Second Revision No. 3-NFPA 53-2020 [Detail]

Update Table F.3.4.2(b) superscripts in accordance with the attached file.

Supplemental Information

File Name	Description	Approved
53_SR3_Detail_Table_F.3.4.2b_2_.docx	for staff use	
Detail_SR-3_FINAL.docx	for balloting	

Submitter Information Verification

Committee:

Submittal Date: Wed May 13 17:05:05 EDT 2020

Committee Statement

Committee Statement: The superscript references to the footnotes for this table were found not to match the source material. The source table does not have the equivalent of footnote (a), so some of the entries in this table were off by one letter.

Response Message: SR-3-NFPA 53-2020

[SR-3]

Table F.3.4.2(b) Threshold Pressures[a][BM1] in Oxygen of 3.2 mm (0.13 in.) Diameter, Pure Metal Rods Ignited at the Bottom (63)

Element	Threshold Pressure[a]		Next Lower Pressure Tested	
	MPa	psia[b]	MPa	psia[b]
Li	≤Ambient air[c]		None	None
Be	4.1	600	3.4	500
C (as graphite)	0.34	50	0.17	25
Mg	≤0.007	≤1	None	None
Al	≤0.17	25	None	None
Si	27.6	4,000	20.7	3,000
Ti	≤0.007	≤1	None	None
V	1.4	200	0.7	100
Cr	4.1	600	3.4	500
Fe	0.5	≤70	None	None
Co	>69[de]	>10,000[d]	None	None
Ni	>69[de]	>10,000[d]	None	None
Cu	>69[de]	>10,000[d]	None	None
Zn	5.5	800	4.8	700
Sr	≤ Ambient air[c]		None	None
Zr	≤0.06	≤8	None	None
Cb	≤0.7	≤100	None	None
Mo	0.7	100	0.34	50
Ag	>69	>10,000[d]	None	None
In	0.14	20	0.08[ed]	12.3[e]
Sn	1.0	150	None	None
Sb	4.1	600	3.4	500
Yb	0.08[e]	12.3[e]	Ambient air[cb]	
Hf	0.07	10	None	None
Ta	0.14	20	None	None
W	0.34	50	0.07	10
Pt	>69[de]	>10,000[d]	None	None
Au	>69[de]	>10,000[d]	None	None
Pb	5.2	750	3.4	500

[a]Threshold pressure is the minimum test pressure required to support complete combustion of the test sample. *(See last paragraph of F.3.4.1.)*

[b]Pressures above 100 psi are gauge pressure of psi rather than absolute pressure of psi.

[c]Samples burned completely in ambient air at an atmospheric pressure of 85 kPa (absolute pressure of 12.3 psi).

[d]Samples did not support combustion in at least three tests at this pressure. The threshold pressure, if it exists, is greater than this pressure.

[e]These tests were run in 85 kPa (absolute pressure of 12.3 psi) oxygen.

Second Revision No. 2-NFPA 53-2020 [Section No. 1.4]

1.4 Interpretations.

The National Fire Protection Association does not approve, inspect, or certify any installation, procedure, equipment, or material. With respect to this recommended practice, and to fire and associated hazards in OEAs, its role is limited solely to an advisory capacity. The acceptability of a particular material, component, or system for use in an OEA is solely a matter between the user and the provider. However, to assist in the determination of such acceptability, the National Fire Protection Association has established interpretation procedures. These procedures are outlined in ~~the NFPA~~ NFPA's “ Regulations Governing the Development of NFPA Standards.” ~~Committee Projects.~~

Submitter Information Verification

Committee: OXY-AAA
Submittal Date: Tue Apr 14 14:43:16 EDT 2020

Committee Statement

Committee Statement: Correcting the title of the regulations.
Response Message: SR-2-NFPA 53-2020

Second Revision No. 5-NFPA 53-2020 [Section No. 2.4]

2.4 References for Extracts in Recommendations Sections.

NFPA 68, *Standard on Explosion Protection by Deflagration Venting,* 2018 edition.

~~NFPA 99, *Health Care Facilities Code,* 2018 edition.~~

NFPA 921, *Guide for Fire and Explosion Investigations,* 2017 edition.

Supplemental Information

File Name	Description	Approved
SR-5_2.4_FINAL.docx	For prod use	

Submitter Information Verification

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Committee Statement

Committee Statement: The only extract from NFPA 99 has been removed from Chapter 3 by a Second Revision.

Response Message: SR-5-NFPA 53-2020

Second Revision No. 1-NFPA 53-2020 [Section No. 3.3.25]

3.3.25* Oxygen-Enriched Atmosphere (OEA).

~~For the purposes of this [recommended practice], an~~ An atmosphere in which the concentration of oxygen exceeds ~~23.5~~ 21 percent by volume or its partial pressure exceeds 21.3 kPa (160 torr) . ~~[**99,** 2018]~~

A.3.3.25 Oxygen Enriched Atmosphere (OEA).

The definition of an oxygen-enriched atmosphere (OEA) varies across industries, standards, guides, and codes based on varying hazard considerations within each sector. The differences in the selection of an OEA by standardizing organizations varies between 21 percent (i.e., atmospheric oxygen) and 25 percent; however, some industry considerations allow concentrations up to 50 percent before OEA conditions are considered. The following provides examples of some of the authoritative standards available addressing OEA considerations in different industries:

(1) ADCI: *ADCI Consensus Standard 6.3: Association of Diving Contractors International* states greater than 50 percent for hose assemblies.

(2) ASTM: ASTM G126, *Standard Terminology Related to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres*, defines an oxygen-enriched atmosphere as a fluid mixture containing more than 25-mole percent oxygen. ASTM observes in G126 that the definition of 25 percent oxygen (by volume) was historically used by ASTM relating to materials testing and pressurized piping systems; and that this level has been shown for the applications considered to be effective and reasonable. However, ASTM further notes that different applications could require a more conservative oxygen concentration.

(3) CGA: The Compressed Gas Association (CGA) addresses OEA consideration in several documents, including the following:

   (a) CGA G-4.1, *Cleaning Equipment for Oxygen Service* (Section 1, Note 2), provides cleaning methods used in the production, storage, distribution, and use of liquid and gaseous oxygen. CGA considers that equipment and systems handling any gas in excess of 23.5 percent oxygen by volume be designed as handling pure oxygen.

   (b) CGA P-39, *Guidelines for Oxygen-Rich Atmospheres*, defines oxygen-rich atmospheres as those exceeding 23.5 percent at sea level (or partial pressures exceeding 175 torr). The CGA has reported that 23.5 percent reflects an error factor of 2.5 percent over ambient 21 percent oxygen to account for the permissible tolerance on the percentage of oxygen in compressed air when reconstituting air from gaseous nitrogen and oxygen.

   (c) CGA P-45, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres*, is intended to increase hazard awareness of personnel working with oxygen. It specifies that an OEA exists for air and gas mixtures in which the oxygen concentration by volume exceeds 23.5 percent at sea level or whose partial pressure exceeds 175 torr (mm Hg).

   (d) CGA PS-13, *Position Statement on Definition of a Threshold Oxygen-Mixture Concentration Requiring Special Cleaning of Equipment*, specifies that equipment exposed to oxygen concentrations of 23.5 mole percent or greater should be specifically cleaned according to CGA G-4.1.

(4) EIGA: The European Industrial Gases Association (EIGA) also address OEA considerations in several documents, including the following:

   (a) EIGA IGC Doc 33/18, *Cleaning of Equipment for Oxygen Service*, treats oxygen as gas or liquid that contains greater than 23.5 percent oxygen by volume with the remainder of its components being inert.

   (b) EIGA IGC Doc 04/18 (Revision of Doc 04/09), *Fire Hazards of Oxygen and Oxygen Enriched-Atmospheres*, treats oxygen-enriched atmospheres as air and gas mixtures in which the oxygen concentration by volume exceeds 23.5 percent at sea level or whose partial pressure exceeds 175 torr (mmHg). This standard is a general standard and recognizes the increased fire risk for enrichment levels greater than atmospheric air for a wide variety of industrial applications, including leaking piping systems to liquefaction of air.

(5) IMCA: The International Marine Contractors Association (IMCA) also address OEA considerations in several documents, including the following:

(a) IMCA D 031, *Cleaning for Oxygen Service: Setting up Facilities and Procedures* , considers an OEA as those with concentrations greater than 25 percent oxygen by volume.

(b) IMCA D 048, *Guidance on Surface Supplied Diving Operations Using Nitrox* , considers an OEA as those with concentrations greater than 25 percent oxygen by volume.

(6) ISO: The International Organization for Standardization, commonly known as ISO, addresses OEA considerations in the standard ISO 10156, *Gas Cylinders – Gases and gas mixtures – Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets* , which treats OEA conditions as those equal to or greater than 23.5 percent oxygen by volume.

(7) MIL-STD: A United States defense standard or Military Standard is known as an MIL-STD. One such MIL-STD that addresses OEA considerations is MIL-STD-1330D, *Precision Cleaning and Testing of Shipboard Oxygen, Helium, Helium-Oxygen, Nitrogen, and Hydrogen Systems* , which treats OEA conditions as those greater than 25 percent oxygen by volume.

(8) NFPA: The National Fire Protection Association (NFPA) addresses OEA consideration in several documents, including the following:

(a) NFPA 99 defines an oxygen-enriched atmosphere as an atmosphere in which the concentration of oxygen exceeds 23.5 percent by volume; and an atmosphere of increased burning rate as any atmosphere containing a percentage of oxygen or oxygen and nitrous oxide greater than the quotient of 23.45 divided by the square root of the total pressure in atmospheres (e.g., $23.45/P_{atm}^{0.5}$). NFPA 99 specified an OEA based on an increased fire hazard, related to the increased burning rate of filter paper with increased oxygen concentration (Schmidt, et al. [1]). This standard has also recognized the hazard of an increased fire spread rate when total pressure increases, as in hyperbaric chambers, and provides the OEA relationship, $23.45/P_{atm}^{0.5}$.

(b) NFPA 99B defines an oxygen-enriched atmosphere as an atmosphere in which the concentration of oxygen exceeds 23.5 percent by volume; and an atmosphere of increased burning rate as any atmosphere containing a percentage of oxygen or oxygen and nitrous oxide greater than the quotient of 23.45 divided by the square root of the total pressure in atmospheres (e.g., $23.45/P_{atm}^{0.5}$).

(9) NOAA: National Oceanic and Atmospheric Administration's (NOAA) *Diving Manual* treats OEA conditions as those with greater than 40 percent oxygen by volume.

(10) OSHA: The Occupational Safety and Health Administration (OSHA) also address OEA considerations in several documents, including the following:

(a) OSHA 29 CFR 1910.430 (i)(2): Treats OEA conditions as those with greater than 40 percent oxygen by volume for commercial diving equipment/operation except umbilicals.

(b) OSHA 29 CFR 1910.146: Treats OEA conditions as those with greater than 23.5 percent oxygen by volume for permit-required confined spaces.

(c) OSHA 29 CFR 1915.11: Treats OEA conditions as those with equal to or greater than 22 percent oxygen by volume for confined and enclosed spaces and other dangerous atmospheres in shipyard employment.

In NFPA 53, an OEA is considered any atmosphere with greater than 21 percent oxygen (by volume) or a partial pressure greater than 160 torr; and is established to emphasize the potential changes in material flammability hazards that occur as oxygen concentrations increase above ambient. Incremental increases in oxygen concentration can result in enhanced flammability of a variety of materials, particularly nonmetals. Substantial testing has established that as the oxygen concentration (or oxygen partial pressure) increases above 21 percent, an accompanying increase in the fire spread rate, decreases in ignition energy, and a reduction in the autogenous ignition temperature (AIT) also occur. For instance, 100 percent cotton cloth exhibits a steady increase in burn rate from 7 cm/min at 21 percent O_2 to 25 cm/min at 45 percent O_2 in testing by ASTM G125, *Standard Test Method for Measuring Liquid and Solid Material Fire Limits in Gaseous Oxidants* , at 1 atm, as shown in Figure A.3.3.25(a) . This testing was configured to ignite the sample at the top of a test material within a column of oxygen/nitrogen flow ascending slowly at 3–5 cm/sec. The testing reported here was all conducted at 3 cm/sec to minimize the flow effect on propagation. The flame spread rate was evaluated for downward burning, propagating against the direction of predominant flow. It is noteworthy that for the conditions of the ASTM G125 test, between 45 percent and 50 percent oxygen, a dramatic increase in burn rate (i.e., flashover) develops as observed by the sudden increase in fire spread rate. Further, in ignition testing, the cotton cloth also exhibits a rapid reduction in ignition energy by electrostatic discharge (ESD) from about 90 mJ at 1 atm (160 torr) to 44 mJ at 3 atm (478 torr), per unpublished testing performed by WHA International Inc. compared with ESD testing by NASA in TN-D-5579, “Static Electricity in the Apollo Spacecraft,” as shown in Figure A.3.3.25(b) .

Figure A.3.3.25(a) Cotton Burn Rate by ASTM G125.

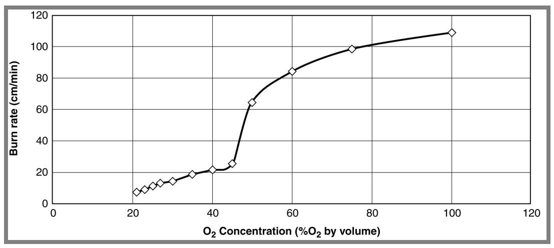
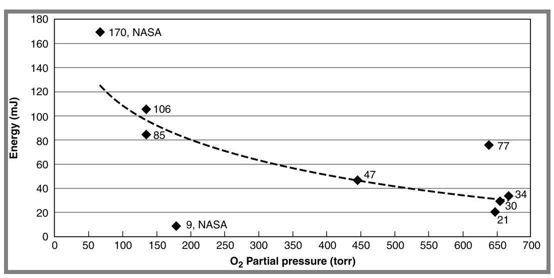


Figure A.3.3.25(b) Cotton Ignition Energy (mJ) vs. O_2 Partial Pressure (torr).



Further, the OEA material hazards discussed previously are exaggerated by increased pressure. (Smith [2]) has reported that “materials are easier to ignite as oxygen concentration increases,” and reports AIT trends for six common nonmetallic sealing materials in Table A.3.3.25 . In Table A.3.3.25 , the oxygen index (OI) by ASTM G125 is also shown. It is noteworthy that the change in AIT with O_2 concentration appears to vary more with the specific material properties than with the OI exhibited by the material (note comparison of Silicone Rubber with Zytel 42). The pressure dependence was also demonstrated by (Benning [3]) for several common sealing materials subjected to pressurized OI testing [see Figure A.3.3.25(c)]. In the Benning tests, the materials exhibited an increase in burn rate with increasing pressures when compared at the same concentrations. For instance, the burning rate for PTFE at a concentration of about 81 percent increased by a factor of about 5 from 1.7 atm to 10.5 atm. Viton exhibited a similar trend with pressure increases above ambient. Further, all materials tested exhibited a strong increase in burn rate, at 10.5 atm, as oxygen concentration increased, as shown in the trendlines for Figure A.3.3.25(c) . (See G.1.2.10.1 for references.)

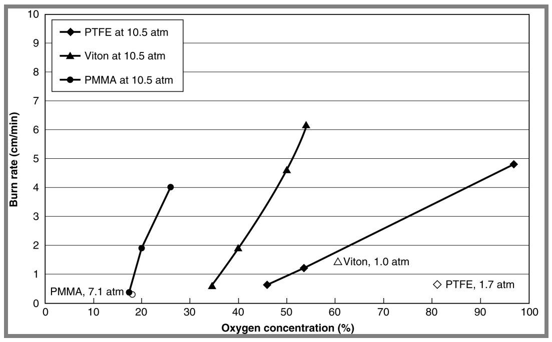
Table A.3.3.25 Change in AIT with Oxygen Percentage (by ASTM G72 at 102 atm)

Material	**Oxygen Index* (OI%)**	**Average AIT (°C)**			
		21%	34%	45%	100%
Polysiloxane (Silicone Rubber)	21	306	301	301	302
Nitrile Rubber (Buna N®)	22	394	392	391	385
Polyamide (Zytel® 42)	30	272	255	247	203

Material	Oxygen Index* (OI%)	Average AIT (°C)			
FKM Elastomer (Viton® A)	32	312	305	299	293
Polyimide SP-21 (Vespel® SP-21)	53	420	376	368	342
Polytetrafluoroethylene (Teflon®)	95	446	442	440	439

*Measured OI values vary within the technical literature and can vary a few percent from one laboratory to another. For instance, measured OI values for Nitrile rubber are reported as low as 18 percent. Further OI values can vary between different compounds of the same material.

Figure A.3.3.25(c) Material Burning Rate at 10.5 atm with Increased Oxygen Concentration (baseline pressure/concentration conditions also shown for each material).



Supplemental Information

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53_SR1_A.3.3.25.docx	for staff use	

Submitter Information Verification

Committee: OXY-AAA

Submittal Date: Tue Apr 14 14:11:01 EDT 2020

Committee Statement

Committee Statement: The definition for oxygen enriched atmosphere is returning to the definition that has been used in NFPA 53, while providing annex material to explain the differences in OEA thresholds between different standards and organizations.

Response Message: SR-1-NFPA 53-2020

Second Revision No. 4-NFPA 53-2020 [Chapter G]

Annex G Informational References

G.1 Referenced Publications.

The documents or portions thereof listed in this annex are referenced within the informational sections of this recommended practice and are not part of the recommendations of this document unless also listed in Chapter 2 for other reasons.

G.1.1 NFPA Publications.

National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 51, *Standard for the Design and Installation of Oxygen–Fuel Gas Systems for Welding, Cutting, and Allied Processes*, 2018 edition.

NFPA 51B, *Standard for Fire Prevention During Welding, Cutting, and Other Hot Work*, 2019 edition.

NFPA 55, *Compressed Gases and Cryogenic Fluids Code*, 2020 edition.

NFPA 99, *Standard for Health Care Facilities*, 2005 edition.

NFPA 99, ~~*Standard for*~~ *Health Care Facilities* Code , 2021 edition.

NFPA 99B , *Standard for Hypobaric Facilities* , 2021 edition.

NFPA 410, *Standard on Aircraft Maintenance*, 2020 edition.

G.1.2 Other Publications.

G.1.2.1 ADCI Publications.

Association of Diving Contractors International, 5206 Cypress Creek Parkway, Suite 202, Houston, TX 77069.

ADCI Consensus Standard 6.3: Association of Diving Contractors International , 2019.

G.1.2.2 ASTM Publications.

ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959.

ASTM D56, *Standard Test Method for Flash Point by Tag Closed Cup Tester*, 2016a.

ASTM D92, *Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester*, 2018.

ASTM D568, *Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Flexible Plastics in a Vertical Position*, Withdrawn.

ASTM D1230, *Standard Test Method for Flammability of Apparel Textiles*, 2017.

ASTM D1929, *Standard Test Method for Determining Ignition Temperature of Plastics*, 2016.

ASTM D2863, *Standard Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)*, 2017a.

ASTM D4809, *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)*, 2018.

ASTM D7194, *Standard Specification for Aerospace Parts Machined from Polychlorotrifluoroethylene (PCTFE)*, 2012.

ASTM D7211, *Standard Specification for Parts Machined from Polychlorotrifluoroethylene (PCTFE) and Intended for General Use*, 2013.

ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*, 2018b.

ASTM E136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C*, 2016a.

ASTM E162, *Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source*, 2016.

ASTM E659, *Standard Test Method for Autoignition Temperature of Liquid Chemicals*, 2015.

ASTM G63, *Standard Guide for Evaluating Nonmetallic Material for Oxygen Service*, 2015.

ASTM G72/G72M, *Standard Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment*, 2015.

ASTM G88, *Standard Guide for Designing Systems for Oxygen Service*, 2013.

ASTM G93, *Standard Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments*, 2003 (reapproved 2011).

ASTM G94, *Standard Guide for Evaluating Metals for Oxygen Service*, 2005 (reapproved 2014).

ASTM G125, *Standard Test Method for Measuring Liquid and Solid Material Fire Limits in Gaseous Oxidants*, 2015.

ASTM G126, *Standard Terminology Relating to the Compatibility and Sensitivity of Materials in Oxygen Enriched Atmospheres* , 2016.

ASTM G128/G128M, *Standard Guide for the Control of Hazards and Risks in Oxygen-Enriched Atmospheres*, 2015.

Fire Hazards in Oxygen Systems.

G.1.2.3 CGA Publications.

Compressed Gas Association, 14501 George Carter Way, Chantilly, VA 20151.

CGA E-2, *Hose Line Check Valve Standards for Welding and Cutting*, 2004.

CGA G-4, *Oxygen*, 2015.

CGA G-4.1, *Cleaning Equipment for Oxygen Service*, 2018.

CGA G-4.4, *Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping Systems*, 2012.

CGA P-14, *Accident Prevention in Oxygen-Rich and Oxygen-Deficient Atmospheres*, 1992.

CGA P-39, *Guidelines for Oxygen-Rich Atmospheres*, 2015.

CGA P-45, *Fire Hazards of Oxygen and Oxygen-Enriched Atmospheres*, 2018.

CGA PS-13, *Position Statement on Definition of a Threshold Oxygen-Mixture Concentration Requiring Special Cleaning of Equipment*, 2007 (R2016).

CGA Video AV-8, "Characteristics and Safe Handling of Cryogenic Liquid Gaseous Oxygen."

G.1.2.4 EIGA Publications.

European Industrial Gases Association, Avenue des Arts 3-5, B-1210 Brussels, Belgium.

EIGA 04/18, *Fire Hazards of Oxygen and Oxygen Enriched-Atmospheres*.

EIGA 5/75/E, *Code of Practice for Supply Equipment and Pipeline Distributing Non-Flammable Gases and Vacuum Services for Medical Purposes*.

EIGA 6/77, *Oxygen Fuel Gas Cutting Machine Safety*.

EIGA 8/76/E, *Prevention of Accidents Arising from Enrichment or Deficiency of Oxygen in the Atmosphere*.

EIGA 10/17, *Reciprocating Compressors for Oxygen Service*.

EIGA 12/80/E, *Pipelines Distributing Gases and Vacuum Services to Medical Laboratories*.

EIGA 27/82/E, *Turbo Compressors for Oxygen Service, Code of Practice*.

EIGA 33/18, *Cleaning of Equipment for Oxygen Service*.

G.1.2.5 IMCA Publications.

International Marine Contractors Association, 52 Grosvenor Gardens, London, SW1W 0AU, United Kingdom.

IMCA D 031, *Cleaning for Oxygen Service: Setting up Facilities and Procedures*, 2003.

IMCA D 048, *Guidance on Surface Supplied Diving Operations Using Nitrox*, 2017.

G.1.2.6 ISO Publications.

International Organization for Standardization, ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland.

ISO 10156, *Gas Cylinders – Gases and gas mixtures – Determination of fire potential and oxidizing ability for the selection of cylinder valve outlets*, 2017.

G.1.2.7 Military Specifications.

Department of Defense Single Stock Point, Document Automation and Production Service, Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-1330D, *Precision Cleaning and Testing of Shipboard Oxygen, Helium, Helium-Oxygen, Nitrogen, and Hydrogen Systems*, 2007.

G.1.2.8 NOAA Publications.

National Oceanic and Atmospheric Administration, 8403 Colesville Road, Suite 500, Silver Springs, MD 20910-3282.

NOAA Diving Manual, 2017.

G.1.2.9 U.S. Government Publications.

U.S. Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20402.

NASA TN-D-5579, "Static Electricity in the Apollo Spacecraft," 1969.

OSHA 29 CFR 1910.430(i) Oxygen Safety.

OSHA 29 CFR 1910.146 Permit-required Confined Spaces.

OSHA 29 CFR 1915.11 Confined and Enclosed Spaces and Other Dangerous Atmospheres in Shipyard Employment.

G.1.2.10 Other Publications.

G.1.2.10.1 References for A.3.3.25 Oxygen-Enriched Atmosphere (OEA).

[1] Schmidt, T.C., et.al., Technical Memorandum UCRI-721, "Chamber Fire Safety," Ocean Systems, Inc., Research and Development Laboratory, Tarrytown, NY, 1973.

[2] Smith, Sarah, "Effect of Oxygen Concentration on Autogenous Ignition Temperature and Pneumatic Impact Ignitability of Nonmetallic Materials," *Journal of ASTM International* , October 2009.

[3] Benning, M.A., "Measurement of Oxygen Index at Elevated Pressures," *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres* , ASTM STP 812, 1983.

G.1.2.10.2 References for Annex F.

(1) NFPA 325M, *Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids* , National Fire Protection Association, Quincy, MA, 1991 edition.

(2) Humphrey, H. B., and Margis, G. "Safety with Solvents." BuMines Information Circular 7757, 1957, 25 pp.

(3) Litchfield, E. L., Kuchta, J. M., and Furno, A. L. "Flammability of Propellant Combinations." BuMines Explosives Research Report 3997, October 30, 1966, 69 pp. (Government Order H-76708, NASA, Huntsville, AL). *Ibid.* Explosives Research Report 3958, June 30, 1965, 83 pp.

(4) Perlee, H. E., Martindill, G. H., and Zabetakis, M. G. "Flammability Characteristics of Selected Halogenated Hydrocarbons." BuMines Report of Investigations 6748, 1966, 12 pp.

(5) Scott, G. S., Jones, G. W., and Scott, F. E. "Determination of Ignition Temperatures of Combustible Liquids and Gases." *Analytical Chemistry* , Vol. 20, March 1948, p. 238.

(6) Zabetakis, M. G. "Flammability Characteristics of Combustible Gases and Vapors." BuMines Bulletin 627, 1985, 121 pp.

(7) Lewis, B., and Von Elbe, G. "Combustion, Flames and Explosion of Gases." Academic Press, New York, 1961, pp. 323–346.

(8) "Basic Considerations in the Combustion of Hydrocarbon Fuels with Air." NACA Report 1300, 1957.

(9) Blanc, M. V., Guest, P. G., Von Elbe, G., and Lewis, B. J. *Chemistry Physics* , Vol. 15, 1947, p. 798. *Ibid* . Third Symposium on Combustion and Flame and Explosion Phenomena. Williams and Wilkins, Baltimore, 1949, p. 363.

(10) Calcote, H. F., Gregory, C. A., Barnett, C. M., and Gilmer, R. B. "Spark Ignition." *Industrial and Engineering Chemicals* , Vol. 44, No. 11, November 1952, p. 2656.

(11) Coward, H. F., and Jones, G. W. "Limits of Flammability of Gases and Vapors." BuMines Bulletin 503, 1952, 155 pp.

(12) Fenn, J. B. "Lean Flammability Limit and Minimum Spark Ignition Energy." *Industrial and Engineering Chemicals* , Vol. 43, No. 12, December 1951, p. 2865.

(13) Kuchta, J. M., and Cato, R. J. "Review of Ignition and Flammability Properties of Lubricants." Air Force Aero Propulsion Laboratory, Tech. Report AFAPL-TR-67-126, January 1968 (AD-665121).

(14) Benz, F. J., Shaw, R. C.,, and Homa, J. M. "Burn Propagation Rates of Metals and Alloys in Gaseous Oxygen." *Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres:* Second Volume, ASTM STP 910. M. A. Benning, editor, American Society for Testing and Materials, Philadelphia, 1986, pp. 135–152.

(15) Zawierucha, R., McIlroy, K., and Mazzarella, R. B. "Promoted Ignition Combustion Behavior of Selected Hastelloys in Oxygen Gas Mixtures." *Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres:* Fifth Volume, ASTM STP 1111. J. M. Stoltzfus and K. McIlroy, editors, American Society for Testing and Materials, Philadelphia, 1991.

(16) Sato, J. "Fire Spread Rates along Cylindrical Metal Rods in High Pressure Oxygen." *Symposium on Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres:* Fourth Volume, ASTM STP 1040. J. M. Stoltzfus, F. J. Benz, and J. S. Stradling, editors, American Society for Testing and Materials, Philadelphia, 1989.

(17) Nagy, J., et al. "Explosibility of Dusts Used in the Plastics Industry." U.S. Bureau of Mines, RI 6516, 1964.

(18) Guest, P. G. "Oily Fibers May Increase Oxygen Tent Fire Hazard." *The Modern Hospital* , May 1965.

(19) Voigtsberger, P. "The Ignition of Oxygen-Impregnated Tissues by Electrostatic and Mechanically Produced Sparks." British Ministry of Power, SMRE Translation No. 5005, June 1964.

(20) Fisher, H. D., and Gerstein, M. "Investigation of Materials Combustibility and Fire and Explosion Suppression in a Variety of Atmospheres." Summary Report Nr. SN-6401 for the

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