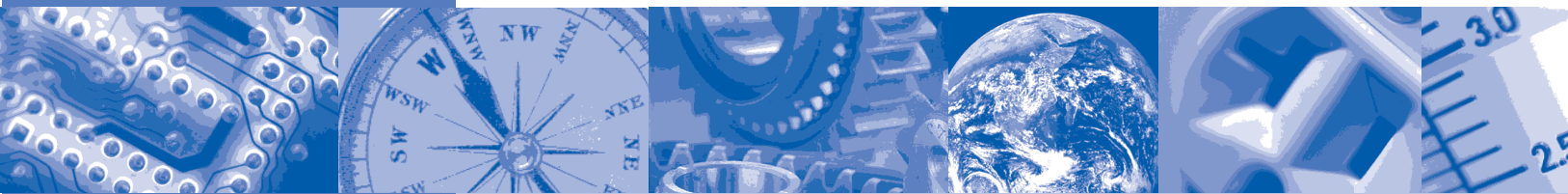


STANDARD

## **ISA-71.04-1985**

Formerly ISA-S71.04-1985



# **Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants**



**ISA—The Instrumentation,  
Systems, and  
Automation Society**

**Approved 3 February 1986**

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Airborne Contaminants

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## Preface

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This preface is included for informational purposes and is not part of ISA-71.04-1985.

This standard has been prepared as part of the service in the ISA toward a goal of uniformity in the field of instrumentation. To be of real value, this document should not be static, but should be subject to periodic review. Toward this end, the Society welcomes all comments and criticisms, and asks that they be addressed to the Secretary, Standards and Practices Board, ISA, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, NC 27709, Telephone (919) 549-8411, e-mail: standards@isa.org.

The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to U.S.A. users of ISA standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Toward this end, this Department will endeavor to introduce SI-acceptable metric units in all new and revised standards to the greatest extent possible. *The Metric Practice Guide*, which has been published by the Institute of Electrical and Electronics Engineers as ANSI/IEEE Std. 268-1982, and future revisions will be the reference guide for definitions, symbols, abbreviations, and conversion factors.

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The information contained in the preface, footnotes, and appendices is included for information only and is not a part of the standard.

This document is one of several standards covering various environmental conditions affecting process measurement and control systems. In developing this standard, the committee goals included the following:

- 1) To provide a practical standard that can be applied with a minimum of research and technical effort by the user.
- 2) To provide a concise method of stating environmental classifications for convenient communication between users of the standard.
- 3) To cover real-world ranges of each classified parameter.

This standard is limited to airborne contaminants and biological influences only, covering contamination influences that affect industrial process measurement and control systems.

The persons listed below served as members of ISA Committee SP71, which prepared this standard.

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## 1 Purpose

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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.

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## 2 Scope

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**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.

**2.2** This standard establishes airborne contaminant classes for fixed (non-mobile) installations during normal operation (nonemergency conditions) or during transportation and storage.

**2.3** The classes of environmental conditions stated in this standard are suitable for use in activities related to process instrumentation, including design, manufacturing, sales, installation, test, use, and maintenance. These classes may also be used as a guide when establishing requirements for environmental control of buildings or other protective housings for industrial process measurement and control systems.

**2.4** These classifications pertain only to the environment external to the equipment which may affect the equipment externally or internally.

**2.5** The effects of environmental conditions on safety, comfort, and performance of operating and maintenance personnel are not considered in this standard.

**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.

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## 3 Introduction

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**3.1** Environmental classifications have been established according to the type of contaminant. Within each classification, severity levels have also been established. Parameter limit values are tabulated for each classification and severity level of the contaminant. The classification consists of a class contaminant letter followed by a severity identification numeral.

**3.2** Some of these contaminants may appear in more than one form: i.e., gas, liquid, or solid. For the purpose of this document, a particular contaminant will be classified in the form in which it most often exists under ambient conditions.

**3.3** The user or equipment manufacturer should specify the equipment performance in the stated environmental class and severity level. It is possible to specify several sets of contaminant classes and severity levels for the same equipment.

**3.4** Chemical/temperature effects may cause the rates of destructive chemical reactions to more than double for every 10°C increase in temperature.

**3.5** High or variable relative humidity and contaminant mixtures may accelerate corrosive effects. These concerns are addressed in Section 6 and Table 3.

**3.6** Contaminants are listed as Class A, Class B, etc., or as Special Class X with increasing Severity Levels 1, 2, 3, and X.

The contaminants are listed with a prefix of "L" for liquid, "G" for gas, and "S" for solids.

An example of table usage would be:

### EXAMPLE

Suitable to operate for normal life in the following Airborne Contaminant Severity Levels:

	Contaminant	Concentration	Reference	
			Class/ Severity	Table No.
Liquids:	Trichloroethylene	<5 µg/kg	LA2	1
	Oils	<100 µg/kg	LB3	1
	Sea salt mist	Within 0.5 km inland	LC2	1
Solids:	Particle size	Concentration level		
	>1 mm	<1000 µg/m <sup>3</sup>	SA1	2
	100 to 1000 µm	<3000 µg/m <sup>3</sup>	SB2	2
	1 to 100 µm	<350 µg/m <sup>3</sup>	SC3	2
	<1 µm	<350 µg/m <sup>3</sup>	SD3	2
Gases:	Harsh: >2000 angstroms film formation on exposed copper coupon after one month exposure		G3	3



## 4 Airborne contaminants — liquids

(Refer to Table 1)

**4.1 Liquids** — This refers to liquids that will corrode unprotected equipment. They are transported to the equipment by condensation, rain, splashing liquids, or cleaning fluids sprayed from hoses. The majority of these are not classified, but should be specified to the manufacturers of equipment by special classification *LX*.

**4.2 Vapors** — Solvents sometimes occur as vapors, which may condense and form puddles that become corrosive to instruments and controls.

**4.3 Aerosols** — Aerosols are liquids carried in gas or air in the form of small droplets generating mists.

Aerosols can vary in composition and are a major source of chemical contamination to equipment.

**4.4 Sea salt mist** (Refer to Table 1)

Example: Class LC1: Inland more than 0.5 km from shore  
 Class LC2: Inland less than 0.5 km from shore  
 Class LC3: Offshore installations (oil rigs, etc.)

**4.5 General examples** (Refer to Table 1)

Contaminant	Contaminant Classes
Trichloroethylene	LA2
Oils (engine rooms, compressor station)	LB1
Specials (contaminant must be specified)	LX3

**Table 1 — Classification of chemically active contaminants: liquid aerosols (measured in  $\mu\text{g}/\text{kg}$  except as specified)**

		Severity Level 1	Severity Level 2	Severity Level 3	Severity Level X (special)
Contaminant	Class	Value	Value	Value	Value
Vapors*	LA	< 1.0	< 5.0	< 20.0	$\geq$ 20.0
Oils	LB	< 5.0	< 50.0	< 100.0	$\geq$ 100.0
Sea salt mist	LC	More than 0.5 km inland	Within 0.5 km inland	Offshore installation	T.B.S.
Special	T.B.S.	LX	T.B.S.	T.B.S.	T.B.S.

\*For example, trichloroethylene ( $\text{CHCl}_2\text{CCl}_2$ )

**NOTES:**  $1.0 \mu\text{g}/\text{kg} = 1.0$  part per billion ( $\text{p}/10^9$ )

T.B.S. = To Be Specified

< is defined as "less than"

> is defined as "more than"

$\geq$  is defined as "greater than or equal to"

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## 5 Airborne contaminants — solids

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(Refer to Table 2)

### 5.1 General

Dust is a universal contaminant and is a cause of environmentally induced equipment failures. Failure modes may be mechanical, chemical, electrical, thermal, or magnetic. To maximize equipment reliability and life, every effort should be made to minimize exposure to airborne particulates. The sensitivity of control equipment to different types of particulates varies widely. Some of the major effects are discussed in Section 5.2. Specifications should include a description of these characteristic types of particulates if they are relevant. Particle size and concentration classifications are given in Table 2.

### 5.2 Particulate properties that affect equipment

**5.2.1 Magnetic permeability** — Magnetically permeable substances can accumulate in magnetic fields; for example, the movement of forcecoils or galvanometer movements can be severely restricted or entirely demobilized by magnetic substances accumulating in air gaps of the permanent magnets. Likewise, electrical motors can be seriously damaged by magnetic materials accumulating between rotor and stator.

**5.2.2 Thermal conductivity** — The thermal insulating properties of some solid particles can cause overheating of cooling systems (which become insulated by surface deposits of these substances). For example, the cooling fins of power electronics can be seriously insulated by textile fibers.

**5.2.3 Electrical conductivity** — Solid substances are divided into two groups, the good electrical conductors and the highly insulating substances.

Electrical conductors — such as metals, carbon blacks, and coal dusts — can cause short circuits when settling between terminals.

Insulating substances can accumulate static charges that upset the functioning of computers and integrated circuits. Some insulators adsorb moisture under conditions of high relative humidity. This causes an increase in conductivity and can result in equipment failures due to electrical leakage.

**5.2.4 Adhesiveness** — This characteristic causes a contaminant to adhere to and accumulate on surfaces. This intensifies undesirable effects such as thermal insulation, high voltage discharge, and bearing failures. Adhesive qualities may be inherent to the contaminant, such as tobacco smoke, which contains sticky tars.

**5.2.5 Chemical** — Airborne particulate matter varies from hard crystalline structures such as metallic ores to soft porous structures such as atmospheric dust, fly ash, and smoke. Porous particles with sizes less than one micrometer may adsorb gaseous contaminants and moisture. This can cause equipment failure due to accelerated corrosion.

**5.2.6 Abrasiveness** — Abrasiveness is a significant factor in mechanical erosion by high velocity solid contaminants. It also contributes to the accelerated wear of moving parts.

### 5.3 Explanation of Table 2

Solid particulates are classified by size. The environment should be described in terms of concentration severity level for each class, Classes SA through SD.

**Table 2 — Classification of airborne particulates**

Particle Size	Class	Severity Level (Concentration measured in $\mu\text{g}/\text{m}^3$ )			
		1	2	3	X
> 1 mm	SA	< 1000	< 5000	< 10 000	$\geq$ 10 000
100 $\mu\text{m}$ to 1000 $\mu\text{m}$	SB	< 500	< 3000	< 5000	$\geq$ 5000
1 $\mu\text{m}$ to 100 $\mu\text{m}$	SC	< 70	< 200	< 350	$\geq$ 350
< 1 $\mu\text{m}$	SD	< 70	< 200	< 350	$\geq$ 350

**Notes:**  $\mu\text{m}$  = micrometer = 0.001 millimeter  
 $\mu\text{m}/\text{m}^3$  = micrograms per cubic meter

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## 6 Airborne contaminants — gases

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(Refer to Table 3)

### 6.1 Reactivity

Two methods have been used for environmental characterization. One is a direct measure of selected gaseous air pollutants. The other, which can be termed "reactivity monitoring," provides a quantitative measure of the overall corrosion potential of an environment.

Pollution analysis may provide short-term estimates for specific sites. High values will confirm that a severe environment exists. The reverse, however, is not necessarily true. Industrial environments may contain a complex mixture of contaminants that interact to greatly accelerate (or retard) the corrosive action of individual gas species.

To avoid these practical difficulties, the nature of industrial environments is defined in terms of the rate at which they react with copper. As a direct measure of overall corrosion potential, reactivity monitoring involves the placement of specially prepared copper coupons in the operating environments. Copper has been selected as the coupon material because data exists which correlates copper film formation with reactive (corrosive) environments. It has proven to be particularly useful for environmental characterization. Analyses may consist of measurements of film thickness, film chemistry, or weight loss. Sensitivity of reported techniques is well within the range required for meaningful application data.

Four levels of corrosion severity are established in Table 3. Concentration levels of some gases that contribute to these reactivity rates are also cited.

### 6.2 Contamination effects

Each site may have different combinations and concentration levels of corrosive gaseous contaminants. Performance degradation can occur rapidly or over many years, depending on the particular concentration levels and combinations present at a site. The following paragraphs describe how various pollutants contribute to equipment performance degradation.

### 6.2.1 Relative humidity

High relative humidity accelerates the corrosion caused by gaseous contaminants in an exponential manner. Equally important is the recognition of the fact that temperature fluctuations dramatically affect relative humidity and often induce local condensation. Although water is universally present in industrial atmospheres, the concentration varies widely. It promotes the corrosive degradation of equipment in the three major ways described below.

- 1) Directly, as a reactive chemical attacking metals and plastics.
- 2) Interactively with other atmospheric constituents, in most cases forming a more reactive combination. An example of this is sulfur dioxide,  $\text{SO}_2$ , which combines with water to form sulfurous acid.
- 3) Electrochemically: Many species when dissolved in water form a conductive solution. When electric potential differences exist between two dissimilar metals, the conditions for electrolytic or galvanic corrosion processes are set up. These are different phenomena, but both are caused by and/or promoted by an electrolyte.

### 6.2.2 Inorganic chlorine compounds (expressed as $\text{Cl}_2$ in Table 3)

This group includes chlorine, chlorine dioxide, hydrogen chloride, etc., and reactivity will depend upon the specific gas composition. In the presence of moisture, these gases generate chloride ions which react readily with the copper, tin, silver, and iron alloys. These reactions are significant even when the gases are present at low parts per billion levels. For example, the corrosivity of air containing 1 part per billion of chlorine would probably place that environment in the "Moderate" Class G2 category described in 6.3.2. A concentration of 10 parts per billion would probably increase the severity level to Class G3 or GX. These reactions are attenuated in dry atmospheres. At higher concentrations, many elastomers and some plastics are oxidized by exposure to chlorinated gases. Particular care must be given to equipment which is exposed to atmospheres which contain chlorinated contaminants. Sources of chloride ions, such as cleaning compounds and cooling tower vapors, etc., should be considered when classifying industrial environments. They are seldom absent in major installations.

### 6.2.3 Active sulfur compounds (expressed as $\text{H}_2\text{S}$ in Table 3)

This group includes hydrogen sulfide, elemental sulfur, and organic sulfur compounds such as the mercaptans. When present at low parts per billion levels, they rapidly attack copper, silver, aluminum, and iron alloys. The presence of moisture and small amounts of inorganic chlorine compounds greatly accelerates sulfide corrosion. Note, however, that attack still occurs in low relative humidity environments. Active sulfurs rank with inorganic chlorides as the predominant cause of atmospheric corrosion in the process industries.

### 6.2.4 Sulfur oxides (expressed as $\text{SO}_2$ and $\text{SO}_3$ in Table 3)

Oxidized forms of sulfur ( $\text{SO}_2$ ,  $\text{SO}_3$ ) are generated as combustion products of sulfur-bearing fossil fuels. Low parts per billion levels of sulfur oxides can passivate reactive metals and thus retard corrosion. At higher levels they attack certain types of masonry, metals, elastomers, and plastics. The reaction with masonry and metals normally occurs when these gases dissolve in water to form sulfurous and sulfuric acid.

### 6.2.5 Nitrogen oxides (expressed as $\text{NO}_x$ in Table 3)

$\text{NO}_x$  compounds ( $\text{NO}$ ,  $\text{NO}_2$ ,  $\text{N}_2\text{O}_4$ ) are formed as combustion products of fossil fuels and have a critical role in the formation of ozone in the atmosphere. They are also believed to have a catalytic effect on corrosion of base metals by chlorides and sulfides. In the presence of moisture, some of these gases form nitric acid which, in turn, attacks most common materials.

### **6.2.6 Hydrogen fluoride (expressed as HF in Table 3)**

This compound is a member of the halogen family and reacts like inorganic chloride compounds.

### **6.2.7 Ammonia and derivatives (expressed as NH<sub>3</sub> in Table 3)**

Reduced forms of nitrogen (ammonia, amines, ammonium ions) occur mainly in fertilizer plants, agricultural applications, and chemical plants. Copper and copper alloys are particularly susceptible to corrosion in ammonia environments.

### **6.2.8 Photochemical species (expressed as O<sub>3</sub> in Table 3)**

The atmosphere contains a wide variety of unstable, reactive species which are formed by the reaction of sunlight with moisture and other atmospheric constituents. Some have lifetimes measured in fractions of a second as they participate in rapid chain reactions. In addition to ozone, a list of examples would include the hydroxyl radical as well as radicals of hydrocarbons, oxygenated hydrocarbons, nitrogen oxides, sulfur oxides, and water. Because of the transient nature of most of these species, their primary effect is on outdoor installations and enclosures. In general, plastics and elastomers are more susceptible than metals to photochemical effects.

### **6.2.9 Strong oxidants**

This includes ozone plus certain chlorinated gases (chlorine, chlorine dioxide). Ozone (O<sub>3</sub>) is an unstable form of oxygen which is formed from diatomic oxygen by electrical discharge or by solar radiation in the atmosphere. These gases are powerful bleaching and oxidizing agents. They attack the surface of many elastomers and plastics. Photochemical oxidation — the combined effect of oxidants and ultraviolet light (sunlight) — is particularly potent. Ozone may also function as a catalyst in sulfide and chloride corrosion of metals, but its precise role is unclear.

## **6.3 Explanation of contaminant severity levels**

There is a broad distribution of contaminant concentrations and reactivity levels existing within industries using process measurement and control equipment. Some environments are severely corrosive, while others are mild.

The purpose of the contaminant classes is to define environments on the basis of corrosion rate of oxygen-free high conductivity copper, which is prepared and tested as described in Appendix C.

### **6.3.1 Severity level G1**

Mild — An environment sufficiently well-controlled such that corrosion is not a factor in determining equipment reliability.

### **6.3.2 Severity level G2**

Moderate — An environment in which the effects of corrosion are measurable and may be a factor in determining equipment reliability.

### **6.3.3 Severity level G3**

Harsh — An environment in which there is a high probability that corrosive attack will occur. These harsh levels should prompt further evaluation resulting in environmental controls or specially designed and packaged equipment.

### **6.3.4 Severity level GX**

Severe — An environment in which only specially designed and packaged equipment would be expected to survive. Specifications for equipment in this class are a matter of negotiation between user and supplier.

## 7 Biological influences

### 7.1 Biological influences

Flora and fauna are important constituents of the environment in which industrial process measurement and control equipment is expected to function properly. Usually a tropical climate has more living contaminants, but other climates can have similar problems.

For example, insects can cause unexpected shutdowns of pneumatic equipment by blocking off all breather openings with a clay-like cement which they use to form their nests. Also, insulating material is often subject to damage by cockroaches and rodents, etc., which simply remove the insulation by nibbling it off the wires. The accumulation of fungi, molds, dead animals, or insects can cause mechanical, electrical, or thermal equipment failures.

The subject of "flora and fauna" is a general classification for plant growth and animal (insect) life and is not specific enough to be useful. Therefore, any plant growth or animal life which may affect equipment performance should be considered.

**Table 3 — Classification of reactive environments Terminology– Terminology**

Severity Level	G1 Mild	G2 Moderate	G3 Harsh	GX Severe		
Copper Reactivity Level (in angstroms)*	< 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 Concentration †						
Contaminant	Gas	Concentration				
Reactive Species †,‡	Group A	H <sub>2</sub> S	< 3	< 10	< 50	≥ 50
		SO <sub>2</sub> , SO <sub>3</sub>	< 10	< 100	< 300	≥ 300
		Cl <sub>2</sub>	< 1	< 2	< 10	≥ 10
	Group B§	NO <sub>x</sub>	< 50	< 125	< 1250	≥ 1250
		HF	< 1	< 2	< 10	≥ 10
		NH <sub>3</sub>	< 500	< 10 000	< 25 000	≥ 25 000
	O <sub>3</sub>	< 2	< 25	< 100	≥ 100	

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

†mm<sup>3</sup>/m<sup>3</sup> (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.

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## Appendix A — Terminology

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**Corrosion** — Deterioration of a substance (usually a metal) because of a reaction with its environment.

**Contaminant** — That which contaminates to make impure or corrupt by contact or mixing.

**Electrochemical corrosion** — Corrosion of metal caused by current flowing through an electrolyte between anode and cathode areas.

**Erosion** — Deterioration by the abrasive action of fluids, usually accelerated by the presence of solid particles in suspension.

**Halide** — Compound containing fluorine, bromine, chlorine, or iodine.

**Halogen** — Bromine, chlorine, fluorine, or iodine.

**Hygroscopic** — Having a tendency to absorb water.

**Oxidation** — Loss of electrons by a constituent of a chemical reaction.

**Oxide** — Chemical compound of an element, usually metal, with oxygen.

**Reduction** — Gain of electrons by a constituent of a chemical reaction.





## Appendix B — Section 1: Some common sources of reactive environmental constituents

Category	Symbol	Constituent	Some Common Sources
Gas	H <sub>2</sub> S	Hydrogen sulfide	Geothermal emissions, microbiological activities, fossil fuel processing, wood pulping, sewage treatment, combustion of fossil fuel, auto emissions, ore smelting, sulfuric acid manufacture
Gas	SO <sub>2</sub> , SO <sub>3</sub>	Sulfur dioxide	Combustion of fossil fuel, auto emissions, ore smelting, sulfuric acid manufacture, tobacco smoke
Gas	S <sub>8</sub> , R-SH	Mercaptans	Foundries, sulfur manufacture
Gas	HF	Hydrogen fluoride	Fertilizer manufacture, aluminium manufacture, ceramics manufacture, steel manufacture, electronics device manufacture, fossil fuel
Gas	NO <sub>x</sub>	Oxides of nitrogen	Automobile emissions, fossil fuel combustion, microbes, chemical industry
Gas	N <sub>2</sub>	Active organic nitrogen	Automobile emissions, animal waste, vegetable combustion, sewage, wood pulping
Gas	NH <sub>3</sub>	Ammonia	Microbes, sewage, fertilizer manufacture, geothermal steam, refrigeration equipment, cleaning products, reproduction (blueprint) machines
Solid	C	Carbon	Incomplete combustion (aerosol constituent), foundry
Gas	CO	Carbon monoxide	Combustion, automobile emissions, microbes, trees, wood pulping
Gas	Cl <sub>2</sub> , ClO <sub>2</sub>	Chlorine, Chlorine dioxide	Chlorine manufacture, aluminium manufacture, paper mills, refuse decomposition, cleaning products
Gas	HCl	Hydrogen chloride	Automobile emissions, combustion, oceanic processes, polymer combustion
Gas	HBr, HI	Halogen compounds	Automotive emissions
Liquid	Cl	Chloride ions	Aerosol content, oceanic processes, ore processing
Gas	O <sub>3</sub>	Ozone	Atmospheric photochemical processes mainly involving nitrogen oxides and oxygenated hydrocarbons, automotive emissions, electrostatic filters
Gas	C <sub>n</sub> H <sub>n</sub>	Hydrocarbons	Automotive emissions, fossil fuel processing, tobacco smoke, water treatment, microbes. Many other sources, both natural and industrial, paper mill
Solid	—	Inorganic dust	Crystal rock, rock and ore processing, combustion, blowing sand and many industrial sources

## Appendix B — Section 2 : Some common emissions of natural and industrial processes

<b>Natural Processes</b>	<b>Emissions</b>
Microbes	H <sub>2</sub> , NH <sub>3</sub> , NO <sub>x</sub> , H <sub>2</sub> S, CO, large variety of organics of many types
Sewage	NH <sub>3</sub> , aldehydes, many organics, H <sub>2</sub> S, mercaptans, H <sub>2</sub> , S, CO
Geothermal	H <sub>2</sub> , H <sub>2</sub> S, SO <sub>2</sub>
Marshy area	H <sub>2</sub> S, NH <sub>3</sub> , SO <sub>2</sub>
Animal matter	Many organics, mainly oxygenated
Forest fire	HCl, CO, CO <sub>2</sub>
Oceans	NaCl, chloride ions
<b>Industrial Processes</b>	<b>Emissions</b>
Power generation	SO <sub>2</sub> , C, CO, NO <sub>x</sub> , hydrocarbons, organics
Automotive combustion	SO <sub>2</sub> , SO <sub>3</sub> , HCl, HBr, NO <sub>x</sub> , hydrocarbons, organics, CO, HBr
Diesel combustion	CO, NO <sub>x</sub> , many organics
Fossil fuel processing	H <sub>2</sub> S, S, SO <sub>2</sub> , NH <sub>3</sub> , hydrocarbons, other organics, mercaptans
Plastic manufacture	All organics, aldehydes, alcohols, NH <sub>3</sub> , SO <sub>2</sub>
Cement plants	SO <sub>3</sub> , dust, SO <sub>2</sub> , NO <sub>x</sub> , CO
Steel blast furnaces	H <sub>2</sub> S, SO <sub>2</sub> , CO, HF, coal dust
Steel electric furnaces	H <sub>2</sub> S, SO <sub>2</sub> , C, CO
Coke plants	H <sub>2</sub> S, CO, HCN, carbon, dust
Pulp manufacture	Cl <sub>2</sub> , SO <sub>2</sub> , H <sub>2</sub> S, CO, wood fibers, dust
Chlorine plants	Chlorine, chlorine compounds, NaCl
Fertilizer manufacture	HF, NH <sub>3</sub> , CH <sub>4</sub> , gas, liquids, dust, acids
Food processing	Hydrocarbons, many organics
Rubber manufacture	H <sub>2</sub> S, S <sub>8</sub> , R-SH
Paint manufacture	C, hydrocarbons, oxygenated hydrocarbons, dust
Aluminum manufacture	HF, SO <sub>2</sub> , C, dust
Ore smelting	SO <sub>2</sub> , CO, H <sub>2</sub> , dust
Tobacco smoke	H <sub>2</sub> S, SO <sub>2</sub> , HCN, CO, tars and particulates
Gasoline and fuel vapors	Hydrocarbons, oxygenated hydrocarbons
Battery manufacture	SO <sub>2</sub> , acids, dust

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## Appendix C — Copper reactivity samples

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**C.1 Sample preparation** — Copper samples (nominal size 15 cm<sup>2</sup>) should be prepared from 99.99 purity, oxygen-free high conductivity (OFHC), 0.635 mm thick sheet; 1/2 – 3/4 hard.

Prepare as follows:

- 1) Abrade with 240X metallograph paper using a wax lubricant.
- 2) Abrade with 400X metallograph paper as in Step (1).
- 3) Abrade with 600X metallograph paper as in Step (1).\*
- 4) Scrub with cotton soaked in hot reagent grade acetone.
- 5) Dip in hot reagent grade isopropyl alcohol.
- 6) Store in glass containers purged with dry nitrogen.

**C.2 Sample exposure** — Three copper coupons should be placed vertically at the site being monitored. Particular care should be taken to avoid surface contamination such as fingerprints. Installation should be in an area which has air flow rates that are characteristic of the site.

Corrosion is defined in terms of the corrosion film thickness which builds up with one month of exposure. It is recognized that film buildup will be quite slow in mild areas but rapid in severe sites. To facilitate film thickness measurements in these extreme conditions, test times can be extended to three months at mild sites or reduced to two weeks in harsh environments. Copper corrosion is nonlinear, so changes of this type must be made with great care. Experience has shown that measurements over longer or shorter test times can be reduced to a normalized one month value by using the relationship

$$x_1 = x(t_1/t)^A$$

where  $x_1$  is the equivalent film thickness after one month  
 $x$  is the measured film thickness after time  $t$   
 $t_1$  is thirty days  
 $t$  is the actual test time (days)  
 $A$  is equal to 0.3 for G1, 0.5 for G2, 1 for G3 and GX

**C.3 Sample analysis** — Film thickness should be determined by cathodic reduction using the method of W. E. Campbell and U. B. Thomas, "Tarnish Studies," Bell Telephone System Technical Publications, Monograph 13, 1170 (1939).

### C.4 References

Abbott, W. H. "The Effects of Operating Environments on Electrical and Electronic Equipment Reliability in the Pulp and Paper Industry." Paper presented at the IEEE Industry Applications Society 1983 Pulp and Paper Technical Conference, May 1983. *IEEE Conference Record*. New York: Institute of Electrical and Electronics Engineers, Inc., 1983.

Rice, D. W., et al. "Atmospheric Corrosion of Copper and Silver." *Electrochem. Soc.* 128, no. 2 (February 1981): 275-284.

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\*Steps (3) through (5) should be done as near to placement time as possible.





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