Designation:G128–95 Designation: G 128 – 02 (Reapproved 2008)

Standard Guide for Control of Hazards and Risks in Oxygen Enriched Systems[1]

This standard is issued under the fixed designation G 128; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers an overview of the work of ASTM Committee G-4 on Compatibility and Sensitivity of Materials in Oxygen-Enriched Atmospheres. It is a starting point for those asking the question: "Are there any problems associated with my use of oxygen?" and an An introduction to the unique concerns that must be addressed in the handling of oxygen. The principal hazard is the prospect of ignition with resultant fire, explosion, or both. This hazard requires design considerations beyond those that apply to all systems, such as adequate strength, corrosion resistance, fatigue resistance, and pressure safety relief.

1.2 This guide also lists several of the recognized causes of oxygen system fires and describes the methods available to prevent them. Sources of information about the oxygen hazard and its control are listed and summarized. The principal focus is on Guides G 63, G 88, Practice G 93, and Guide G 94. Useful documentation from other resources and literature is also cited.

NOTE 1—This guide is an outgrowth of an earlier (1988) Committee G-4 videotape adjunct entitled *Oxygen Safety* and a related paper by Koch[2] that focused on the recognized ignition source of adiabatic compression—among compression as one of the more significant but often overlooked causes of oxygen fires. This guide recapitulates and updates material in the videotape and paper.

1.3 *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.* For specific precautionary statements see Sections 8 and 11.

[1] This guide is under the jurisdiction of ASTM Committee G-4 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmosphere and is the direct responsibility of Subcommittee G04.02 on Recommended Practices .

Current edition approved Jan. 15, 1995. Published March 1995.

[1] This guide is under the jurisdiction of ASTM Committee G04 on Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres and is the direct responsibility of Subcommittee G04.02 on Recommended Practices.

Current edition approved Sept. 1, 2008. Published October 2008. Originally approved in 1995. Last previous edition approved in 2002 as G 128–95(2002)$^{\varepsilon 1}$.

[2] Koch, U. H., "Oxygen System Safety," *Flammability and Sensitivity of Materials In Oxygen-Enriched Atmospheres* , Vol 6, ASTM STP 1197, ASTM, 1993, pp. 349–359.

NOTE 2—ASTM takes no position respecting the validity of any evaluation methods asserted in connection with any item mentioned in this guide. Users of this guide are expressly advised that determination of the validity of any such evaluation methods and data and the risk of use of such evaluation methods and data are entirely their own responsibility.

2. Referenced Documents

2.1 *ASTM Standards:*[3]

G 63 Guide for Evaluating Nonmetallic Materials for Oxygen Service

G 88 Guide for Designing Systems for Oxygen Service

G 93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments

G 94~~Guide for Evaluating Metals for Oxygen Service[3]~~ Guide for Evaluating Metals for Oxygen Service

G 126 Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres

G 128 Guide for Control of Hazards and Risks in Oxygen Enriched Systems

2.2 *ASTM Adjuncts:*

Video: Oxygen Safety[4]

2.3 *ASTM CHETAH Program:*

CHETAH ~~Chemical Thermodynamic Data and Energy Release Computer Program~~ Chemical Thermodynamic and Energy Release Evaluation[5]

2.4 *Compressed Gas Association (CGA) Standards:*[6]

G-4.1 Cleaning Equipment for Oxygen Service

G-4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems

2.5 *European Industrial Gas Association (EIGA) Standards:*[7]

~~33/86/E~~33/97/E Cleaning of Equipment for Oxygen Service

2.6 ~~*NATIONAL*~~*National Fire Protection Association (NFPA) Standards:*[8]

50~~Bulk Oxygen Systems at Consumer Sites~~ Standard for Bulk Oxygen Systems at Consumer Sites

~~51Oxygen-Fuel Gas Systems for Welding, Cutting and Allied Processes~~ 51 Standard for the Design and Installation of Oxygen-Fuel Gas Systems for Welding, Cutting and Allied Processes

53 ~~Fire Hazards in Oxygen Enriched Atmospheres~~ Recommended Practice on Material, Equipment, and Systems Used in Oxygen Enriched Atmospheres

99~~Health Care Facilities~~ Standard for Health Care Facilities

2.7 ~~*Praxair Documents:*~~

~~GS-38Cleaning~~

~~L-5110NGuidelines for Design and Installation of Industrial Gaseous Oxygen Distribution Piping Systems~~

~~2.8~~ *Military Specifications:*[9]

~~MIL-G-27617Military Specification, Grease, Aircraft, Fuel and Oil Resistant~~

~~MIL-G-47219(MI) Military Specification, Grease, Lubricating, Halogenated~~ MIL-PRF-27617 Performance Specification, Grease, Aircraft and Instrument, Fuel and Oxidizer Resistant

DOD-L-24574 (SH) Military Specification, Lubricating Fluid for Low and High Pressure Oxidizing Gas ~~Systems~~Mixtures

~~2.9~~2.8 *NASA Documents:*[10]

KSC 79K22280 Specification for 1,000-GPM LO_2 Pump Bearings

3. Terminology

3.1 *Definitions*~~—See Guides G63 and G94~~ — See Terminology G 126 for the terms listed in this section.

3.1.1 ~~*autoignition temperature*~~autoignition temperature (AIT), *n*~~—the temperature at which a material will spontaneously ignite in oxygen under specific test conditions.~~ — the lowest temperature at which a material will spontaneously ignite in an oxygen-enriched atmosphere under specific test conditions.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* ~~, Vol 14.02.~~volume information, refer to the standard's Document Summary page on the ASTM website.

~~[4] Oxygen Safety, adjunct is available from ASTM Customer Service, 100 Barr Harbor Drive, West Conshohocken, PA 19428. Request PCN #12-700880-31.~~

[4] Available from ASTM International Headquarters. Order Adjunct No.ADJG0088.

~~[5] Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428, order 0505189015 (3.5-in. media) and 0505189115 (5.25-in. media).~~

[5] Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428, Order # DSC 51C, Version 7.2.

~~[6] Available from Compressed Gas Association, 1725 Jefferson Davis Highway, Suite 1004, Arlington, VA 22202.~~

[6] Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, http://www.cganet.com.

[7] Available from European Industrial Gas Association, Publication de la Soudure Autogene, 32 Boulevard de la Chapelle, 75880 Paris Cedex 18, France.

~~[8] Available from the National Fire Protection Association, 1 Batterymarch Park, Box 9101, Quincy, MA 02269-9101.~~

[8] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

~~[9] Available from Praxair, Inc., Linde Division Communications Dept., P.O. Box 44, Tonawanda, NY 14151-0044.~~

[9] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

~~[10] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.~~

[10] Available from NASA, Engineering Documentation Center, John F. Kennedy Space Center, FL 32899.

3.1.2 ~~*impact-ignition resistance*~~hazard, *n*~~—the resistance of a material to ignition when struck by an object in an oxygen atmosphere under a specific test procedure.~~ —source of danger; something that could harm persons or property.

3.1.2.1 *Discussion*—The magnitude of a hazard relates to the severity of the harm it could cause.

3.1.3 *ignition temperature*, *n*—the temperature at which a material will ignite in ~~oxygen~~an oxidant under specific test conditions.

3.1.4 ~~*nonmetallic*~~impact-ignition resistance, *n*~~—any material, other than a metal, or any composite in which the metal is not the most easily ignited component and for which the individual constituents cannot be evaluated independently.~~ —the resistance of a material to ignition when struck by an object in an oxygen-enriched atmosphere under a specific test procedure.

3.1.5 ~~*oxygen-enriched*~~nonmetal, ~~*adj*—applies to a fluid (gas or liquid) that contains more than 25 mol % oxygen.~~ n—any material, other than a metal, nonpolymeric alloy, or any composite in which the metallic component is not the most easily ignited component and for which the individual constituents cannot be evaluated independently, including ceramics, such as glass; synthetic polymers, such as most rubbers, thermoplastics, and thermosets; and natural polymers, such as naturally occurring rubber, wood, and cloth. **nonmetallic**, adj.

3.1.6 ~~*qualified technical personnel*~~oxidant compatibility, *n*~~— persons such as engineers and chemists who, by virtue of education, training, or experience, know how to apply the physical and chemical principles involved in the reactions between oxygen and other materials.~~

~~3.2*Definitions of Terms Specific to This Standard:*~~

~~3.2.1*hazard*~~—the ability of a substance to coexist at an expected pressure and temperature with both an oxidant and a potential source(s) of ignition within a risk parameter acceptable to the user.

3.1.7 *oxygen-enriched*, ~~*n*—source of danger; something that could harm persons or property.~~

~~3.2.1.1~~*adj*—containing more than 25 mol percent oxygen.

3.1.7.1 *Discussion*~~—The magnitude of a hazard relates to the severity of the harm it could cause.~~

~~3.2.2 *oxygen compatibility, n*—the ability of a substance to coexist both with oxygen and with a potential source(s) of ignition at an expected pressure and temperature with a magnitude of risk acceptable to the user.~~

~~3.2.3~~*—Other standards such as those published by NFPA and OSHA differ from the definition in their specification of oxygen concentration.*

3.1.8 *qualified technical personnel*, *n*— persons such as engineers and chemists who, by virtue of education, training, or experience, know how to apply the physical and chemical principles involved in the reactions between oxidants and other materials.

3.1.9 *risk*, *n*—probability of loss or injury from a hazard.

~~3.2.3.1~~

3.1.9.1 *Discussion*—The magnitude of a risk relates to how likely a hazard is to cause harm. **G 128**

4. Significance and Use

4.1 The purpose of this guide is to introduce the hazards and risks involved with the handling of oxygen, cautioning the reader about the limitations of present practices and technology and about common hazards that often are overlooked. It then provides an overview of the standards produced by ASTM Committee G-4 and their uses, as well as similar documents available from other knowledgeable sources. It does not highlight standard test methods that support the use of these practices from this or other committees.

4.2 The standards discussed here focus on reducing the hazards and risks associated with the use of oxygen. In general, they are not directly applicable to process reactors in which the deliberate reaction of materials with oxygen is sought, as in burners, bleachers, or bubblers. ~~In this latter aspect, other~~ Other ASTM Committees and products (such as the CHETAH program[5]) and other outside groups are more pertinent for these.

4.3 This guide is not intended as a specification to establish practices for the safe use of oxygen. The documents discussed here do not purport to contain all the information needed to design and operate an oxygen system safely. The control of oxygen hazards has not been reduced to handbook procedures, and the tactics for using oxygen are not unique. Rather, they require the application of sound technical judgement and experience. Oxygen users should obtain qualified technical expertise to design systems and operating practices to ensure the safe use of oxygen in their specific applications.

5. Summary

5.1 Oxygen and its practical production and use are reviewed. The recognized hazards of oxygen are described. Accepted and demonstrated methods to diminish those hazards are reviewed. Applicable ASTM standards from Committee~~s~~ G-4 and how these standards are used to help mitigate oxygen system hazards are discussed. Similar useful documents from the National Fire Protection Association, the Compressed Gas Association, and the European Industrial Gas Association also are cited.

6. ~~Oxygen~~

~~6.1Oxygen is the most abundant element, making up 21% of the air we breathe and 55% of the earth's crust. It supports plant and animal life. Oxygen also supports combustion, causes iron to rust, and reacts with most metals. Pure oxygen gas is colorless, odorless, and tasteless. Liquid oxygen is light blue and boils at−183°C.~~

~~6.2*Commercial Uses of Oxygen*:~~

~~6.2.1*Metals processing*:~~
~~6.2.1.1steelmaking, and~~
~~6.2.1.2flame cutting and welding.~~
~~6.2.2*Chemical processes*:~~
~~6.2.2.1synthetic gas, gasoline, methanol production;~~
~~6.2.2.2ammonia, aldehydes, alcohol production;~~
~~6.2.2.3nitric acid, ethylene oxide, propylene oxide production;~~
~~6.2.2.4oxy-fuel combustion; and~~
~~6.2.2.5waste water treatment.~~
~~6.2.3*Life-support systems*:~~
~~6.2.3.1high-altitude flight;~~
~~6.2.3.2clinical respiratory therapy or anesthesiology; and~~
~~6.2.3.3emergency medical and fire service rescues.~~ Oxygen

6.1 Oxygen is the most abundant element, making up 21 % of the air we breathe and 55 % of the earth's crust. It supports plant and animal life. Oxygen also supports combustion, causes iron to rust, and reacts with most metals. Pure oxygen gas is colorless, odorless, and tasteless. Liquid oxygen is light blue and boils at −183 °C (−297 °F).

6.2 Oxygen has many commercial uses. For example, it is used in the metals industry for steel making, flame cutting, and welding. In the chemical industry it is used for production of synthetic gas, gasoline, methanol, ammonia, aldehydes, alcohol production, nitric acid, ethylene oxide, propylene oxide, and many others. It is also used for oxygen-enriched fuel combustion and wastewater treatment. For life support systems it is used in high-altitude flight, clinical respiratory therapy or anesthesiology, and emergency medical and fire service rescues.

7. Production and Distribution

7.1 Most oxygen is produced cryogenically ~~(by~~by distilling liquid ~~air); the~~air. The recent demand for ultra-high purity within the semiconductor industry has led to much more thorough distillation of cryogenic oxygen. Further, noncryogenic production has become significant in recent years. The principal difference among these sources of oxygen is the resulting oxygen purity. The hazards of oxygen are affected greatly by ~~purity; higher~~ purity ~~is more hazardous~~ and, in general, ~~and there are a few~~ higher purity is more hazardous However, fire events ~~that~~ can and do ~~not~~ occur ~~at lower purities.~~ in any oxygen–enriched atmosphere.

7.2 *Cryogenic Production*—Cryogenically produced oxygen is distilled in a five-step process in which air is: (*1*) filtered to remove particles; (*2*) compressed to approximately 700 kPa (100 psig) pressure; (*3*) dried to remove water vapor and carbon dioxide; (*4*~~) cooled to−160°C (−250°F) to liquefy it partially; and (~~*) cooled to −160 °C (−256 °F) to liquefy it partially; and (5) distilled to separate each component gas. The end products are oxygen, nitrogen, and inert gases such as argon and neon; the principal secondary products are nitrogen and argon. Commercial oxygen is produced to a minimum 99.5 % purity, but typical oxygen marketed today is more likely to be near 99.9 % purity.*

7.2.1 For high-volume bulk users, such as steel or chemical plants, the oxygen plant is often adjacent to the user's facility, and gas is delivered by pipeline at low to medium pressures, usually 700 to 5500 kPa (100 to 800 psig).

7.2.2 Cryogenic liquid oxygen is delivered by trailer to large-volume users, who utilize storage tanks and equipment to pump, vaporize, and distribute the gas (Fig. 1).

7.2.3 Most users buy oxygen in small amounts, usually in 20-MPa or 2500-psig cylinders, and use it directly from the cylinders or through manifolds and a piping distribution system. Usually, the pressure is reduced with a regulator at the cylinder or manifold.

7.3 ~~*Ultra-High-Purity*~~*Ultrahigh-Purity Oxygen*—There are a few markets that require high- and ultra-high-purity oxygen. High-purity oxygen typically delivers >99.99 % purity, whereas the demands of the semiconductor industry have resulted in the marketing of >99.999 % purity oxygen.

7.4 *Noncryogenic Production*—Noncryogenic oxygen production processes include pressure swing adsorption (PSA), vacuum swing adsorption (VSA), and membrane separation. In general, these methods produce oxygen less pure than cryogenically produced oxygen—typically< 97 %, with the balance being nitrogen, argon, and carbon dioxide. However, these processes use less power and offer a cost advantage for high-volume users who do not need higher purity.

~~7.4.1The~~The equipment for these systems is typically large and is located on site. However, small medical-oxygen generators used in the home also are included in this category.

8. Hazards and Risks

8.1 How can oxygen be hazardous? It is all around us. It supports life and is used to support or resuscitate a person with oxygen deficiency (hypoxemia). It may have been used in ~~an ordinary~~ a common familiar system for years without a problem. Could it be that ~~the hazard~~ oxygen is ~~unimportant? Definitely not.~~ not hazardous? No, oxygen presents definite hazards.

8.2 Despite its apparent innocence in many instances, oxygen is a serious fire hazard. It makes materials easier to ignite and their subsequent combustion more intense, more complete, and more explosive than in air alone. Fires in ~~air that~~air, which contain just 21 % oxygen, are common. ~~the~~The injuries, loss of life, and property damage they cause can be devastating. Fires and explosions that occur in ~~conjunction with concentrated oxygen~~oxygen-enriched atmospheres can be even more devastating, whether involving a patient in an oxygen-enriched environment or someone at an industrial site that uses oxygen.

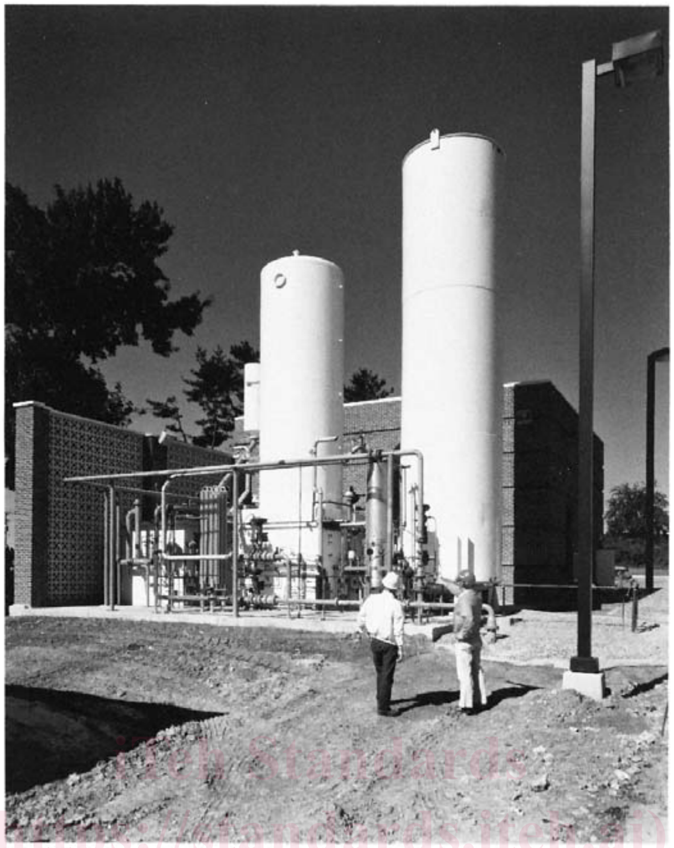

FIG. 1 High-volume Oxygen Users Buy the Gas in Bulk, Storing It in an Adjacent Facility

8.3 Oxygen is not flammable by itself, but it supports combustion. In most instances, a fire occurs when an oxidant such as oxygen is combined chemically with a fuel. Hence, although oxygen is not flammable, its contribution to the production of fire and heat is otherwise comparable to that of the fuel. If there is no fuel, there is no fire. If there is no oxidant, there is no fire.

8.4 The ability of an oxygen-enriched atmosphere to support and enhance combustion after ignition occurs is its hazard. The risk to people and property that accompanies this hazard is variable. Sometimes the human risk is grave; sometimes the economic risk is severe. In these instances, the need to prevent combustion is ~~strong.~~imperative. Occasionally the risk is small enough that it can be accepted~~—~~ and other tactics may be used to minimize the risk. The overall concepts of hazard and risk have been lumped into the term "oxygen compatibility."

8.4.1 ASTM Committee G-4 first codified its interpretation of the concept of "oxygen compatibility" in its ~~Standards Technology~~ Technical and Professional Training course textbook *~~Fire Hazards in~~ Manual 36, Safe Use of Oxygen and Oxygen Systems: Guidelines for Oxygen System Design, Materials Selection, Operations, Storage, and Transportation*:[11]

"The ability of a substance to coexist with both oxygen and a potential source(s) of ignition within the acceptable risk parameter of the user [at an expected pressure and temperature]."

8.4.1.1 In this definition, a system is oxygen compatible if it cannot or is unlikely to burn, if the occurrence of fires is adequately infrequent, or even if potential fires can be isolated and their effects can be tolerated.

8.5 Other organizations have a similar respect for the hazards of oxygen. NFPA 53 is a concise, readable booklet that describes oxygen, its uses and hazards, design guidelines, aids to material selection, and references. Significantly, NFPA 53 presents more than 40 case studies of accidents with oxygen that shows just how serious, yet subtle, the hazard can be. Further, in most of its publications (NFPA 50, NFPA 51, NFPA 99), the NFPA view of oxygen compatibility is given as:

"Compatibility involves both combustibility and ease of ignition. Materials that burn in air will burn violently in pure oxygen at normal pressure and explosively in pressurized oxygen. Also many materials that do not burn in air will do so in pure oxygen,

~~[11] Available from NASA, Engineering Documentation Center, John F. Kennedy Space Center, FL 32899.~~

[11] For more information regarding Standards Technology Training Courses and corresponding text material, contact ASTM Headquarters, Standards Technology Training, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

particularly under pressure. Metals for containers and piping must be carefully selected, depending on service conditions. The various steels are acceptable for many applications, but some service conditions may call for other materials (usually copper or its alloys) because of their greater resistance to ignition and lower rates of combustion.

"Similarly, materials that can be ignited in air have lower ignition energies in oxygen. Many such materials may be ignited by friction at a valve seat or stem packing or by adiabatic compression produced when oxygen at high pressure is rapidly introduced in a system initially at low pressure."

9. Sources of Information

9.1 Despite the hazards inherent with pure oxygen and its mixtures, the risk of injury and economic loss can largely be controlled ~~with technology that is~~ using methods documented in ASTM publications and many other sources. This is an overview of such sources~~—~~, by no means complete~~—~~, intended only to assist the reader in finding additional information.

9.1.1 Designing equipment and systems to function safely in oxygen-enriched environments requires information about the behavior of materials in such environments. ASTM standard test methods have been developed to measure the ignition and combustion properties of materials in gaseous and liquid oxygen, at various concentrations and pressures, by tests that relate to the common ignition mechanisms.

9.1.2 Guides G 63 and G 94 provide the designer with compilations of data obtained by the above ASTM test methods and present a structured approach to using that data in practical applications. Guide G 88 presents a systematic approach to system design with emphasis on the special factors that should be considered to minimize the risk of ignition and fire.

9.1.3 Practice G 93 ~~covers the selection of methods and materials that may be used to clean materials and equipment for oxygen service. Examples are provided for specific materials and applications.~~

~~9.1.4ASTM Committee G-4 sponsors an international Symposium on the Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres. The papers presented at these symposia cover topics from combustion theory to practical applications and fire experiences. They are published in Special Technical Publications, which—along with their extensive list of references—represent the largest existing collection of published work on this subject.~~

~~9.1.5A two-day Standards Technology Training Course, Controlling Fire Hazards in Oxygen Handling Systems, is presented by ASTM G-4 members two or more times each year at a variety of locations. The textbook,~~ *covers the selection of methods and materials to clean equipment for oxygen service. Examples are provided for specific materials and applications.*

9.1.4 ASTM Committee G-4 sponsors an international Symposium on the Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres every two to three years. The papers presented at these symposia cover topics from combustion theory to practical applications and fire experiences. They are published in Special Technical Publications, which, along with their extensive list of references, represent the largest existing collection of published work on this subject.

9.1.5 A two-day Technical and Professional Training Course, Fire Hazards in Oxygen Handling Systems, is presented by ASTM G-4 members at least twice a year at a variety of locations. This course introduces participants to the fire risk in oxygen systems and presents a systematic approach to reducing the fire risk through the application of relevant ASTM and other industry standard publications. The textbook, *Fire Hazards in Oxygen Systems*,[11] teaches how to apply the many resources available to reduce the risk of oxygen fires. The video used in the course, *Oxygen Safety*,[4] is a brief introduction to some of the hazards present in oxygen systems, particularly those often overlooked.

9.2 Industry associations such as the Compressed Gas Association, National Fire Protection Association, and European Industrial Gas Association have developed product standards, design guides, codes, and training aides to assist in reducing the risk of oxygen system fires.

9.3 Government agencies serving aerospace programs, the military, and national research laboratories, offer oxygen system safety information. In some countries, product testing and approval services are available through national laboratories.

9.4 Most oxygen producers provide their users with safety publications and offer resources to assist in design, operation, and training for personnel. A few examples of such publications are listed in Appendix X1~~, that~~. That list is neither complete nor is it an endorsement of those publications.

10. Causes of Fires in Oxygen

10.1 There is a considerable body of useful information that can aid in understanding the principles of ignition and flammability in oxygen-enriched environments. New theories are ~~developing,~~ under development, as frequently reported at Committee G-4 symposia. These developments ~~have not completed~~ are expanding our ~~knowledge; indeed,~~knowledge of oxygen safety. Indeed, some oxygen fires have not been explained fully and their causes are not known. However, many common ignition mechanisms and causes of oxygen system fires are recognized and well understood.

10.2 *Kindling Chain*—Ignition usually begins as a small event and grows into a fire through the kindling chain sequence. A small amount of energy ignites a material with a low ignition temperature or a particle with a large surface area and small mass. Once ignited, the material gives off enough heat to ignite bulk materials with higher ignition temperatures~~—~~, which generate more heat~~—~~, until the process is self-sustaining.

10.3 *Ignition Mechanisms*—Oxygen fires require a source of energy to trigger ignition, as do most fires. The most common ignition energy sources are: (*1*) mechanical impact; (*2*) particle impact; (*3*) friction; and (*4*) pneumatic impact or compression heating. The risk of ignition by these mechanisms, and others less often encountered, increases as the severity of the operating