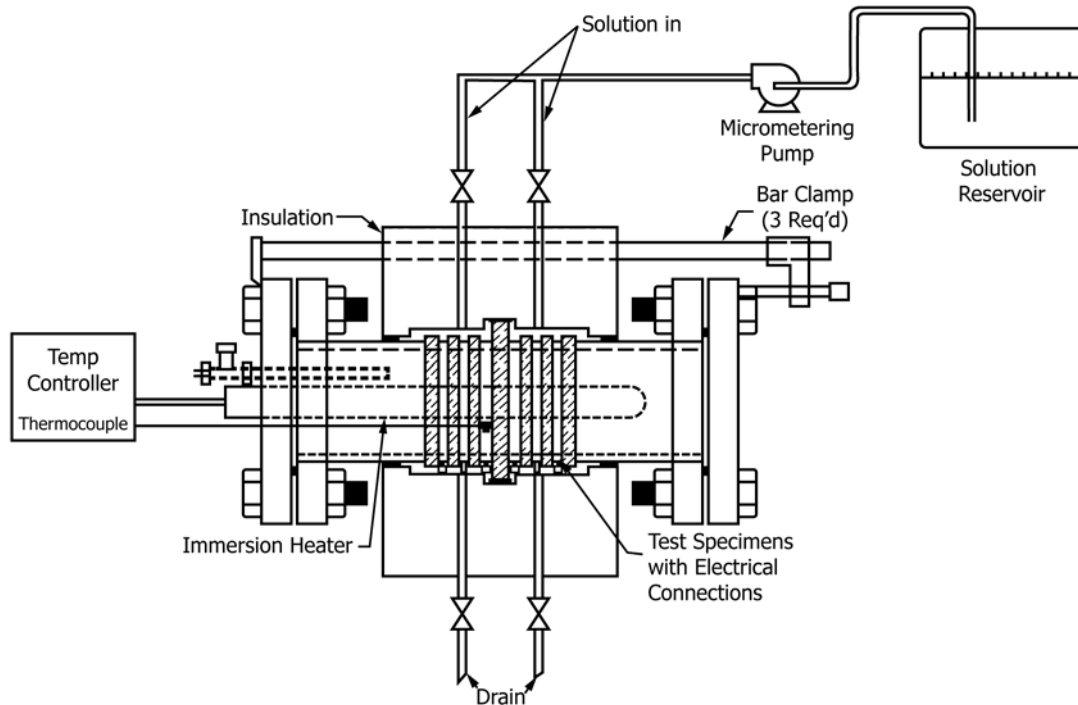
6.1.1 *Blind Flange Sections*—The CUI-Cell consists of two, nominal two-inch diameter pipe sections [that is, two-inch nominal diameter pipe material with a thickness of 0.187 in. (4.75 mm) as shown in Specification A106/A106M, Grade B, or alternative material to match that being evaluated by this simulation]; one for each end of the cell. Each end includes a bolted flange pair consisting of a weldneck, threaded or lap joint flange and a blind flange and attached pipe section. Pipe clamps or other suitable devices can be used to hold the flanged ends and the ring specimens together. Any device is acceptable that provides adequate sealing force between the various sections of the CUI-Cell.

6.1.2 *Ring Specimens*—The CUI-Cell consists of six ring specimens that are separated by nonporous, nonconductive spacers (see Section 7 for more detailed information). The evaluation portion, which includes alternate ring specimens of the intended material and nonconductive rings, is held together by two blind flanged pipe sections on both ends. The two sets of three ring specimens and spacers should be separated by an extra thick, nonconductive ring spacer (dam) at the center of the CUI-cell. This allows for separate corrosion measurements to be made on each set of specimens. For electrochemical measurements, each ring specimen should contain an attachment screw for connection of electrical leads to the potentiostat (Fig. 2). The connections should be made outside of the area exposed to the corrosive environment. The nonconductive spacers should be made from a machinable, temperature resistant, non-conductive material. Machinable polytetrafluoroethylene (PTFE) resins with high melting points are suitable in most cases for use up to about 400 °F to 450 °F (200 °C to 230 °C).

6.1.3 *Internal Heater and Temperature Controller*—The temperature on the outer surface of the ring specimens is achieved via an immersion heater (nominally 0.625 in. (1.6 cm) in diameter) having 400 W located on the inside of the pipe section mounted through the center of one of the blind

⁴ Abayarathna, D., Ashbaugh, W. G., Kane, R. D., McGowan, N., and Heimann, B., "Measurement of Corrosion Under Insulation and Effectiveness of Protective Coatings," *Corrosion/97*, Paper No. 266, NACE International, Houston, Texas, March 1997.

⁵ Ullrich, O. A., MTI Technical Report No. 7, "Investigation of an Approach for Detection of Corrosion Under Insulation," MTI Project 12, Phase II, Materials Technology Institute of the Chemical Process Industries, March 1982.



NOTE 1—The electrical connections to the specimens and contact of the thermocouple must be made outside of the wetted portion of the CUI-Cell (see Figs. 3 and 4 for more details).

FIG. 2 Schematic of CUI-Cell

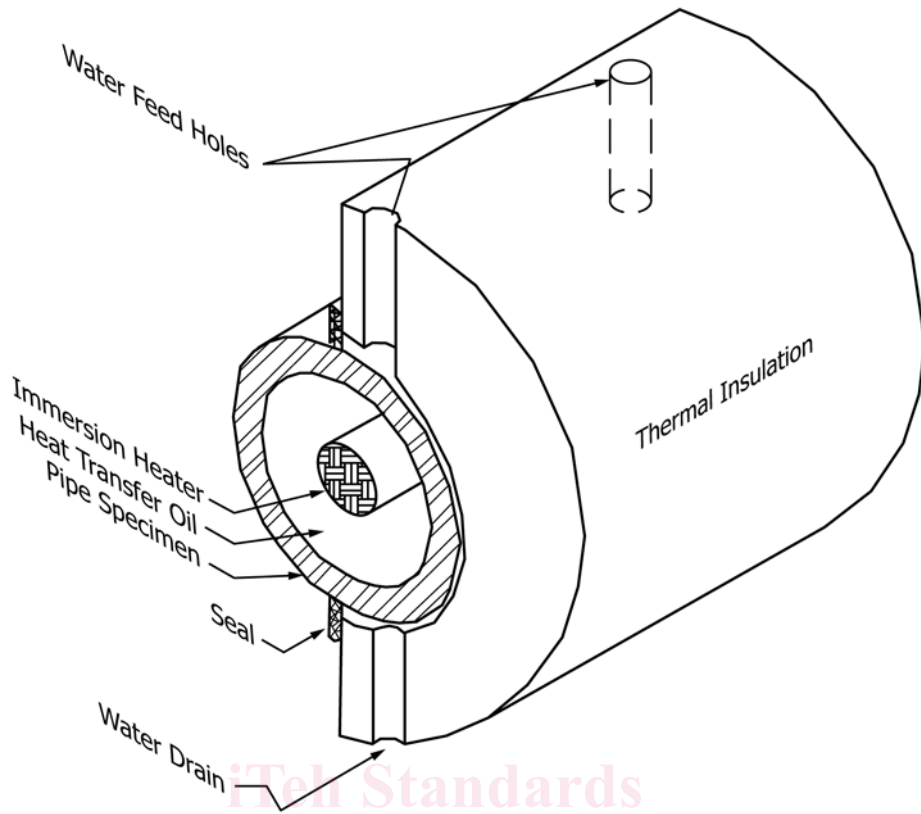
flanges using an NPT connection. The temperature of the evaluation section of the CUI-Cell should be monitored and controlled with a thermocouple contacting the outer surface of the innermost ring specimen at a location outside of the area exposed to the corrosive environment but under the thermal insulation as shown in Figs. 3 and 4. The inside of the pipe section is filled with a heat transfer oil stable at the maximum intended temperature. The oil inside the cell assembly is connected to an oil reservoir of at least 100 mL capacity through a metal tube allowing for the expansion and contraction of the oil with temperature. The temperature controller employed should be able to control temperature to ± 2 °F (1 °C). If cyclic temperature exposures are desired, the controller should have multiple programmable temperature settings, heat-up rates and soak times.

6.1.4 *Thermal Insulation*—Thermal insulation placed on the side of the evaluation section provides the annular space of at least 0.25 in. (6.4 mm) around the outer surface if the specimens to retain the solution as shown in Fig. 2 and in greater detail in Figs. 3 and 4. The thermal insulation should be sealed with silicone adhesive materials forming an annular pocket to hold the solution. Two holes should be drilled in the insulation at both the top and the bottom for the addition and draining of the solution from the annular pocket on the CUI-Cell. Where possible, the thermal insulation should be selected based on those materials used in the particular condition(s) of interest. The control condition should use a water resistant molded foam glass thermal insulation in accordance with Specification C552 with low concentration of chlorides (<40 ppm) and other leachable compounds. For the

simulations involving specific surface treatments, solutions or insulative materials, typical materials and environments for the intended application should be used, where possible. Alternatively, those insulative materials specified in the control condition can be used.

6.1.5 *Potentiostat(s)* (For potentiodynamic polarization resistance measurement only.) In cases where electrochemical measurements are to be made, a potentiostat should be used in accordance with Test Method G59 and Practice G102 to determine the open circuit potential (OCP) and to make potentiodynamic polarization resistance measurements of current versus electrode potential over a range up to at least ± 20 mV of the OCP. The potentiostat(s) should be capable of monitoring both electrochemical cells in the apparatus by using either separate channels, a multiplexer, or by employing two separate potentiostat units (see Fig. 5).

6.1.6 *Micrometering Pump and Solution Reservoir*—In order to maintain or control the addition of the solution during the simulation, or both, a suitable metering pump should be used that can administer a liquid solution to the CUI cell over a range of pumping rates from 0.5 mL/min to 5 mL/min. The reservoir should be made from glass or high density polyethylene (HDPE) and should have a volume large enough to hold the entire quantity of solution needed for the complete run at the desired pumping rate. The solution should be conveyed to and from the cell using 0.125 in. tubing made from a corrosion resistant material. There should be valves with on/off regulation on the lines coming from the outlets in the bottom of the CUI-Cell. These valves are used to control the amount of solution in the cell during the wet portion of the exposure.



NOTE 1—Opposite half of thermal is added after seals has been made and thermocouple has been inserted into the proper position (see Fig. 2).

FIG. 3 Cross-section of CUI-Cell Showing Orientation of Thermal Insulation

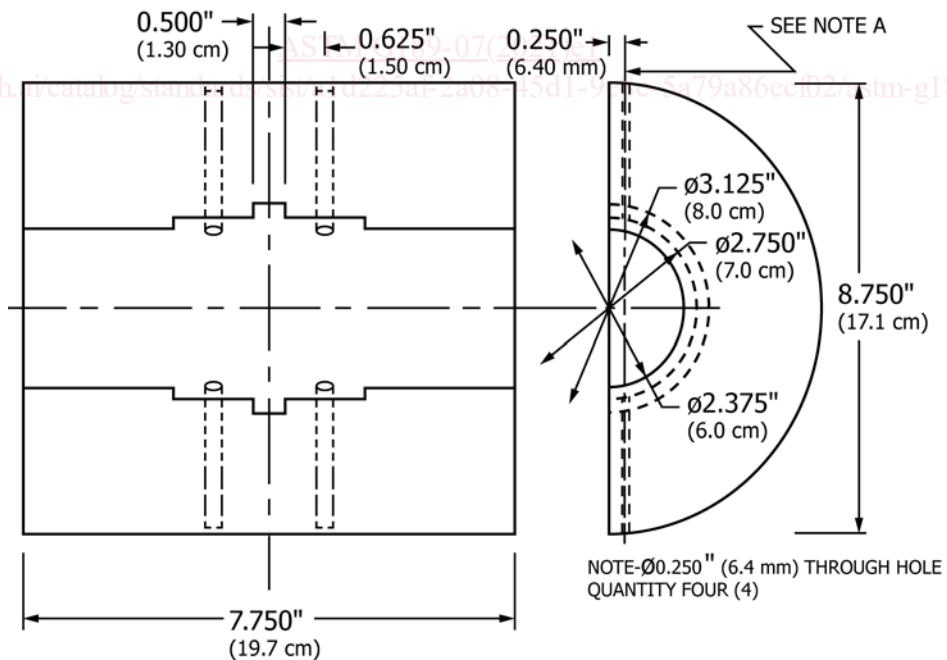
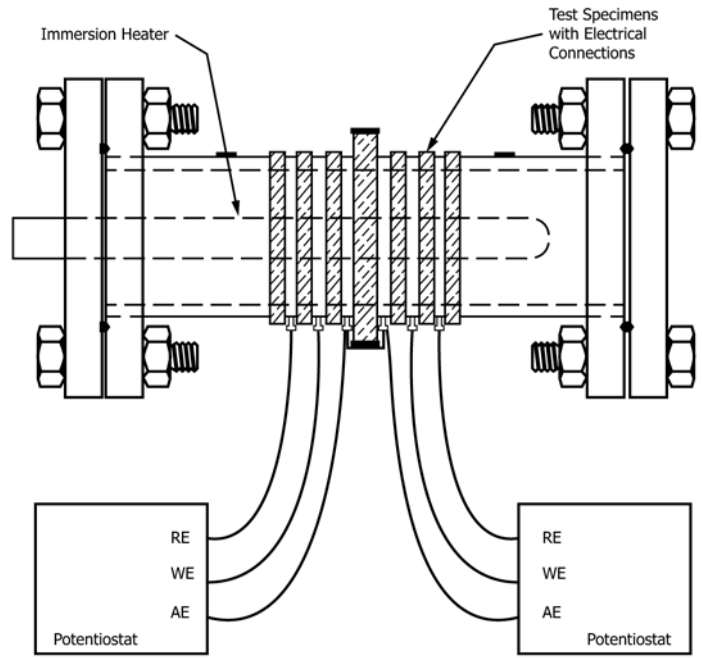
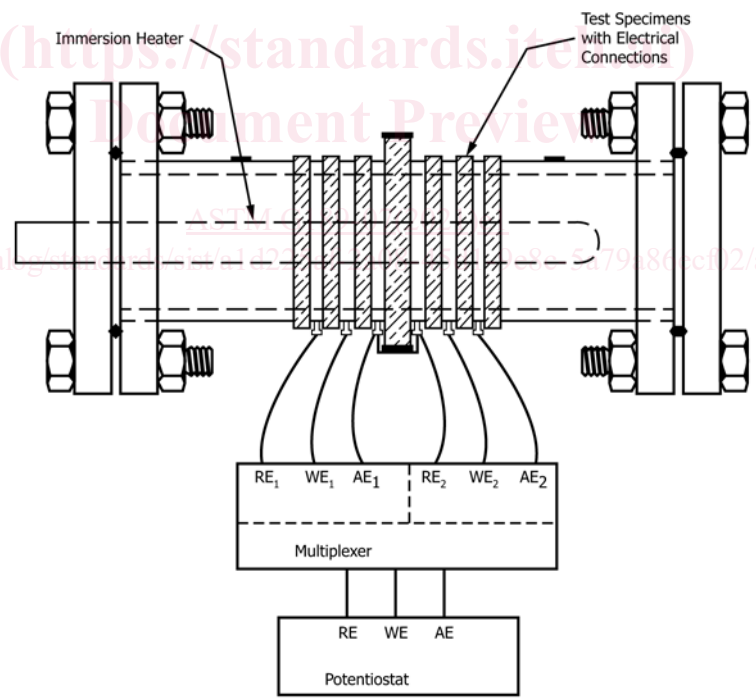


FIG. 4 Dimensions of Thermal Insulation for CUI Simulation



Two Potentiostat Set-up



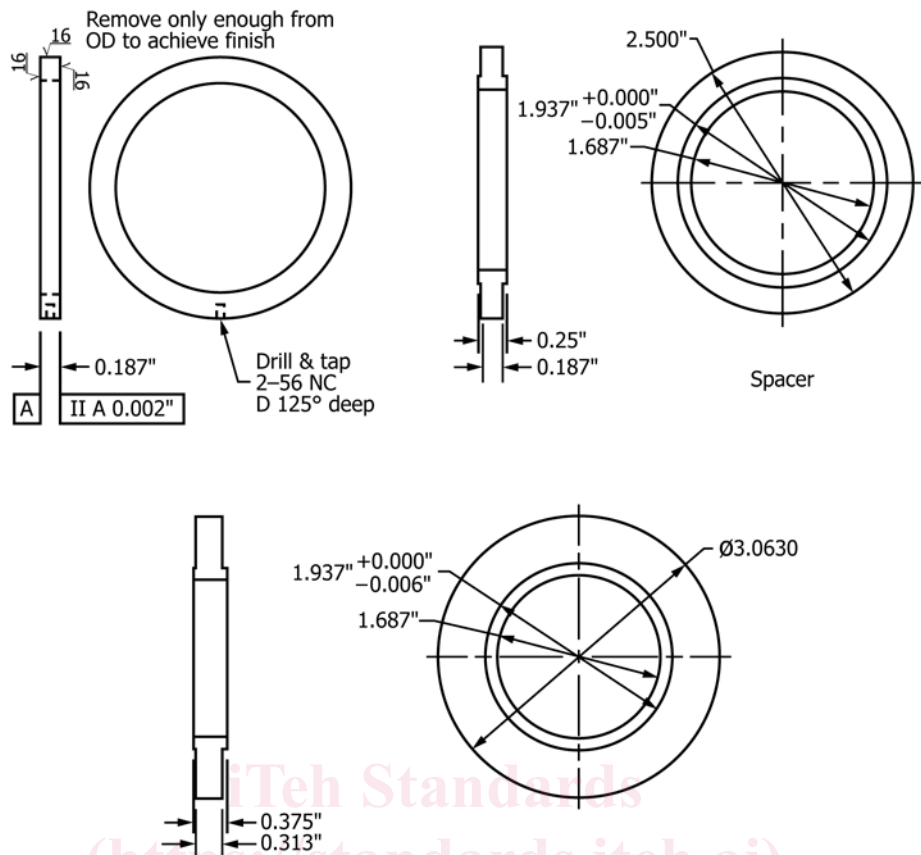
One Potentiostat with Multiplexer

Top—Set-up with two separate potentiostats.

Bottom—Set-up with one potentiostat and multiplexer.

NOTE 1—Electrical connects to CUI-Cell specimens to be made outside wetted area of cell.

FIG. 5 Schematic of Wiring of Potentiostat to CUI-Cell Ring Specimens for Procedure B



Top Left—Configuration of the ring specimen.
 Top Right—Nonconductive spacer.
 Bottom—Nonconductive large spacer (dam) located between the two sides of the CUI-Cell.
 Dimension Conversion: 1 in. = 2.54 cm.

FIG. 6 Ring specimen and Nonconductive Spacer

7. Specimens

7.1 For the purposes of conducting this simulation, the ring specimens should be prepared from a two-inch nominal diameter pipe material with a thickness of 0.187 in. (4.75 mm) and a width of 0.25 in. 6.35 mm). The ring specimens and nonconductive spacers should have interlocking surfaces to assist in sealing for containing of the heat transfer oil on the inside of the cell and the solution on the outside (see Fig. 6). The outer surface of the ring specimens should be polished to a 600 grit finish.

7.2 Unless otherwise required for simulation purposes, the ring specimens can be prepared from carbon steel made in accordance with Specification A106/A106M, Grade B. A mill certification for the actual material should be obtained.

7.3 A minimum of three ring specimens are required for one exposure per evaluation. This provides of triplicate mass loss corrosion and localized corrosion measurements. A minimum of three ring specimens are also needed for electrochemical corrosion measurements. Where such electrochemical corrosion measurements are being made using the potentiodynamic polarization resistance technique, the three ring specimens should be used as the working electrode, auxiliary electrode and reference electrode as described in Test Method G59. For comparative evaluations to be conducted simultaneously, a

total of six specimens are required for both cases. This includes two sets of three specimens.

8. Environment

8.1 The solution used in CUI simulation should be relevant to the intended application, where possible. It can be based on anticipated service conditions involving various levels of impurities specified for the particular case. It can also consist of a leachants derived from a selected thermal insulation or dilutions prepared from the leachants. Procedures for this extraction and analysis techniques are given in Test Methods C871.

8.2 Unless otherwise required for a specific simulation, a suggested solution that can be used to produce an accelerated exposure environment with the CUI-Cell should consist of 100 ppm NaCl dissolved in reagent water made in accordance with Specification D1193 (Type IV) acidified with addition of H₂SO₄ to pH 6 (±0.1 pH unit) at 75 °F (24 °C). Five litres of stock solution is made by adding 0.5 g of NaCl to 5 L of reagent water followed by addition of a small quantity of 1 M solution of H₂SO₄ in water using a dropper as needed to attain the required pH. This solution is designed to represent an atmospheric condensate with impurities of chlorides and acids found in industrial and coastal environments.