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Standard Guide for Mixed Flowing Gas (MFG) Tests for Electrical Contacts¹

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1. Scope

1.1 The techniques described in this guide pertain to mixed flowing gas (MFG) tests containing species that are applied to evaluate devices containing electrical contacts such as slip rings, separable connectors, electromechanical relays or switch contacts. These techniques may be relevant to other devices, but it is the responsibility of the user to determine suitability prior to testing.

1.2 The MFG tests described in this guide are designed to accelerate corrosive degradation processes. These accelerations are designed such that the degradation occurs in a much shorter time period than that expected for such processes in the intended application environment of the device being tested. Application environments can vary continuously from benign to aggressively corrosive. Connectors and contacts within closed electronic cabinets may be affected by an environment of different severity than the environment on the outside of such cabinets. In general, indoor environments are different than outdoor environments. The MFG tests described herein, being discrete embodiments of specific corrosive conditions, cannot be representative of all possible application environments. It is the responsibility of the test specifier to assure the pertinence of a given test condition to the specifier's application condition.

1.3 The MFG tests described herein are not designed to duplicate the actual intended application environmental of the device under test. An extended bibliography, Section 10, that provides information which is useful to test specifiers to assist them in selecting appropriate test methods is included in this guide. The bibliography covers the scope from application condition characterization, single and multiple gas effects, and material and product effects to key application and test variables as well as discussions of atmospheric corrosion processes.

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

¹ This guide is under the jurisdiction of ASTM Committee B-2 on Nonferrous Metals and Alloys and is the direct responsibility of Subcommittee B2.11 on Electrical Contact Test Methods.

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2. Referenced Documents

2.1 ASTM Standards:

- B 542 Terminology Relating to Electrical Contacts and Their Use²
- B 808 Test Method for Monitoring of Atmospheric Corrosion Chambers by Quartz Crystal Microbalances²
- B 810 Test Method for Calibration of Atmospheric Corrosion Test Chambers by Change in Mass of Copper Coupons²
- B 825 Test Method for Coulometric Reduction of Surface Films on Metallic Test Samples²
- B 826 Test Method for Monitoring Atmospheric Corrosion Tests by Electrical Resistance Probes²
- B 827 Practice for Conducting Mixed Flowing Gas (MFG) Environmental Tests²

2.2 Other Documents:

- EIA-364B-TP65 Mixed Industrial Gas Test Procedure³
- IEC Standard 68-2-42 Basic Environmental Testing Procedures, Test K_c Sulphur Dioxide Test for Contacts and Connections⁴
- IEC Standard 68-2-43 Basic Environmental Testing Procedures, Test K_d Hydrogen Sulfide Test for Contacts and Connections⁴
- IEC Technical Trend Document 68-2-60 TTD Environmental Testing, Corrosion Tests in Artificial Atmosphere at Very Low Concentration of Polluting Gas(es)⁴
- IEC 68-2-60 (second edition) Environmental Testing—Part 2: Tests—test K_e: Flowing mixed gas corrosion test, 1995
- IEEE P1156.1 Environmental Specifications for Computer Modules (Draft 4 June 10, 1992—unapproved)⁵

3. Terminology

3.1 Terms relevant to this guide are defined in Terminology B 542 except as noted in the following section.

3.2 Other term:

3.2.1 *mixed flowing gas test*—a laboratory test conducted in air that flows through a test chamber in which the temperature,

² Annual Book of ASTM Standards, Vol 03.04.

³ Available from Electronic Industries Association (EIA), 2001 Pennsylvania Ave. N.W., Washington, DC 20006-1813.

⁴ Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

⁵ Available from the Institute of Electrical and Electronic Engineers, Inc., 345 E. 47th St., New York, NY 10017.



relative humidity, concentrations of gaseous pollutants, and other critical variables are carefully defined, monitored and controlled.

4. Significance and Use

4.1 Preservation of a conducting surface on electrical contact is vital to the continued functioning of such contacts. Contamination of the surface with insulating layers formed by corrosion processes is one potential hazard. Laboratory testing of contacts in MFG tests is used to assess the effectiveness of design features and materials.

4.2 MFG tests are used in development studies of processes and materials for contacts. For example, coupon specimens may be exposed to MFG tests to evaluate new contact materials, layers of new coating materials on a supporting substrate, reduced coating thicknesses, or protective surface treatments.

4.3 MFG tests are also employed to test the durability of a finished product with respect to atmospheric corrosion. For example, finished connectors may be exposed to a MFG test and their performances compared against each other or against a set of fixed requirements. Relays or switch contacts may be exposed in the operated and non-operated conditions to compare performance.

4.4 MFG tests are useful for determining the effectiveness of connector housings and shrouds as barriers to ingress of atmospheric corrodants to the contact surfaces. These tests can also be used to assess the screening of the metal-to-metal contact areas of mated connectors.

4.5 MFG tests are employed as qualification tests to determine connector failure rates in application environments for which correlation between test and application has previously been established.

4.6 This guide provides test conditions which are to be applied in conjunction with Practice B 827 which defines the required test operation and certification procedures, tolerances, and reporting requirements. Where the test specifier requires certifications or tolerances different than those provided in Practice B 827, the required certifications or tolerances shall be part of the test specification. Differences from the specifications in Practice B 827 shall be reported in the test report provided by the test operator to the test specifier. Specification of one of the test conditions defined in this document in the form of a statement such as, "Parts shall be tested in accordance with ASTM B 845 Method Z.", implicitly requires test condition, Z, applied according to Practice B 827.

5. Procedure

5.1 Decide upon a test plan appropriate for the contacts being evaluated. Consider test parameters such as preconditioning, performance measurement and other evaluation techniques, and experimental controls.

5.2 Select a MFG test and exposure length appropriate for the parts being evaluated. Table 1 lists a number of such tests that have been documented in the technical literature. The next section provides brief discussions of the origins and intended purpose of each of the methods.

6. Abstracts of Methods

6.1 *Method A*—Method A was originally developed as a

highly accelerated test to stress equipment that might be exposed to environments with high levels of air pollution from combustion of high sulfur coal (1). The method is included in this list for completeness. It is generally not considered realistic for evaluation of electronic equipment for the vast majority of applications. Typical exposure time is 4, 10 or 21 days, depending upon the specification for the product under test.

6.2 *Method B*—Method B was originally developed as a European standard, and has largely been replaced by methods with lower levels of sulfur bearing gases (2). The method is included in this list for completeness. It is generally not considered realistic for evaluation of electronic equipment for the vast majority of applications. Typical exposure time is 4, 10 or 21 days, depending upon the specification for the product under test.

6.3 *Method C*—Method C was developed in Europe as an alternative to Method A in response to requests for a less aggressive test that would simulate exposures in less aggressive environments (3,4). Method C may simulate the majority of usage environments better than Method A. Typical exposure time is 4, 10 or 21 days depending upon the specification for the product under test.

6.4 *Method D*—Method D was developed in Europe as an alternative to Method B for the same reasons cited in the above discussion of Method C (3,4). Typical exposure time is 4, 10 or 21 days, depending upon the specification for the product under test.

6.5 *Method E*—Method E was developed in Europe as a first step toward a test containing more than one pollutant gas [3,4]. Typical exposure time is 4, 10 or 21 days depending upon the specification for the product under test.

6.6 *Method G, H, and K—General Information*—These methods are often called the Battelle Class II, III, and IV Tests⁶ respectively, since they were developed by the Battelle Columbus Laboratories after an extensive study of electronic equipment operating conditions (5). The test conditions were the result of correlation studies between corrosion products and mechanisms, and test and application conditions, in order to obtain a valid estimate of the corrosion response in the expected electronic service environments. From this study, it was concluded that most operating or application environments for electrical connectors and electronic components can be categorized by a limited number of Severity Classes, which can be simulated, and their effects accelerated, by adjusting the critical parameters of the MFG test.

6.6.1 The descriptions in reference (5) of operating environment Classes I through IV are as follows: Class I is characterized by formation of oxides on copper coupons and no visible attack on porous gold plated, nickel underplated, copper coupons (Au/Ni/Cu) Class II is characterized by pore corrosion of Au/Ni/Cu coupons and formation of oxides and complex copper hydroxy chlorides on copper coupons. Class III is characterized by pore and tarnish creepage corrosion of Au/Ni/Cu coupons and the formation oxides, sulfides and other

⁶ It was found that the lack of electrical corrosion failure mechanisms in Class I environments made it unnecessary to develop a Class I MFG Test.



TABLE 1 Test Conditions of Mixed Flowing Gas Tests

ASTM Method	H ₂ S ppb ^A	SO ₂ ppb ^A	Cl ₂ ppb ^A	NO ₂ ppb	Temp. °C	RH %	Air Changes (#/h)	Air Velocity (m/h)	Duration (days)	Source	Ref.	Notes
A		25,000 ±5000			25 ± 2 ^B	75 ±5		20-60	4, 10, 21	K _c	(1)	^C
B	12,500 ±2500				25 ± 2 ^B	75 ±5	3-5	20-60	4, 10, 21	K _d	(2)	
C		500 ±100			25 ± 1 ^B	75 ±3	3-5	60	4, 10, 21	K _e Method A	(3,4)	
D	100 ±20				25 ± 1 ^B	75 ±3	3-5	60	4, 10, 21	K _e Method B	(3,4)	
E	100 ±20	500 ±100			25 ± 1 ^B	75 ±3	3-10	60	4, 10, 21	K _e IEC 68-2-60 Test Method 1	(3,4)	
G	10 +0/-4		10 +0/-2	200 ±25	30 ±2	70 ±2	3-8			Battelle Class II	(5,16,17) (8)	^D
H	100 ±10		20 ±5	200 ±25	30 ±2	75 ±2	3-8			Battelle Class III	(5,16,17) (8)	^{E,F}
K	200 ±10		50 ±5	200 ±25	50 ±2	75 ±2	3-8			Battelle Class IV	(5,8)	
L	40 ±5 %	350 ±5 %	3 ±15 %	610 ±5 %	30 ±0.5	70 ±2		1832		G1(T)	(9)	
M	10 ± 5	200 ± 20	10 ± 5	200 ± 20	25 ± 1 ^B	75 ± 3	3-10		10, 21	K _e IEC 68-2-60	(3,4,11) (12)	
N	10 +0/-4	200 ± 25	10 + 0/-2	200 ± 25	30 ± 2	70 ± 2	per ASTM B 827	per ASTM B 827	5-30	Telecom central office	(14,15)	
O	10 ± 5	100 ± 20	10 ± 3	200 ± 50	30 ± 1	70 ± 2	per ASTM B 827	per ASTM B 827	10, 20	Telecom central office	(16,17)	
P	100 ± 20	200 ± 50	20 ± 5	200 ± 50	30 ± 1	70 ± 2	per ASTM B 827	per ASTM B 827	20	Telecom uncontrolled environment	(16,17)	

Notes:
^AGas concentrations in ppb refer to parts per billion (1 in 10⁹) volume per volume (vol/vol) in air.
^BThe test temperature of 25°C may require refrigeration in order to assure compliance with specified temperature and humidity variation limits.
^CCarbon dioxide, 4500 parts per million (vol/vol) maximum.
^DReferences (16 and 17) show NO₂ level as 100 ppb and temperature as 25°C while reference (5) shows the values in the table above; difference in corrosion of copper is minor between the two sets of conditions per private communication dated April 26, 1991, W. H. Abbott to E. Sproles.
^ERelative humidity of 75 % (as shown in References (16 and 17)) is the recommended test condition for Class III per private communication dated April 26, 1991, W. H. Abbott to E. Sproles.
^FTest conditions are defined in purchase contract.

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unknown corrosion products on copper coupons. Class IV is characterized by tarnish creepage on Au/Ni/Cu coupons and copper coupon corrosion products similar to Class III except that sulfide presence greatly exceeds oxide presence whereas for Class III, the oxide presence is equivalent to the sulfide presence (5).

6.6.1.1 *Method G*—Method G accelerates the effects of Battelle Class II environments. These correspond to conditions that are often found in business offices or control rooms that are associated with light industrial areas or where environmental controls are not operating effectively and continuously (5,6). Light tarnish creepage corrosion has been reported to be found in Class II gas tests. Typical industry practice has been to expose test hardware (such as connectors) to this test for 1 to 3 weeks.⁷

6.6.1.2 *Method H*—Method H accelerates the effects of Battelle Class III environments. These correspond to many industrial and related locations (including many storage areas) where moderate amounts of pollutants are present in poorly controlled environments. These might be found nearer to primary sources of atmospheric pollutant gases or in industrial

environments where there are a multiplicity of sources for pollutant gases within a region such that all businesses in such regions are susceptible. Potential failure mechanisms in this test include severe pore corrosion and corrosion product migration from the pores or from the base-metal edges adjoining the gold finish. Heavy film growth on base metals and accelerated attack on other susceptible materials are also possible (5). Typical industry practice has been to expose test hardware (such as connectors) to this test for 10 or 20 days.⁸

6.6.1.3 *Method K*—Method K accelerates the effects of Battelle Class IV environments. These represent the most severe electronic equipment operating environments, such as might be found at or adjacent to primary sources of atmospheric pollutant gases or where the combined effects of multiple pollutant gases and high humidity combine to rapidly destroy the integrity of precious metal finishes and produce thick corrosion films on some base metal surfaces (4). Testing to Class IV environments is not generally recommended because material selection alone is seldom sufficient to protect the reliability of electrical contact surfaces. See Section 4 for

⁷ EIA 364 TP-65 designates these test conditions as 'Environmental Class II' (8).

⁸ EIA 364 TP-65 designates these test conditions as 'Environmental Class III' (8).



information on attenuation of pollutant effects. Exposure time in this test is best determined by study of the specific application environment.⁹

6.7 *Method L*—Method L refers to the GIT test conditions which have been used by IBM to qualify connectors and electrical components for operation in the IBM business office applications environment as part of a comprehensive corrosion evaluation strategy (9).¹⁰ The GIT test conditions were selected to provide correlation of both corrosion product and mechanism between test and application conditions to obtain a valid estimate of the corrosion response in the expected environment. The selection of test conditions was based on X-ray diffraction studies of copper coupons exposed to both application (field) sites and test conditions.

6.8 *Method M*—Method M has been developed by the International Electrotechnical Commission (IEC) SC 50B and consists of the Method G (Battelle Class II) three gas mixture plus sulfur dioxide. It is based upon investigations conducted, over several years, by the Siemens Corporation of Munich, Germany, in public buildings belonging to the German Federal Railways and Post Office Department (11,12). Tolerances on gas composition have been added since the draft versions of the IEC document were published. Verification of test performance using mass gain of copper coupons is recommended because allowed tolerances on chlorine and hydrogen sulfide content of the test atmosphere permit a large range in relative gas composition. The IEC standard recommends a mass gain on copper of 1.2 to 2.4 mg/dm²·day.

6.9 *Method N*—The values for pollutant gases are identical to the IEC standard in Method M above with the provision for testing at 30°C rather than at 25°C as in the proposed IEC standard (14). These test conditions have been used in some

qualification testing of connectors for telecommunications products and included in an industry round robin. Present industry practice is use of Methods O and P in place of Method N.

6.10 *Method O*—This method is used to evaluate connectors for use in telephone central offices and similar environments (14). Typical practice is exposure 10 days in the unconnected state, followed by 10 days in the connected state. Users normally place requirements for verification of test severity based on mass gain of copper coupons per Standard B 810. Once widely used recommendation for mass gain is $15 \pm 3 \mu\text{g}/\text{cm}^2 \cdot \text{day}$.

6.11 *Method P*—This method is used to evaluate connectors for use in telephone equipment exposed to uncontrolled environments such as outdoor sheltered, semisealed enclosure (14). Typical practice is exposure 10 days in the unconnected state, followed by 10 days in the connected state. Users normally place requirements on test severity based on mass gain of copper coupons per Standard B 810. One widely used recommendation for mass gain is $45 \pm 9 \mu\text{m}/\text{cm}^2 \cdot \text{day}$.

6.12 *Method X*—The interested parties, for example, purchaser and supplier, may require a test different than any already defined. In such cases, the parties must agree upon values for all relevant parameters including those listed in Table 1.

7. Report

7.1 Reporting requirements are as per Practice B 827 unless otherwise stated by agreement between test specifier and test vendor or operator.

8. Keywords

8.1 accelerated test; air velocity; atmospheric corrosion; chlorine; connector; corrosion; corrosive gas testing; electrical contacts; environmental; humidity; hydrogen sulfide; mixed flowing gas; nitrogen dioxide; pollutant; reliability; sulfur; sulfur dioxide; tarnish; temperature; testing

REFERENCES

- (1) International Electrotechnical Commission, IEC Standard 68-2-42, *Basic Environmental Testing Procedures, Test K_e: Sulphur Dioxide Test for Contacts and Connections*, 1976.
- (2) International Electrotechnical Commission, IEC Standard 68-2-43, *Basic Environmental Testing Procedures, Test K_d: Hydrogen Sulfide Test for Contacts and Connections*, 1976.
- (3) International Electrotechnical Commission, IEC Technical Trend Document 68-2-60 TTD, *Environmental Testing, Corrosion Tests in Artificial Atmosphere at Very Low Concentration of Polluting Gas(es)*, 1989.
- (4) IEC 68-2-60 (second edition) *Environmental Testing—Part 2: Tests—tests Ke: Flowering mixed gas corrosion test*, 1995.
- (5) Abbott, W. H., "The Development and Performance Characteristics of Flowing Mixed Gas Test Environments," *IEEE Trans. CHMT*, vol. 11, no. 1, pp. 22-42, March 1988.
- (6) Currence, R., Reyes, W., and Sie, C., "Characterizing the Machine Internal Environment for Specifying and Testing Contact Materials," *Proceedings of the 19th Annual Connector and Interconnection Technology Symposium, September, 1986, Anaheim, California*, pp. 23-29, 1986.
- (7) Heinonen, R., Rakkolainen, J., Saarinen, T., and Aberg, M., "Nordic Project on Corrosion in Electronics-V: Atmospheric Corrosion in Electronics-A Comparative Study on Field and Laboratory Test Results of Various Electronic Contacts," *Proceedings of the Fourteenth International Conference on Electrical Contacts, June 20-24, 1988, Paris, France*, pp. 271-276, 1988.
- (8) Electronic Industries Association, EIA-364B-TP65 Mixed Industrial Gas Test Procedure, 1992.
- (9) Gore, R., Witska, R., Kirby, J. R., and Chao J., "Corrosive Gas Environmental Testing for Electrical Contacts," *IEEE Trans. CHMT*, vol. 13, no. 1, pp. 27-32, March 1990.
- (10) IBM Corporate Director of Standards. 2000 Purchase St., Purchase, NY 10577.
- (11) Cosack, U., "Survey of Corrosion Tests with Pollutant Gases and Their Relevance for Contact Materials," *Proceedings of the Thirteenth International Conference on Electrical Contacts, Sept. 15-19,*



- 1986, Lausanne, Switzerland, pp. 316–324, 1986.
- (12) Cosack, U., “Defending a Four-Gas Mixture with Low Concentrations as an IEC Standard,” *Provisional Information, Basis for the German Standards Proposal, Supplement to TTD IEC SC 50B (Central Office) 270, April 24, 1990*, pp. 1–6, 1990.
- (13) Persson, D., and Leygraft, C., “Analysis of Atmospheric Corrosion Products of Field Exposed Nickel,” *J. Electrochem. Soc.*, vol. 139, no. 8, pp. 2243–2249, August 1992.
- (14) Bellcore, Information Management Services Generic Requirements for Separable Electrical Connectors Used in Telecommunication Hardware, Bellcore TR-NWT-001217, Issue 1, September, 1992
Bellcore TA-NWT-000063, Issue 2, December 1991, Network Equipment-Building Systems (NEBS), Bellcore, Room 1B252, 60 New England Avenue, Piscataway, NJ 08854-4196, 1992.
- (15) Institute of Electrical and Electronics Engineers, Inc., IEEE P1156.1 Environmental Specifications for Computer Modules (Draft 4 June 10, 1992—unapproved), Item 7.7, 1992.
- (16) Turn, J. C., “Corrosion Behavior of Beryllium Copper in Simulated Industrial Environments,” *Corrosion 89, April 1989, NACE Meeting New Orleans, Louisiana*, p. Paper #337, Houston, TX: NACE, 1989.
- (17) “Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware,” Bellcore, GR 1217-Core, November 1995, Section 9.1.

BIBLIOGRAPHY

- (1) Vernon, W. H. J., and et al., “Laboratory Study of the Atmospheric Corrosion of Metals,” *Trans. Faraday Soc.*, vol. 27, p. 255, 1931.
- (2) Campbell, W. E., and Thomas, U. B., “Tarnish Studies: Electrolytic Reduction Method for the Accurate Analysis of Thin Films on Metal Surfaces,” *Transactions of the Electrochemical Society*, vol. 76, p. 303, 1939.
- (3) Ullsh, H., and Olmes, B., “Electrical Characteristics of Oxide Films on Copper Base Materials before Electrical Breakdown and Contact Resistance,” *Proceedings of the Engineering Seminar on Electrical Contacts—June 10–14, 1957, University Park, Pennsylvania*, p. Paper 2, 1957.
- (4) Lambert, R. H., and Trevoy, D. J., “Analysis of Films on Copper by Coulometric Reduction,” *J. Electrochem. Soc.*, vol. 105, no. 1, pp. 18–23, January 1958.
- (5) Blake, B. E., “Some Measurements of Contact Resistance in an Accelerating Atmosphere,” *Proceedings of the Engineering Seminar on Electrical Contacts—June 16–18, 1958, University Park, Pennsylvania*, p. Paper 4, 1958.
- (6) Antler, M., and Gilbert, J., “Effects of Air Pollution on Electric Contacts,” *Proceedings of the Engineering Seminar on Electrical Contacts—June 10–12, 1963, Orono, Maine*, p. Paper 8, 1963.
- (7) Blake, B. E., “Summary Report of the ASTM Section G Contact Field Tests,” *Proceedings of the Second International Research Symposium on Electrical Contact Phenomena, May 4–6, 1964, Graz, Austria*, pp. 531–544, 1964.
- (8) Chiarenzelli, R. V., “Air Pollution Effects on Contact Materials,” *Proceedings of the Engineering Seminar on Electrical Contacts—June 14–18, 1965, Orono, Maine*, pp. 63–102, 1965.
- (9) Campbell, W. E., “The Tarnishing of Silver and Copper,” *Proceedings of the Engineering Seminar on Electrical Contacts—June 14–18, 1965, Orono, Maine*, p. 341, 1965.
- (10) Chiarenzelli, R. V., “Tarnishing Studies on Contact Materials,” *Proceedings of the Third International Research Symposium on Electrical Contact Phenomena, June 6–10, 1966, Orono, Maine*, pp. 83–94, 1966.
- (11) Snowball, R. F., and Williamson, J. P. B., “The Ingress of Reactants between Contacting Surfaces,” *Proceedings of the Third International Research Symposium on Electrical Contact Phenomena, June 6–10, 1966, Orono, Maine*, pp. 377–384, 1966.
- (12) Stepke, E. T., “Electrical Conduction Processes through Very Thin Tarnish Films Grown on Copper,” *Proceedings of the Engineering Seminar on Electrical Contact Phenomena, November 6–9, 1967, Chicago, Illinois*, pp. 125–136, Chicago, IL: Illinois Institute of Technology, 1967.
- (13) Abbott, W. H., and Ogden, H. R., “The Influence of Environments on Tarnishing Reactions,” *Proceedings of the Fourth International Research Symposium on Electrical Contact Phenomena, July 15–18, 1968, Swansea, United Kingdom*, pp. 35–39, 1968.
- (14) Krumbein, S. J., “Corrosion through Porous Gold Plate,” *Proceedings of the Engineering Seminar on Electrical Contact Phenomena, November 11–15, 1968, Chicago, Illinois*, pp. 67–84, Chicago, IL: Illinois Institute of Technology, 1968.
- (15) Campbell, W. E., and Thomas, U. B., “Tarnishing and Contamination of Metals,” *Proceedings of the Engineering Seminar on Electrical Contact Phenomena, November 11–15, 1968, Chicago, Illinois*, pp. 233–266, Chicago, IL: Illinois Institute of Technology, 1968.
- (16) Abbott, W. H., “The Mechanism of Tarnishing of Precious Metal Contact Alloys,” *Electrical Contacts-1969. Proceedings of the Holm Seminar on Electrical Contacts*, pp. 1–6, Chicago, IL: Illinois Institute of Technology, 1969.
- (17) Kronenfels, W. V. V., “Tarnishing Films on Plated Gold Contacts from H₂S,” *Proceedings of the Fifth International Research Symposium on Electrical Contact Phenomena May 4–9, 1970, Munich, West Germany*, pp. 204–207, 1970.
- (18) Crossland, W. A., and Knight, E., “The Tarnishing Behaviour of Silver-Palladium Contact Surfaces and Its Relationship to the Accelerated Testing,” *Proceedings of the Fifth International Research Symposium on Electrical Contact Phenomena May 4–9, 1970, Munich, West Germany*, pp. 324–328, 1970.
- (19) Stocker, H., “Method to Determine Transient Resistance of a Contact with a Tarnishing Film,” *Proceedings of the Fifth International Research Symposium on Electrical Contact Phenomena May 4–9, 1970, Munich, West Germany*, pp. 338–341, 1970.
- (20) Dekany, I., “Distribution of Contact Resistance of Precious Metal Contacts with Different Tarnishing Films,” *Proceedings of the Fifth International Research Symposium on Electrical Contact Phenomena May 4–9, 1970, Munich, West Germany*, pp. 355–358, 1970.
- (21) Mollen, J. C., and Trzeciak, M. J., “Copper Films Field Exposure,” *Proceedings of the Sixteenth Holm Seminar on Electrical Contact Phenomena November 9–12, 1970, Chicago, Illinois*, pp. 37–44, 1970.
- (22) Campbell, W. E., “Reduction of the Rate of Film Formation on Silver and Brass by Purification of the Atmosphere,” *Proceedings of the Sixth International Conference on Electrical Contact Phenomena meeting in conjunction with the Eighteenth Holm Seminar on Electrical Contact Phenomena June 5–9, 1972, Chicago, Illinois*, pp. 185–194, 1972.
- (23) Graedel, T. E., “The Atmospheric Environments Encountered by Electrical Contacts,” *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, pp. 62–79, 1973.
- (24) Robbins, R. C., “Economic Effects of Air Pollution on Electrical Contacts,” *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, pp. 80–86, 1973.
- (25) Mano, K., “Studies of Environmental Test Methods of Electrical Contact in Japan,” *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, pp. 87–93, 1973.



- (26) Peytchev, L., Pantcheva, M., Moschekow, K., and Pindev, G., "Influence of Aggressive Factors on Some Contact Materials," *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, pp. 100–105, 1973.
- (27) Crossland, W. A., and Knight, E., "The Tarnishing of Silver-Palladium Surfaces and Its Effect on Contact Resistance in Low Energy Circuits," *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, pp. 248–264, 1973.
- (28) Crossland, W. A., Knight, E., and Wright C. R., "The Accelerated Tarnish Testing of Contacts and Connection Employing Silver Alloy Contacts," *Proceedings of the Nineteenth Holm Seminar on Electrical Contact Phenomena October 15–18, 1973, Chicago, Illinois*, p. 2 Illinois Institute of Technology, 1973.
- (29) Hobgood, L. D., and Lorenzen, J. A., "Environmental Monitoring Device," *US Patent 3847552*, November 1974.
- (30) Lindborg, U., and Lind, L., "Gold Electroplate, Porosity, Corrosion Behaviour and Bendability," *Proceedings of the Seventh International Symposium on Electrical Contact Phenomena June 5–9, 1972, Paris, France*, pp. 80–86, 1974.
- (31) Thibault, M., and Galand, J., "Corrosion Mechanisms of Coated Contacts," *Proceedings of the Seventh International Symposium on Electrical Contact Phenomena June 5–9, 1972, Paris France*, pp. 232–238, 1974.
- (32) Thibault, M., and Carbellerira, A., "Evaluation of Corrosion Behaviour of Connector Contacts," *Proceedings of the Seventh International Symposium on Electrical Contact Phenomena June 5–9, 1972, Paris, France*, pp. 239–244, 1974.
- (33) Potinecke, J., and Pechhold, E., "Influence of Aggressive Gases on Contact Surfaces," *Proceedings of the Seventh International Symposium on Electrical Contact Phenomena June 5–9, 1972, Paris, France*, pp. 245–249, 1974.
- (34) Kirchdorfer, J., "A Contribution to the Study of the Long Time Behaviour of Electrical Contacts in Industrial Atmospheres," *Proceedings of the Seventh International Symposium on Electrical Contact Phenomena June 5–9, Paris, France*, pp. 259–265, 1974.
- (35) Holm, R., "The Effect of Environment on Electrical Contacts: A Discussion at the 1973 Holm Seminar," *Proceedings of the Twentieth Holm Seminar on Electrical Contacts October 29–31, 1974, Chicago, Illinois*, p. 281, 1974.
- (36) Abbott, W. H., and Whitely, J. H., "The Lubrication and Environmental Protection of Alternatives to Gold for Electronic Connectors," *Proceedings of the Twenty-First Holm Seminar on Electrical Contacts October 14–16, 1975, Chicago, Illinois*, pp. 9–16, 1975.
- (37) Schiff, K. L., Harmsen, N., and Schnabl, R., "The Tarnishing Behavior of Gold-Base Alloys in Corrosive Atmospheres," *Proceedings of the Twenty-First Holm Seminar on Electrical Contacts October 14–16, 1975, Chicago, Illinois*, pp. 37–46, 1975.
- (38) Potinecke, J., "Behaviour of Contact Surfaces Consisting of Silver and Palladium Alloys in Hydrogen Sulfide Nitrous Oxide Sulfur Dioxide Atmospheres," *Proceedings of the Twenty-First Holm Seminar on Electrical Contacts October 14–16, 1975, Chicago, Illinois*, pp. 139–144, 1975.
- (39) Long, T. R., and Bradford, K. F., "Contact Resistance Behaviour of the 60 Palladium 40 Silver Alloy in Tarnishing Environments," *Proceedings of the Twenty-First Holm Seminar on Electrical Contacts, October 14–16, 1975, Chicago, Illinois*, pp. 145–154, 1975.
- (40) Lewis, N. E., Reed, C. W., DeCorpo, J. J., and Wyatt, J. R., "A Comparative Study of the Performance of Electrical Sliding Contact Lubricants in a Chemically Active Atmosphere," *Proceedings of the Twenty-First Holm Seminar on Electrical Contacts October 14–16, 1975, Chicago, Illinois*, pp. 155, 1975.
- (41) Lorenzen, J. A., "Environmental Monitoring Device for X-ray Determination of Atmospheric Chlorine, Reactive Sulfur and Sulfur Dioxide," *Adv. X-ray Analysis*, vol. 18, pp. 568–578, 1975.
- (42) Harmsen, N., "Spring-Hard Precious Metal Alloys with Good Tarnishing Behaviour for Electrical Contacts," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 69–74, 1976.
- (43) Kuczog, E., "Semiconducting Tarnish Films on Contact Metals," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 83–88, 1976.
- (44) Bresgen, H., "Reducing the Contact Resistance of Tarnish Layers on Silver by Means of an Oscillating Load," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 89–94, 1976.
- (45) Potinecke, J., "Behaviour of Contact Surfaces Consisting of Gold Alloys in Hydrogen Sulfide Nitrous Oxide Sulfur Dioxide Atmospheres," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 275–280, 1976.
- (46) Yamazaki, S., Nagayama, T., Kishimoto, Y., and Kanno, N., "Investigation of Contact Resistance of Open Contacts Covered by Ammonium Sulfate Film," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 281–286, 1976.
- (47) Hoft, H., "Reliability and Formation of Films on Switching Contacts," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 287–294, 1976.
- (48) Kirchdorfer, J., "A Contribution to the Study of the Long Time Behaviour of Electrical Contacts in Industrial Atmospheres-Part II," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 295–300, 1976.
- (49) Baker, R. G., "Accelerated Corrosion Testing of Electronic Components—A Developing Science," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 372–332, 1976.
- (50) Mayer, U., "Test Atmospheres for Electrical Contact Materials—Generation and Application," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 333–338, 1976.
- (51) Kishimoto, M., Ishino, M., Mitani, S., and Hiratsuka, Y., "Evaluation Method of Gold and Palladium Contacts in Environments Containing Sulfur Dioxide, Nitrous Oxide and Ammonia," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 339–346, 1976.
- (52) Nakamura, K., "A Method for Forced Environmental Test of Connectors in a Condition Combined Mechanical Shock and Hydrogen Sulfide Atmosphere," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 667–672, 1976.
- (53) Fujino, H., and Tomita, M., "Porosity Test of gold Plating Contacts and Evaluation Test of Connectors," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 699–704, 1976.
- (54) Antler, M., and Drozdowicz, M. H., "Gold Plated Contacts—The Relationship between Porosity and Contact Resistance on Elevated Temperature Aging," *Proceedings of the Eighth International Conference on Electrical Contact Phenomena August 22–26, 1976, Tokyo, Japan*, pp. 705–710, 1976.
- (55) Antler, M., Feder, M., Hornig, C. F., and Borland, J., "The Corrosion Behaviour of Single and Multiphase Tin-Nickel Alloy Electrodeposits," *Electrical Contacts-1976, Proceedings of the Twenty-Second Annual Holm Conference on Electrical Contacts*, pp. 33–40, Chicago, IL: Illinois Institute of Technology, 1976.
- (56) International Electrotechnical Commission, IEC Standard 68–2–42, Basic Environmental Testing Procedures, Test K_c: Sulphur Dioxide Test for Contacts and Connections, 1976.