

ISA Standard 71.04: Changes Required for Protection of Today's Process Control Equipment

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ABSTRACT

Corrosion-induced failures remain frequent in electronics products used in industrial environments. The International Society for Automation (ISA) Standard 71.04-1985 provides a classification system using corrosion (or reactivity) monitoring to determine the corrosive potential of an environment towards electronic equipment. Changes to electronic equipment mandated by the European Union directive 2002/95/EC "on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment" (RoHS) required the elimination of lead in electronic equipment. Recent research has shown that printed circuit boards made using lead-free materials can be more susceptible to corrosion than their tin/lead counterparts. Now even environments previously considered relatively benign concerning electronics corrosion are experiencing serious problems as a direct result of RoHS compliance.

With the passage of a number of RoHS regulations and the switch to lead-free finishes on printed circuit boards, many are now questioning whether this type of environmental monitoring is adequate. Reactivity monitoring now needs to provide a more complete environmental assessment than the monitoring techniques described in ISA Standard 71.04. This standard is long overdue for a major revision to address issues described for and since the implementation of RoHS. This paper will discuss changes that have been proposed for the current vision and what changes may be anticipated in future revisions.

INTRODUCTION

Ever since the pulp and paper industry began replacing pneumatic and hydraulic controls with computer control systems, the reliability of these electronic and electrical devices has been challenged by attack from corrosive gaseous contaminants present in the operating environment. In the context of electronic equipment, corrosion is defined as the deterioration of a base metal resulting from a reaction with its environment. More specifically, corrosive gases and water vapor coming into contact with a base metal result in the buildup of various chemical reaction products. As the chemical reactions continue, these corrosion products can form insulating layers on circuits which can lead to thermal failure or short-circuits. Pitting and metal loss can also occur.

Corrosion of metals is a chemical reaction caused (primarily) by attack of gaseous contaminants and is accelerated by heat and moisture. Rapid shifts in either temperature or humidity cause parts of circuits to fall below the dewpoint temperature, thereby facilitating condensation of contaminants. Relative humidity above 50% accelerates corrosion by forming conductive solutions on a small scale on electronic components. Microscopic pools of condensation then absorb contaminant gases to become electrolytes where crystal growth and electroplating occur. Above 80% RH, electronic corrosive damage will occur regardless of the levels of contamination.

STANDARDS FOR AIR QUALITY ASSESSMENT

To address these concerns and to protect multi-million dollar investments in new control systems, a 10-year study was performed by Battelle Laboratories underwritten by process control system manufacturers and by many of the major pulp and paper companies. The goal was to develop the information necessary to establish a correlation between electronic equipment reliability and environmental corrosion rates. This ultimately led to the publication of standard S71.04-1985: "Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants," by the Instrument Society of America (ISA, now known as the International Society of Automation) [1].

This document was followed in 1987 by the International Electrotechnical Commission (IEC) Standard, IEC 60654-4 (1987-07) "Operating Conditions for Industrial-Process Measurement and Control Equipment. Part 4: Corrosive and Erosive Influences" [2]. Japan's standard, JEIDA-29-1990, was revised in 1990 and published as the Japan

Electronic Industry Development Association's (JEIDA) "Standard for Operating Conditions of Industrial Computer Control System" [3]. The goal of all three standards was the same – correlate equipment reliability to levels of airborne corrosive contaminants.

ISA Standard 71.04-1985

Standard 71.04-1985, as it is known now, presents the manufacturers and users of electronic devices and computer control systems a classification system to gauge the corrosive potential of an environment. It establishes environmental classifications, and severity levels within each classification, according to the type of contaminant. Although the standard also includes classifications for liquid and solid contaminants, only gaseous contaminants will be considered in this paper.

This standard defines or characterizes environments in terms of their overall corrosion potential. By the use of "reactivity monitoring," a quantitative measure of this potential can be established. Reactivity monitoring involves placing specially prepared metal strips into the environment. These "corrosion classification coupons," or CCCs, would be exposed for a period of time and then analyzed to determine the thickness of the corrosion films that had formed. Copper reactivity was measured as the total corrosion film thickness (in angstroms) normalized to a 30-day exposure. This analysis technique allows for the classification of the total amount of corrosion, as well as the thicknesses individual corrosion films attributed to different classes of corrosive gases.

Four levels of corrosion severity have been established by Standard 71.04 (see TABLE I). The optimum severity level is G1 - Mild. At this level, corrosion is not a factor in determining equipment reliability. As the corrosive potential of an environment increases, the severity level may be classified as G2, G3 or GX (the most severe). The effects of humidity and temperature are also quantified in this standard. High or variable relative humidity and elevated temperatures may cause the acceleration of corrosion by gaseous contaminants. Relative humidity of less than 50 percent is specified by the standard.

TABLE I - ISA Classification of reactive environments

Severity Level	G1	G2	G3	GX		
	Mild	Moderate	Harsh	Severe		
Copper Reactivity Level (in angstroms, Å)*	< 300	< 1000	< 2000	2000		
The gas concentration levels shown below are provided for reference purposes. They are believed to approximate the Copper Reactivity Levels stated above, providing the relative humidity is less than 50%. For a given gas concentration, the Severity Level (and Copper Reactivity Level) can be expected to be increased by one level for each 10% increase in relative humidity above 50% or for a relative humidity rate of change greater than 6% per hour.						
Gas Concentrations (in ppb)						
	Contaminant	Gas	Concentration			
Reactive Species ^{†,‡}	Group A	H ₂ S	< 3	< 10	< 50	50
		SO ₂ , SO ₃	< 10	< 100	< 300	300
		Cl ₂	< 1	< 2	< 10	10
		NO _x	< 50	< 125	< 1250	1250
	Group B [§]	HF	< 1	< 2	< 10	10
		NH ₃	< 500	< 10,000	< 25,000	25,000
		O ₃	< 2	< 25	< 100	100

The synergistic effects of various combinations of corrosive gases make the determination of severity levels complex. In addition to the contaminant gases themselves, temperature and humidity also have a major impact on the corrosion rates. Therefore, the easiest method of measurement has been through the use of CCCs according to the method prescribed in the ISA standard. This data is used to determine the severity level of the environment which refers to the potential damage that corrosive gases could cause to electronics and electrical equipment and, therefore, provides a method for determining equipment reliability.

* Measured in angstroms after one month's exposure. See Appendix C, Item Numbers 2, 3.

† mm³/m³ (cubic millimeters per cubic meter) parts per billion average for test period for the gases in Groups A and B.

‡ The Group A contaminants often occur together and the reactivity levels include the synergistic effects of these contaminants.

§ The synergistic effects of Group B contaminants are not known at this time.

The standard actually describes two methods of environmental characterization – direct concentration monitoring and reactivity monitoring. However, the method most commonly used since the standard was published is reactivity monitoring. The standard provides instructions for the preparation, exposure, and analysis of copper reactivity samples.

This standard had been developed with the goal of uniformity of equipment reliability in the field of industrial process measurement and control instrumentation. However, to be of real value, this document cannot be static, but must be periodically reviewed and updated to incorporate changes as necessary to remain relevant as a tool for predicting equipment reliability.

CORROSION RESEARCH APPLICABLE TO STANDARD 71.04

Through the regular ISA review process, standards are subject to review at least once every five to seven years. These reviews are intended to address any comments and criticism as well as any advances in technology, which would enhance the standards application. In the twenty-five years since publication of S71.04, much research has been performed in the area of environmental classification via corrosion monitoring.

From the research performed in support of developing Standard 71.04 [4] and in research performed since its publication, it was discovered that one of the main limitations in using copper alone for environmental monitoring and assessment is that the presence or absence of environmental chlorine, a particularly damaging contaminant to metals, cannot be accurately determined. Silver, on the other hand, is extremely sensitive to chlorine. For this reason, silver coupons, in addition to copper coupons, have been used for almost since the standard was published to provide what is known to be a more accurate assessment of the corrosion potential of a local environment.

Corrosion Coupon Research [5,6,7]

Corrosion reported per Standard S701.04 is actually the sum of individual corrosion films. Depending upon the type of coupon used and the gases present, chloride, oxide, sulfide, and/or other films may be produced. Each coupon can be examined for the type of film present and its relative contribution to the total corrosion. When using electrolytic/cathodic reduction as an analysis technique, each individual film is dissolved, or “stripped away,” at its own unique electrochemical potential. Corrosion potentials have been determined for the various corrosion products which form of copper and silver. When standard S701.04 initially came up for review in 1990, new research was available and applicable for inclusion into the standard. Some of the more important work is summarized below.

Some of the main findings from this corrosion coupon research are listed below.

- Single gas corrosion levels did not agree with the corresponding copper reactivity levels put forth in the standard.
- The standard should be reviewed for inclusion of actual single gas corrosion levels for all severity levels and their use in setting the reactivity levels.
- Using the copper reactivity levels put forth in the standard, one could significantly overstate the corrosive potential of an environment when using gas concentrations as the sole determinant.
- The standard was shown not to be internally consistent with respect to the four main Group A contaminants.
- There was poor correlation with field-observed results.
- Copper corrosion was dominated by active sulfur contamination (e.g., H₂S) when present.
- While H₂S and NO₂ were not particularly corrosive by themselves, this combination produced more than four times the expected silver corrosion.

Initial testing only examined the total amount of corrosion formed on the coupons which was consistent with the reactivity monitoring described in the standard. Data was subsequently examined in terms of the individual corrosion films. Although electrochemical potentials have been determined for individual corrosion products when analyzed by electrolytic/cathodic reduction, the complex nature of gas interactions can produce some unknown films – even in a controlled laboratory environment. These unknown films, too, were used in the data described below.

- Examination of individual corrosion film data for copper and silver coupons further supported the assertion that one cannot accurately determine the corrosive potential of an environment when following the methodology in standard S701.04. The copper-only reactivity monitoring prescribed cannot conclusively determine the presence **or** absence of Cl₂ or SO₂. By reporting only copper corrosion, even with the breakdown of the individual films, one can and often does make incorrect assessments about the environment in question. The most obvious example of this is where some continue to attribute an unknown copper film to the presence of Cl₂.
- The assumption that an unknown copper film could be attributed solely to the presence of chlorine was proved false. Examination of silver corrosion results clearly showed only Cl₂ was present. All testing which included this contaminant produced a silver chloride (AgCl) corrosion film. With the standard giving Cl₂ the lowest tolerable concentration for a G1 environment, one must be able to accurately determine whether or not this contaminant is present or not.
- Total copper corrosion, and particularly copper sulfide film (Cu₂S) formation, is dominated by H₂S. This film was observed only when H₂S was present in the test environment. SO₂, by itself, produced only a copper oxide (Cu₂O) film. Therefore, the absence of Cu₂S does not indicate a sulfur-free environment. This, too, can be clarified by including silver coupons. Cu₂O, without silver sulfide (Ag₂S) confirms a sulfur-free environment.
- A single copper film was produced for only one contaminant – SO₂. This was an oxide film as opposed to a sulfide film. However, on silver, each single contaminant produced a single film and were the only instances where a single film was observed on silver. Except for SO₂, a single silver film can be associated with a specific contaminant and SO₂ can be speciated when copper and silver films are compared.

Corrosion Coupon Field Results

This and other research allowed for examination of field-exposed corrosion coupons. One of the main criticisms with reactivity monitoring has been that some were trying to read too much into what is actually only circumstantial evidence that corrosive gases are present in the subject environment. There have been only a few studies with side-by-side reactivity monitoring, gas concentration monitoring, and temperature and relative humidity monitoring. Some have tried to extrapolate contaminant gases and concentrations from the electrolytic reduction analysis alone. This has been shown to be inconclusive at best. However, examination of some large corrosion coupon databases has produced some interesting observations and conclusions.

- For both copper and silver coupons, single film formation was confined predominantly to G1 and G2 coupons. For the copper coupons almost all of these exhibited only Cu₂O. Examination of the corresponding silver data showed about a quarter of these exhibited only Ag₂S corrosion. These coupons were concluded to have been exposed to a SO₂-only environment.
- Within this group, some copper coupons exhibited no Cu₂S and were concluded to have been exposed in an SO₂-only environment. A few coupons similarly exhibited no Cu₂O and were concluded to have been exposed in H₂S-only environment.
- Of those silver coupons which showed no silver chloride, only one third of the corresponding copper coupons exhibited an unknown copper film. Conversely, about one third of all silver coupons, which did show silver chloride showed no corresponding unknown copper films. This further illustrates how one could mistakenly state the presence or absence of chlorine in the environment.

Standard 71.04 has been, and continues to be, a useful tool for characterizing the corrosive potential of an environment. However, many have acknowledged the shortcomings of the standard by using combination copper/silver corrosion classification coupons. New data for silver and gold (-plated) coupons established the need to review the standard for the applicability and reliability of copper-only environmental reactivity monitoring. By using copper and silver coupons for this monitoring, it has been shown that the subject environment can be more accurately characterized as to the severity class(es) and type(s) of contaminants present. Any remedial actions recommended as a result of this monitoring would be more concise, and consequently, less expensive. The addition of gold coupons provides even further definition of the subject environment.

Real-time Corrosion Monitoring

These inconsistencies and shortcomings, coupled with the time it takes to obtain results from reactivity monitoring using coupons, resulted in the development of real-time corrosion monitors using piezoelectric quartz crystal

microbalances (QCM) as sensors [8]. A QCM is plated with copper, silver, or other reactive metals and circuit is made incorporating an oscillator with the QCM so that the frequency at which the crystal is vibrating can be measured. As corrosion films are formed, the resonance frequency of the crystal changes. These changes can be correlated to the amount of corrosion which has built up over time.

Data from both laboratory and field-exposed copper and silver coupons produced close and reproducible correlation between the passive CCCs and the real-time QCMs because both methods involve the measurement of weight-gain caused by the buildup of corrosion films. The use of QCMs as corrosion monitors has been described in several studies [9,10].

Corrosion-Indicating Bridge (CIB). Another method of monitoring corrosion is to measure the increase in resistance of a metal film, accompanying a reduction in cross-sectional area by film growth. This type of measurement is limited by the sensitivity of the instrumentation. However, in practice, even very slight changes in temperature may produce resistance changes far greater than those due to corrosion alone. This technique appears valid; however, the maximum measurable film thickness still needs to be determined.

These real-time corrosion monitors – especially those using QCMs – have been improved since their introduction in the 1980s due to technology advances and the ability to make these devices smaller, more sensitive, and more reliable. More recently, these devices have been modified due to changes mandated by new environmental laws passed in Europe. These changes had nothing to do with product improvement; rather, they were required due to restrictions on the use of various substances in electronic products.

RoHS AND ELECTRONIC EQUIPMENT RELIABILITY

The European Union (EU) directive 2002/95/EC “on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment” or RoHS was implemented in July 2006 (EU 2003), and was the first of many RoHS (-like) regulations that have been passed [11]. One of the purposes of these regulations has been to restrict the use of hazardous substances in electrical and electronic equipment. The EU's RoHS Directive restricts the use of six substances in electrical and electronic equipment: mercury (Hg), lead (Pb), hexavalent chromium (Cr(VI)), cadmium (Cd), polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).

In order to comply with the EU legislation, all of these substances must either be removed, or must be reduced to within maximum permitted concentrations, in any products containing electrical or electronic components that will be sold within the EU. Manufacturers have made significant investments in new processes that will eliminate these substances – especially lead.

In February 2006, China promulgated a law entitled “Administration on the Control of Pollution Caused by Electronic Information Products.” The purpose of this law is similar to that of the EU's RoHS Directive and the Chinese law is simply called “China RoHS” in the industry. While there is some commonality between the RoHS requirements in the EU and those in China, there are also significant differences that must be recognized and dealt with. However, in both instances these RoHS regulations require the elimination of lead in electronic products and manufacturers have to comply with RoHS if they want to continue in to do business in the EU and China.

Unintended Consequences

A printed circuit board, or PCB, is used to mechanically support and electrically connect electronic components using conductive pathways, or traces, laminated onto a non-conductive substrate. Alternative names are printed wiring board (PWB), and etched wiring board. A PCB populated with electronic components is a printed circuit assembly (PCA), also known as a printed circuit board assembly.

All PCBs have conducting layers on their surface typically made of thin copper foil. If the copper is left unprotected, it will corrode and deteriorate. Traditionally, any exposed copper was plated with lead (-based) solder. Thus the main issue for the electronics industry became the use of lead in the manufacture of components and circuit board assemblies.

The hot air solder leveling (HASL) process worked well for many years, was the predominant surface finish used in the industry, and was also the cheapest PCB available. Now RoHS essentially makes PCBs using the HASL process

obsolete. Failure modes on other common lead-free PCB finishes such as organic solder preservative (OSP) and electroless-nickel immersion gold (ENIG) make these technologies undesirable. As a result, alternatives such as immersion silver (ImmAg) and organically coated copper (OCC) are currently used as board finishes. Due to inherent processing difficulties with OCC boards, ImmAg boards have become the standard PCB finish in the electronics industry [12].

ImmAg is easy to apply to the boards, relatively inexpensive, and usually performs well. While ENIG presently has a larger market share, since RoHS has been in effect, more ImmAg process lines have been installed in PCB facilities than any other finish. However, some manufacturers have complained about issues with corrosion which can lead to shorts and ultimate failure of the board.

RoHS AND ISA STANDARD 71.04

Research has shown that printed circuit boards made using lead-free materials can be more susceptible to corrosion than their tin/lead counterparts [13]. Two common chemical failure modes are copper creep corrosion on circuit boards and the corrosion of silver metallization in miniature surface-mounted components. Creep corrosion failures in high sulfur environments (ISA Class G2) have been reported on hard disk drives, graphic cards, DIMMs, and motherboards in many types of systems.

Corrosion-induced failures are frequent in electronics products used in industrial environments. Now electronics in environments previously considered benign with regards to corrosion are experiencing serious problems as a direct result of RoHS. Table II shows CCC data from a number of pulp and paper mills around the world that met the current definition of an ISA Class G1 environment but still experienced corrosion-related failures of RoHS-compliant electronics. The common factor for all these locations was that the corresponding silver reactivity rates averaged twice that of the copper rate with several locations showing silver corrosion 10-20 times higher.

Table II. Pulp and Paper Mill CCC Data [11]

Location	Area/Room	Cu ₂ S	Cu ₂ O	CuUnk	Copper Total	ISA Class	AgCl	Ag ₂ S	AgUnk	Silver Total
Austria	AHU Room	0	180	0	180	G1	0	3142	0	3142
	DCS Room	182	78	0	260	G1	0	3491	0	3491
	Electrical Room	115	46	0	161	G1	0	1582	0	1582
Brazil	Control Room	192	101	0	293	G1	0	1042	0	1042
	Operations Room	205	88	0	293	G1	0	1234	0	1234
	MCC	0	125	0	125	G1	0	948	0	948
China	DCS Room	182	104	0	286	G1	0	1022	0	1022
	Wet End Control	182	78	0	260	G1	0	1118	0	1118
	Computer Room	124	44	0	168	G1	0	5467	0	5467
Finland	DCS Cabinet	0	118	0	118	G1	0	1636	0	1636
	MCC	0	106	0	106	G1	0	2634	0	2634
	Control Room	0	150	0	150	G1	0	2796	0	2796
Holland	Mechanical Room	0	68	0	68	G1	0	2182	0	2182
	Server Room	0	78	0	78	G1	0	1964	0	1964
	Splicer Room	0	105	0	105	G1	0	1145	0	1145
Japan	Control Room	0	173	0	173	G1	0	1497	0	1497
	IPC Room	0	231	0	231	G1	0	2145	0	2145
	DCS Room	215	62	0	277	G1	0	1038	0	1038
Korea	DCS Panel	187	61	0	248	G1	0	1848	0	1848
	MCC Room	204	56	0	260	G1	0	1810	0	1810
	PLC Panel	102	50	0	160	G1	0	1155	0	1155
USA	Electrical Room	172	34	0	206	G1	35	1315	0	1340
	Wet End Drives	196	81	0	277	G1	0	1565	0	1565
	Control Room	175	86	0	261	G1	0	5073	0	5073

Data centers in many urban locations have reported failures of servers and hard disk drives due to sulfur corrosion. Desktop and laptop computers, servers, data communications (datacom) equipment and other information

technology (IT) equipment are now at risk due to RoHS. This is even being seen in personal computers and electronic devices.

Acidic (corrosive) gases and submicron particulates in urban environments come from motor vehicle exhaust, emissions from other forms of transportation, heat and power generation, and industrial activity. In electronic component corrosion, sulfur oxides, active sulfur compounds, and inorganic chlorides are of primary interest. Although most data centers are protected against temperature and humidity variations, particulates and acidic gases can be drawn in through the building's air handling system(s) causing corrosion of electronics – especially in equipment produced since the passage of RoHS regulations.

In one study that looked at lead-free finishes [14], four alternate PCB finishes were subjected to an accelerated mixed flowing gas corrosion test. Important findings can be summarized as follows:

- Immersion gold (ENIG) and immersion silver (ImmAg) surface finishes failed early in the testing. These coatings are the most susceptible to corrosion failures and may make the PCB the weak link with regards to the sensitivities of the electronic devices to corrosion.
- None of the coatings can be considered immune from failure in an ISA Class G3 environment.
- The gold and silver coatings could not be expected to survive a mid to high Class G2 environment based on these test results.

The increasing number of hardware failures in data centers high in sulfur-bearing gases, highlighted by the number of recent publications on the subject, led to the publication of a white paper on particulate and gaseous contamination [15] by ASHRAE Technical Committee 9.9: *Mission Critical Facilities, Technology Spaces, and Electronic Equipment* (ASHRAE 2009) recommending that gaseous contamination should be within the modified severity level G1 which meets:

1. A copper reactivity rate of less than 300 Å/month **and**
2. A silver reactivity rate of less than 300 Å/month.

The word “modified” is used because Standard 71.04 uses copper corrosion alone to determine severity levels and with the use of silver and/or silver alloys as a replacement for lead, it is felt by many that as mentioned in the studies cited above, copper alone cannot provide as complete a picture of the corrosion risk as when using copper and silver.

The use of new PCB surface finishes – especially ImmAg – and this new susceptibility of electronic equipment to environments previously considered benign has fostered a renewed interest in updating and improving ISA Standard 71.04 to protect RoHS-compliant products for use in both industrial and non-industrial settings.

PROPOSED CHANGES TO STANDARD 71.04

The primary consideration in updating the standard is incorporating silver as a quantifiable metric for corrosion risk assessment. ASHRAE Technical Committee 9.9 has recommended that both copper and silver corrosion rates be used with the higher of the two used to determine severity levels. Data is currently being by a number of organizations to validate the silver reactivity rate. This and other proposed changes to Standard 71.04 are highlighted below.

Title

Current: Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants

Proposed: *Environmental Conditions for Electronic Equipment: Airborne Contaminants*

Purpose

Current: The purpose of this standard is to classify airborne contaminants that may affect process measurement and control instruments.

The classification system provides users and manufacturers of instruments with a means of specifying the type and concentration of airborne contaminants to which a specified instrument may be exposed.

This document is one of a series of standards on environmental conditions for process measurement and control systems.

Proposed: *The purpose of this standard is to classify airborne contaminants that may affect electronic hardware such as process measurement and control equipment, as well as office electronic, networking and data center equipment.*

The classification system provides users and manufacturers of electronic hardware with a means of specifying the type and concentration of airborne contaminants to which a specified piece of electronic hardware may be exposed.

This document is one of a series of standards on environmental conditions for electronic equipment.

Scope

Current: §2.1 – This standard covers airborne contaminants and biological influences that affect industrial process measurement and control equipment. Specifications for other environmental conditions, including nuclear radiation and hazardous atmospheres, are beyond the scope of this standard.

Proposed: §2.1 – *This standard covers airborne contaminants and biological influences that affect industrial process measurement and control equipment, electronic office equipment, data centers, and network equipment. Specific examples of electronic office equipment include: laptop computers, desktop computers, workstations, servers, data storage hardware, terminals, displays, laser and inkjet printers, copiers, and faxes. Examples of data center equipment include: servers, switches, routers, displays, keyboards, data storage hardware, power distribution equipment, and climate control such as HVAC equipment. Some examples of networking equipment include telecommunications hardware, switches, and routers.*

§2.6 – CAUTION – Airborne or biological contaminants not listed in this document could cause equipment damage. Caution should be used when a combination of factors approach or surpass class "X." Obtaining the guidance of a chemical specialist is suggested when this condition occurs.

§2.6 – CAUTION – *It is possible that airborne contaminants not listed in this document could cause equipment damage. Caution should be used under this circumstance or when a combination of factors approach or surpass class "X". Obtaining the guidance of a chemical or biological specialist is suggested when this type of condition occurs.*

Table 3 – Classification of reactive environments – Terminology

Keep only the Severity Levels and Copper and Silver Reactivity Levels in the normative part of the standard and move the part of Table 3 referencing specific gases and concentrations to an informative appendix. This is for several primary reasons: 1) the stated gas concentrations and corresponding copper reactivity levels generally do not agree, 2) it has been generally agreed that a more reliable way to measure the potential for or the effects of corrosion is to monitor corrosion directly via reactivity monitoring, and 3) similar data does not currently exist for silver reactivity levels.

Section 6.1 - Reactivity

Recommended changes to this include the inclusion of silver reactivity monitoring as a metric along with copper. The silver coupons will be used primarily for their ability to discern chlorine in the subject environment.

- It has been suggested that comparing the reaction rates between these metals can infer influences of relative humidity and that this information be included as part of an informational appendix. Another appendix section is proposed to provide further insight as to possible effects relative humidity may have on the corrosion kinetics experienced.
- One recommendation is that the four severity levels described in Table 3 be expanded to five levels, in each of two corrosion reactivity groups. These two groups would be used to indicate whether or not chlorine had detected through silver film analysis.

- The concentration levels of individual gases currently in Table 3 that contribute to these reactivity rates will be moved to a new table in an informative appendix. Because no data exist correlating all possible contaminant of contaminant concentration combinations or the effects of temperature and relative humidity, this table would be included as an aid in understanding the complexities involved in direct gas concentration monitoring. This new table is described more fully in the following sections.
- A final appendix section is proposed, which will offer some idea of the reduction in mean time between failures (MTBF) when equipment is continuously exposed to contaminants at various severity levels.

Section 6.2.1 – Relative Humidity

This section will be reworded for clarity and correctness. It will also include a reference to the appropriate sections of the appendix pertaining to relative humidity.

It is known that the presence or absence of free moisture may accelerate or attenuate the corrosion reaction. A proposal has been offered which correlates the ratio of the silver sulfide/cult of copper sulfide components to humidity effects. These effects are described as low humidity attenuation, high humidity acceleration, or no humidity effects. This is represented in Table III below.

Table III – Humidity Effects Corresponding to Silver Sulfide/Copper Sulfide Ratios

Ag ₂ S/Cu ₂ S Ratio	Effect
≤0.5	High humidity acceleration (HHA)
>0.5 and <1.5	No humidity effects (NHE)
≥1.5	Low humidity attenuation (LHA)

Section 6.3 – Explanation of Contaminant Severity Levels

Two additional corrosion reactivity groups have been proposed, which are differentiated by the absence or presence of reactive chlorides in the reduced silver films. These two reactivity groups would be designated as the primary sulfide group (GS), no silver chloride formed, and the chloride containing group (GC), were silver chloride is present.

If these new groups are accepted, one additional severity level may be considered. The former G1, G2, and G3 levels would remain the same as Mild, Moderate, and Harsh, respectively. The current GX – Severe level would be redesignated as G4 – Severe and the new fifth level would be GX – Extreme. This new level would be defined as an environment in which the operation of process and control equipment is not practical. Attempt to do so would result in immediate catastrophic failure.

Section 7 – Biological influences

Remove this section and all references to “living” contaminants altogether.

New Appendix – Reduction of Mean Time Between Failure by Severity Level

Mean time between failure, or MTBF, is a measure of the time interval expected between faults from a representative sampling of like components or systems. One proposed addition to an appendix is shown in the second of two tables below.

Table IV – Reduction of MTBF

ISA Severity Class	Percent Reduction
G1	None
G2	<25
G3	<50
G4	<75
GX	≥75

STATUS OF 71.04 REVISION

A final draft of the proposed revisions to Standard 71.04 is being prepared and will be discussed in the S71 Committee. Once approved, it will be submitted to the ISA Standards and Practices Board for consideration for public review. Many comments, concerns, criticisms, etc. are anticipated due to the wide acceptance of the standard in the processing control industry and a keen interest exhibited in the preparation of the draft revision. All written reviews will be addressed by the committee and any changes (additions or deletions) agreed upon by all parties. Once this has been accomplished, the standard will be submitted to the ISA for publication.

FUTURE ACTIVITY FOR STANDARD 71.04

Corrosion Classification Database

A corrosion classification database will be established and maintained by the ISA. This database will be set up with data from paired copper and silver coupons** exposed in both industrial and non-industrial environments with an indication of whether the equipment in the spaces monitored are RoHS-compliant. Solicitations are being made for contribution to this database which by some accounts can consist of data from more than 70,000 pairs of coupons. Over 4,000 of these pairs also have a corresponding gold coupon in anticipation that gold coupons may one day be used along with copper and silver.

One of the main uses of this database is to establish and refine silver reactivity levels. The prevailing use of silver maintains the same corrosion rates and severity levels as for copper coupons with the overall severity being determined by the higher of the two. Because the mechanisms of copper and silver corrosion are different, statistical analysis may lead to reformulation of these levels. At the very least, it is expected that review of this data will reveal as of yet undiscovered trends with her between the different severity classes and coupon types.

Gold Pore Corrosion Monitoring

Some are using gold-plated corrosion classification coupons in addition to copper and silver coupons. This type of corrosion monitoring has been examined by a number of organizations but little progress had been made in the development of a “visual” gold coupon standards and work has apparently stalled.

Real-Time Corrosion Monitoring.

Whereas reactivity monitoring with CCCs may require exposure times of between 30 and 90 days before analysis and reporting, electronic corrosion monitors capable of producing useful data almost immediately have been developed and are being used in good success. The dominant monitor type on the market employs copper and silver-plated quartz crystal microbalances (QCM) and have supporting data published that correlates weight gain on the crystal caused by the build-up of corrosion products to changes in crystal frequency, which in turn is correlated to corrosion film thicknesses. Good reproducibility of results has been demonstrated with this real-time monitor and side-by-side comparisons of this methodology with both copper and silver coupon reactivity monitoring have shown a high degree of correlation. QCM-based corrosion monitoring will be proposed for inclusion into the next revision of the standard.

CONCLUSIONS

Whereas silver reactivity monitoring has been accepted as necessary for a number of years, and will be included in the next revision of ISA Standard 71.04, it is real-time corrosion monitoring that has been deemed as vital by many in the process control industries. When this form of reactivity monitoring is incorporated into the Standard and gains even wider acceptance, reactivity monitoring with metal coupons appears to be headed for ancillary role as opposed to its current everyday status. Although the real-time monitors will allow instant access to corrosion data, these devices currently have some shortcomings when compared to coupon monitoring. The main trade-off is that corrosion is reported only in terms of total corrosion. Specific corrosion films cannot be determined without destructive testing of the QCM sensors.

** By paired coupons and is meant a copper and silver coupon exposed simultaneously in a subject environment for an equal period of time.

SUMMARY

The passage of various “lead-free” regulations has resulted in a significant up-tick of corrosion-related failures of new compliant electronic equipment. This is true for industrial application but even more so in non-industrial applications which would have been considered benign had it not been for RoHS

Although having been accepted and in wide use, without revision, for more than 30 years, ISA Standard 71.04 is in need of major revisions to incorporate the use of silver reactivity monitoring as a metric and to take advantage of technology advances in real-time corrosion monitoring. Through the regular ISA standard review processes, the findings described above, and ongoing research, significant changes have been proposed for standard S701.04.

From the examination of the available corrosion film data for copper and silver components, it is apparent that one cannot accurately determine the corrosive potential of an environment when following the current methodology of Standard 701.04. Specifically, copper-only reactivity monitoring will not or cannot conclusively determine the presence or absence of environmental chlorine or sulfur oxides. By reporting only copper corrosion, even with a breakdown of the individual films, one can and often does make an incorrect assessment of the environment in question.

While CCCs are good for the measurement of average corrosion rates, they do not allow for the measurement of any variations that may have occurred during the exposure period. It is possible that all of the corrosion occurred on a single day due to a chemical leak, spill, or some other upset condition common in the process industries. Therefore, the ability to measure the short-term variations lasting several hours or days is desirable. Short and long-term corrosion rate information, both incremental and cumulative is useful in predicting long-term equipment reliability. The development of real-time corrosion monitors measuring both cumulative and incremental corrosion has eliminated these limitations associated with corrosion classification coupons.

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