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Standard Guide for Studying Fire Incidents in Oxygen Systems¹

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1. Scope

1.1 This guide covers procedures and material for examining fires in oxygen systems for the purposes of identifying potential causes and preventing recurrence.

1.2 This guide is not comprehensive and is not intended for forensic use. The analysis of oxygen fire incidents is not a science, and definitive causes have not been established for some events.

1.3 The procedures and analyses in this guide have been found useful for interpreting fire events, for helping identify potential causes, and for excluding other potential causes. The inclusion or omission of any analytical strategy is not intended to suggest either applicability or inapplicability of that method in any actual incident study. Indeed, some material in this guide is considered useful, and therefore worthy of inclusion and consideration in a study, but not necessarily of demonstrated validity.

NOTE 1—Although this guide has been found applicable for assisting qualified technical personnel to analyze incidents, each incident is unique and must be approached as a unique event. Therefore, the selection of specific tactics and the sequence of application of those tactics must be conscious decisions of those studying the event.

NOTE 2—The incident may require the formation of a team to provide the necessary expertise and experience to conduct the study. The personnel analyzing an incident, or at least one member of the team, should know the process under study and the equipment installation.

1.4 **Warning**—During combustion, gases, vapors, aerosols, fumes, or combination thereof, are evolved, which may be present and may be hazardous to people. **Caution**—Adequate precautions should be taken to protect those conducting a study.

1.5 *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.*

2. Referenced Documents

2.1 ASTM Standards:

- E 620 Practice for Reporting Opinions of Technical Experts²
 - E 678 Practice for Evaluation of Technical Data²
 - E 860 Practice for Examining and Testing Items That Are or May Become Involved in Products Liability Litigation²
 - E 1020 Practice for Reporting Incidents²
 - E 1138 Terminology of Technical Aspects of Products Liability Litigation²
 - E 1188 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator²
 - E 1459 Guide for Physical Evidence Labeling and Related Documentation²
 - E 1492 Practice for Receiving, Documenting, Storing, and Retrieving Evidence in a Forensic Science Laboratory²
 - G 63 Guide for Evaluating Nonmetallic Materials for Oxygen Service²
 - G 88 Guide for Designing Systems for Oxygen Service²
 - G 93 Practice for Cleaning Methods for Material and Equipment Used in Oxygen-Enriched Environments²
 - G 94 Guide for Evaluating Metals for Oxygen Service²
 - G 114 Practice for Aging Oxygen-Service Materials Prior to Flammability Testing²
 - G 124 Test Method for Determining the Combustion Behavior of Metallic Materials in Oxygen-Enriched Atmospheres²
 - G 128 Guide for Control of Hazards and Risks in Oxygen-Enriched Systems²
- #### 2.2 ASTM Adjunct:
- Video: *Oxygen Safety*³
- #### 2.3 Compressed Gas Association (CGA) Standards:⁴
- G-4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems
 - G-4.8 Safe Use of Aluminum Structured Packing for Oxygen Distillation

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

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² *Annual Book of ASTM Standards*, Vol 14.02.

³ Available from ASTM Customer Service, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. Request PCN 12-700880-31.

⁴ Available from Compressed Gas Association, 1725 Jefferson Davis Highway, Suite 1004, Arlington, VA 22202.

2.4 *National Fire Protection Association (NFPA) Standard*:⁵

NFPA 53 Fire Hazards in Oxygen Enriched Atmospheres

2.5 *Occupational Safety and Health Act*:⁶

OSHA Process Safety Management Compliance Manual

3. Terminology

3.1 *Definitions*—See Guides G 63, G 94, and G 128 for the terms listed in this section.

3.1.1 *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.

3.1.2 *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 oxygen and other materials.

3.1.3 *oxygen-enriched, adj*—applies to a fluid (gas or liquid) that contains more than 25 mol % oxygen.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *incident, n*—an ignition or fire, or both, that is both undesired and unanticipated or an undesired and unanticipated consequence of an ignition or fire that was anticipated.

3.2.2 *direct incident cause, n*—the mechanical or thermodynamic event (such as breakage of a component or near-adiabatic compression), the physicochemical property (such as heat of combustion), the procedure (such as a valve opening rate), or any departure(s) from the intended state of any of these items, that leads directly to ignition or fire, or both.

3.2.3 *fractional evaporation, v*—the continuous evaporation of a quantity of liquid that results in a progressive increase in the concentration of a less-volatile constituent(s).

4. Summary of Guide

4.1 Following a fire incident in an oxygen-enriched atmosphere, the equipment, operating procedures, and area are considered in light of other incidents, potential contributing factors, suggested analytical strategies, and demonstrated laboratory results. The goal is to determine direct cause(s) of the incident in order to prevent a recurrence.

5. Significance and Use

5.1 This guide helps those studying oxygen system incidents to select a direct cause hypothesis and to avoid conclusions based on hypotheses, however plausible, that have proven faulty in the past.

6. Abstract

6.1 A series of possible causes and common scenarios are described to assist those seeking to understand incidents in oxygen-enriched atmospheres. Many easily misinterpreted factors are described to help avoid faulty conclusions. Several

suspected but unproven incident scenarios are described. Select laboratory data are presented to support assertions about direct causes of incidents.

7. Direct-Cause Analysis

7.1 In this guide, the direct cause of an incident is the mechanical or thermodynamic event (such as breakage of a component or near-adiabatic compression), the physicochemical property (such as heat of combustion), the procedure (such as a valve opening rate), or any departure(s) from the intended state of any of these items, that leads directly to ignition or fire, or both. A fire might also be the result of a financial decision, worker skill, or manufacturing process—all of which can be viewed as causes—but such factors are addressed more properly in a system hazard review. Note that some fires are anticipated and the risks (whether human or economic) are addressed by such things as shielding (for example to control human risk) or acceptance (for example to address economic risk). In these cases, a fire is not an “incident” unless some aspect of the event exceeded the initial parameters (for example, the shielding did not provide the expected containment, or the cost exceeded projections). This guide seeks to identify the material choice, equipment design, assembly procedure, or other factor that led directly to the fire—and more specifically, to distinguish the physical object or action that caused the fire to start, to continue, or to be injurious or destructive. Remedial actions are found in other documents such as Guides G 63, G 88, and G 94, and Practice G 93, as well as publications NFPA 53, CGA G-4.4, and G-4.8, OSHA *Process Safety Management Compliance Manual*, and others.

7.2 *Example*—The direct cause of an incident may be concluded to be the use of an incompatible material, because a polyacetyl component was installed when a material such as PTFE or CTFE was preferred. The direct cause was not that the budget was inadequate to cover the cost of PTFE; nor that specific frictional properties of polyacetyl were required for mechanical purposes; nor that an incorrect part was installed in error. Note that in this example, PTFE and CTFE might be needed to prevent or cope with ignition and fire, but that they might introduce non-fire-related issues such as loss of mechanical strength or production of toxic decomposition products when exposed to heat of compression.

8. Elements of a Study

8.1 *Overview*—The study of an oxygen incident typically begins (preferably promptly) after the event has concluded. The fire is extinguished and any safety requirements or immediate needs are addressed (treating injuries, returning systems to a safe state, and so forth). Then the investigator can begin to document the event, to preserve the artifacts, and to detect how they may have been altered or compromised by the event and follow-up activities. Although many of these steps are itemized here, the intent of this guide is not to specify how or in what order they should be conducted. Rather, information is offered about certain procedures that have been effective in the past, as well as some that have led to faulty conclusions. Typically, good scientific and laboratory skills are useful and adequate. Forensic skills and procedures can be helpful in many cases, but may not be practical in all. For example, the

⁵ Available from National Fire Protection Association, 1 Batterymarch Park, Box 9101, Quincy, MA 02269-9101.

⁶ Available from Occupational Safety and Health Administration, 1825 K Street, NW Washington, DC 20006.

forensic Guide E 1459 can assist with managing post-incident artifacts, and related Practices E 1492, E 620, E 678, E 860, E 1020, and E 1188, as well as Terminology E 1138, may have other uses. However, when a forensic approach is needed because a legal action is involved, the insights in this guide may effectively supplement it.

8.2 Documentation—Among the urgent post-incident efforts are: photographing or videotaping the site and any damaged equipment; obtaining system drawings, supporting design analysis, process hazards analysis, and any other hazard-evaluation materials; interviewing persons knowledgeable about the system, operating procedures and the events before, during, and after the fire; collecting specimens, operating logs, and related information; and preliminary formulation and testing of hypotheses.

8.3 Analysis—The principal effort in a study will be analysis of the data and artifacts. This may require further examination of the equipment and records, laboratory study of selected items, and perhaps even laboratory simulation of the incident.

8.4 Completion of Study—An incident study is completed when the qualified technical personnel involved in the study conclude that the event is understood.

8.4.1 An incident might be understood adequately when a conclusion has been drawn about the direct cause of the event. The following examples show the distinction between direct causes and causes that are not physicochemical or thermodynamic events.

8.4.1.1 Example 1—A substantial amount of hydrocarbon oil was introduced into a system just before an incident. This single factor may be identified as the direct cause of the fire. Any reasons for introducing the lubricant may be important to a new hazard review, but are not the direct cause of the fire. Prevention can focus on cleanliness. *Initiating Event*: ignition of an incompatible oil. *Direct Cause*: contamination of the system.

8.4.1.2 Example 2—Records may show that a component broke and produced a rub in a piece of machinery just before an incident. This factor alone can ignite a fire and could be identified as the direct cause. If the component broke because it contained a flaw, the flaw might be determined to be the direct cause. However, if the part was selected because it offered economy, then the direct cause remains the inadequate part—not a misguided effort to economize. Prevention in this case can focus on component quality. *Initiating Event*: friction during the rub. *Direct Cause*: Mechanical failure.

8.4.1.3 Example 3—Deviation from an important operating practice, such as first equalizing downstream pressure with a bypass valve before opening a quick-opening valve, may be established as the direct cause of a fire. The reasons for departing from mandated practice are important, but they are not the direct cause. Here, prevention can focus on following standard operating procedures. *Initiating Event*: approximately adiabatic compression. *Direct Cause*: incorrect operation.

8.4.2 An incident might be understood adequately when a conservative tactic has been identified that would have prevented or safely managed the event.

8.4.2.1 Example 1—If an item of machinery cannot employ

oxygen-compatible materials because they compromise its operating economy, and it becomes the site of a fire and injures someone, then the event may be understood adequately (regarding preventing recurrence of injury rather than fire) when inadequate shielding or inadequate mechanical design or other comparable factor is identified singly or in combination as the direct cause.

8.4.3 The study is complete when the direct cause has been determined. Preventing the repetition of an event is the function of a hazard review using well-established techniques, including the use of related standards from ASTM Committee G-4. The hazard review may be integral to the incident study and may involve some or all of the same people, but it is a separate activity for the purpose of this guide.

9. Factors Affecting an Incident Study

9.1 Missing Components—Following some oxygen incidents, components have appeared to be absent, leading to speculation that the component was not installed or that its mechanical failure and passage through the system were at fault. Sometimes, the damage is so negligible that the possibility that there was no fire is considered. These conclusions can be in error. In an oxygen-enriched atmosphere, combustion can be remarkably clean. A simple polymer may be converted totally into carbon dioxide and water, leaving no trace of its prior presence. If the component is small or if it has a low heat of combustion, there may be no evidence of heat damage. For example, PTFE seats in ball valves (which are large and have low heat of combustion) and nylon seats in cylinder valves (which are small and have high heat of combustion) have burned completely in some incidents with no melting of metal components, no appearance of residual carbon, and no remains of the polymer itself.

9.2 Contamination:

9.2.1 When contamination is present in an oxygen system, the contaminant may serve to start the incident. Then the ensuing fire involving the polymers, metals, and contaminant may consume the contaminant fully, leaving no indication of its original presence.

9.2.2 When contaminant levels are large, they may produce so large an explosive event that the system integrity can be breached, and the fire can be extinguished without complete combustion of the contaminant. Therefore, some of the contaminant may be found after an incident in the same regions of the system where the fire occurred. In these instances, the flammability of the contaminant can be so much greater than that of the metals and polymers that there may be only scant damage to the system materials.

9.2.3 Example—In laboratory tests of an oxygen system component, hydrocarbon lubricating oil was introduced and ignited. When the amount of lubricant was small, a fire may or may not have resulted, but there was usually no trace of the oil after the test. When the amount of lubricant was large, the component was blown apart. Threads on the component parts were stripped. A pressure gage was in fragments. After the event, neither melting nor consumption of the components was observed, and the parts had an obvious coating of the oil.

9.2.4 Carbon or Black Dust—In many incidents, a black powder will be present on many surfaces. The powder could be