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Standard Guide for Evaluating Nonmetallic Materials for Oxygen Service¹

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1. Scope

1.1 This guide applies to nonmetallic materials, (hereinafter called materials) under consideration for oxygen or oxygen-enriched fluid service, direct or indirect, as defined below. It is intended for use in selecting materials for applications in connection with the production, storage, transportation, distribution, or use of oxygen. It is concerned primarily with the properties of a material associated with its relative susceptibility to ignition and propagation of combustion; it does not involve mechanical properties, potential toxicity, outgassing, reactions between various materials in the system, functional reliability, or performance characteristics such as aging, shredding, or sloughing of particles, except when these might contribute to an ignition.

1.2 When this document was originally published in 1980, it addressed both metals and nonmetals. Its scope has been narrowed to address only nonmetals and a separate standard Guide G94 has been developed to address metals.

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.*

NOTE 1—The American Society for Testing and Materials 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.

NOTE 2—In evaluating materials, any mixture with oxygen exceeding atmospheric concentration at pressures higher than atmospheric should be evaluated from the hazard point of view for possible significant increase in material combustibility.

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2. Referenced Documents

2.1 ASTM Standards:²

- D217 Test Methods for Cone Penetration of Lubricating Grease
- D566 Test Method for Dropping Point of Lubricating Grease
- D1264 Test Method for Determining the Water Washout Characteristics of Lubricating Greases
- D1743 Test Method for Determining Corrosion Preventive Properties of Lubricating Greases
- D1748 Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet
- D2512 Test Method for Compatibility of Materials with Liquid Oxygen (Impact Sensitivity Threshold and Pass-Fail Techniques)
- D2863 Test Method for Measuring the Minimum Oxygen Concentration to Support Candle-Like Combustion of Plastics (Oxygen Index)
- D4809 Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)
- G72 Test Method for Autogenous Ignition Temperature of Liquids and Solids in a High-Pressure Oxygen-Enriched Environment
- G74 Test Method for Ignition Sensitivity of Materials to Gaseous Fluid Impact
- G86 Test Method for Determining Ignition Sensitivity of Materials to Mechanical Impact in Ambient Liquid Oxygen and Pressurized Liquid and Gaseous Oxygen Environments
- G88 Guide for Designing Systems for Oxygen Service
- G93 Practice for Cleaning Methods and Cleanliness Levels for Material and Equipment Used in Oxygen-Enriched Environments
- G94 Guide for Evaluating Metals for Oxygen Service

² 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* volume information, refer to the standard's Document Summary page on the ASTM website.

2.2 Federal Standard:

Fed. Test Method Std. 91B Corrosion Protection by Coating: Salt Spray (Fog) Test³

2.3 Other Standard:

BS 3N:100: 1985 Specification for General Design Requirements for Aircraft Oxygen Systems and Equipment⁴

2.4 Other Documents:

CGA Pamphlet G4.4 Industrial Practices for Gaseous Oxygen Transmission and Distribution Piping System⁵

NSS 1740.15 NASA Safety Standard for Oxygen and Oxygen Systems⁶

3. Terminology

3.1 Definitions:

3.1.1 *autoignition temperature*—the temperature at which a material will spontaneously ignite in oxygen under specific test conditions (see Guide G88).

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *direct oxygen service*—in contact with oxygen during normal operations. Examples: oxygen compressor piston rings, control valve seats.

3.2.2 *impact-ignition resistance*—the resistance of a material to ignition when struck by an object in an oxygen atmosphere under a specific test procedure.

3.2.3 *indirect oxygen service*—not normally in contact with oxygen, but which might be as a result of a *reasonably* foreseeable malfunction, operator error, or process disturbance. Examples: liquid oxygen tank insulation, liquid oxygen pump motor bearings.

3.2.4 *maximum use pressure*—the maximum pressure to which a material can be subjected due to a *reasonably* foreseeable malfunction, operator error, or process upset.

3.2.5 *maximum use temperature*—the maximum temperature to which a material can be subjected due to a *reasonably* foreseeable malfunction, operator error, or process upset.

3.2.6 *nonmetallic*—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.

3.2.7 *operating pressure*—the pressure expected under normal operating conditions.

3.2.8 *operating temperature*—the temperature expected under normal operating conditions.

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

3.2.10 *qualified technical personnel*—persons such as engineers and chemists who, by virtue of education, training, or

³ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁴ Available from British Standards Institute (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., <http://www.bsi-global.com>.

⁵ Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.egonet.com>.

⁶ National Aeronautics and Space Administration, Office of Safety and Mission Assurance, Washington, DC.

experience, know how to apply physical and chemical principles involved in the reactions between oxygen and other materials.

3.2.11 *reaction effect*—the personnel injury, facility damage, product loss, downtime, or mission loss that could occur as the result of an ignition.

4. Significance and Use

4.1 The purpose of this guide is to furnish qualified technical personnel with pertinent information for use in selecting materials for oxygen service in order to minimize the probability of ignition and the risk of explosion or fire. It is not intended as a specification for approving materials for oxygen service.

5. Factors Affecting Selection of Material

5.1 *General*—The selection of a material for use with oxygen or oxygen-enriched atmospheres is primarily a matter of understanding the circumstances that cause oxygen to react with the material. Most materials in contact with oxygen will not ignite *without a source of ignition energy*. When an energy-input rate, as converted to heat, is greater than the rate of heat dissipation, and the temperature increase is continued for sufficient time, ignition and combustion will occur. Thus considered: the material's minimum ignition temperature, and the energy sources that will produce a sufficient increase in the temperature of the material. These should be viewed in the context of the *entire system design* so that the specific factors listed below will assume the proper relative significance. To summarize: *it depends on the application*.

5.2 Properties of the Material:

5.2.1 *Factors Affecting Ease of Ignition*—Generally, in considering a material for a specific oxygen application, one of the most significant factors is its minimum ignition temperature in oxygen. Other factors that will affect its ignition are relative resistance to impact, geometry, configuration, specific heat, relative porosity, thermal conductivity, preoxidation or passivity, and “heat-sink effect.” The latter is the heat-transfer aspect of the material to the mass in intimate contact with it, with respect to both the amount and the physical arrangement of each and to their respective physical properties. For instance, a gasket material may have a relatively low ignition temperature but be extremely resistant to ignition when confined between two steel flanges. The presence of a small amount of an easily ignitable material, such as a hydrocarbon oil or a grease film, can promote the ignition of the base material. Accordingly, cleanliness is vital to minimize the risk of ignition (1).⁷ See also Practice G93 and Refs. 2–3.

5.2.2 *Factors Affecting Propagation*—After a material is ignited, combustion may be sustained or may halt. Among the factors that affect whether fire will continue are the basic composition of the material, the pressure, initial temperature, the geometric state of the matter, and whether the available oxygen will be consumed or the accumulation of combustion products reduce the availability of oxygen sufficiently to stop

⁷ The boldface numbers in parentheses refer to the list of references at the end of this standard.

the reaction. Combustion may also be interrupted by the presence of a heat sink.

5.2.3 Properties and Conditions Affecting Potential Resultant Damage—A material’s heat of combustion, its mass, the oxygen concentration, flow conditions before and after ignition, and the flame propagation characteristics affect the potential damage if ignition should occur and should be taken into account in estimating the reaction effect in 7.5.

5.3 Operating Conditions—Conditions that affect the suitability of a material include the other materials of construction and their arrangement in the equipment and pressure, temperature, concentration, flow, and velocity of the oxygen. Pressure and temperature are generally the most significant, and their effects show up in the estimate of ignition potential (5.4) and reaction effect (5.5), as explained in Section 7.

5.3.1 Pressure—The pressure is important, not only because it generally affects the generation of potential ignition mechanisms, but also because it usually significantly affects the destructive effects if ignition should occur. While generalizations are difficult, rough scales would be as given in Table 1.

NOTE 3—While the pressure generally affects the reaction as indicated in Table 1, tests indicate that it has varying effects on individual flammability properties. For example, for many materials, increasing pressure results in the following:

- (1) An increase in propagation rate, with the greatest increase in rate at lower pressures but with significant increases in rate at high pressures;
- (2) A reduction in ignition temperature, with the greatest decrease at low pressure and a smaller rate at high pressure, however, it should be noted that increasing autoignition temperatures with increasing pressures have been reported for selected polymers, due to competing kinetics (4);
- (3) An increase in sensitivity to mechanical impact;
- (4) A reduction in oxygen index, as measured in an exploratory study (5), with sharper initial declines in materials of high oxygen index but with only slight relative declines in general above 10 atmospheres and up to at least 20 atmospheres;
- (5) A negligible change in heat of combustion; and
- (6) An increase in the likelihood of adiabatic compression ignition, with the greatest likelihood at the highest pressures.

In the case of friction, increased pressure may improve heat dissipation and make ignition at constant frictional energy input less likely than at lower pressure. Increased pressure also reduces the likelihood of spark generation at constant electric field strength through increased breakdown voltage values.

5.3.2 Temperature—Increasing temperature obviously increases the risk of ignition but does not generally contribute to the reaction effect. The material should have a minimum ignition temperature, as determined by an acceptable test procedure, that exceeds the maximum use temperature (as defined in 3.2.5) by a suitable safety margin.

5.3.3 Concentration—As oxygen concentration decreases from 100 %, the likelihood and intensity of a potential reaction

also decrease; therefore, greater latitude may be exercised in the selection of materials.

5.4 Ignition Mechanisms—For an ignition to occur, it is necessary to have three elements present: oxidizer, fuel, and ignition energy. The oxygen environment is obviously the oxidizer, and the material under consideration is the fuel. Several potential sources of ignition energy are listed below. The list is neither all-inclusive nor in order of importance nor in frequency of occurrence.

5.4.1 Friction—The rubbing of two solid materials results in the generation of heat. Example: the rub of a centrifugal compressor rotor against its casing.

5.4.2 Heat of Compression—Heat is generated from the conversion of mechanical energy when a gas is compressed from a low to a high pressure. This can occur when high-pressure oxygen is released into a dead-ended tube or pipe, quickly compressing the residual oxygen that was in the tube ahead of it. Example: a downstream valve in a dead-ended high-pressure oxygen manifold.

5.4.2.1 Equation—An equation that can be used to estimate the theoretical maximum temperature that can be developed when pressurizing oxygen rapidly from one pressure and temperature to an elevated pressure is as follows:

$$T_f/T_i = [P_f/P_i]^{(n-1)/n} \tag{1}$$

where:

- T_f = final temperature, abs,
- T_i = initial temperature, abs,
- P_f = final pressure, abs,
- P_i = initial pressure, abs, and
- $n = \frac{C_p}{C_v} = 1.40$ for oxygen,

where:

- C_p = specific heat at constant pressure, and
- C_v = specific heat at constant volume.

Table 2 gives the theoretical temperatures which could be obtained by compressing oxygen from one atmosphere (absolute) and 20°C to the pressures shown.

TABLE 2 Theoretical Maximum Temperature Obtained When Compressing Oxygen Adiabatically from 20°C and One Standard Atmosphere to the Pressures Shown^A

Final Pressure, P_f		Pressure Ratio P_f/P_i	Final Temperature, T_f	
kPa	psia		°C	°F
345	50	3.4	143	289
690	100	6.8	234	453
1000	145	9.9	291	556
1379	200	13.6	344	653
2068	300	20.4	421	789
2758	400	27.2	480	896
3447	500	34.0	530	986
5170	750	51.0	628	1163
6895	1000	68.0	706	1303
10 000	1450	98.6	815	1499
13 790	2000	136.1	920	1688
27 579	4000	272.1	1181	2158
34 474	5000	340.1	1277	2330
100 000	14 500	986.4	1828	3322
1 000 000	145 000	9883.9	3785	6845

^A See 5.4.2.

TABLE 1 Reaction Effect Assessment for Typical Pressures

kPa	psi	Reaction Effect Assessment
0–70	0–10	relatively mild
70–700	10–100	moderate
700–7000	100–1000	intermediate
7000–20 000	1000–3000	severe
Over 20 000	over 3000	extremely severe

5.4.3 *Heat From Mass Impact*—Heat is generated from the transfer of kinetic energy when an object having relatively large mass or momentum strikes a material. Example: hammer striking oxygen-saturated macadam.

5.4.4 *Heat from Particle Impact*—Heat is generated from the transfer of kinetic and possibly thermal energy when small particles (sometimes incandescent), moving at high velocity, strike a material. Example: dirt particles striking a valve seat in an inadequately cleaned high-velocity pipeline.

5.4.5 *Static Electric Discharge*—Electrical discharge from static electricity, possibly generated by high fluid flow under certain conditions, may occur, especially where particulate matter is present. Example: arcing in poorly cleaned, inadequately grounded piping.

5.4.6 *Electrical Arc*—Electrical arcing may occur from motor brushes, electrical control equipment, instrumentation, lightning, etc. Example: defective pressure switch.

5.4.7 *Resonance*—Acoustic oscillations within resonant cavities are associated with rapid temperature rise. This rise is more rapid and achieves higher values where particulates are present or where there are high gas velocities. Ignition can result. For example: a gas flow into a tee and out of the side port when the remaining port presents a resonant cavity.

5.4.8 *Internal Flexing*—Continuous rapid flexing of a material can generate heat. Such heating may add to environmental factors and increase the possibility of ignition. For example: a gasket protruding into the fluid flow stream.

5.4.9 *Other*—Since little is known about the actual cause of some oxygen fires or explosions, other mechanisms, not readily apparent, may be factors in, or causes of such incidents. These might include external sources, such as defective electric resistance-heating elements, careless smoking, welding sparks or spatter, and nearby open flames; or internal sources such as flow friction and material fracture.

5.5 *Reaction Effect*—The effect of an ignition (and subsequent combustion propagation, if it should occur) has a strong bearing on the selection of a material. While it is an obviously imprecise and strongly subjective judgment, it must be balanced against factors such as those given in 5.6. Suggested criteria for rating the reaction effect severity are given in Table 3, and a method of applying the rating in a material selection

process is given in Section 7. The user should keep in mind that, in many cases, the reaction effect severity rating for a particular application can be lowered by changing other materials that may be present in the system, changing component locations, varying operating procedures, or using barricades or shields and the like.

5.6 *Extenuating Factors*—Performance requirements, prior experience with the material, availability, and cost enter into the decision. For instance, while a particular material may be rated relatively low based on conventional acceptance criteria, many years of successful safe usage or full-life cycle tests might indicate its continued acceptance.

6. Test Methods

6.1 *Calorimeter Test, Test Method D4809*—This is a measurement of the heat evolved per unit of sample mass when a material is completely burned in 25 to 35 atm (2.5 to 3.5 MPa) of oxygen at constant volume. The results are reported in calories per gram (or megajoules per kilogram). For many materials, measured amounts of combustion promoter must be added to ensure complete combustion. Heat of combustion is a test readily conducted and many differing bomb calorimeter methods provide results with adequate accuracy for use with this guide.

6.2 *Ignition Sensitivity of Materials to Mechanical Impact in Ambient and Pressurized Oxygen Environments, Test Method G86*—This is a determination of the drop-height required to produce a reaction when energy from a known mass is transmitted through a striker pin in contact with a sample immersed in liquid oxygen or exposed to gaseous oxygen. Results are reported in drop-height and number of reactions in 20 drops. Test Method G86 is currently the only mechanical impact test that is fully standardized, although other procedures are used in some laboratories. For this reason, and for the large quantity of background data already obtained using this procedure, Test Method G86 is the recommended screening test to evaluate materials for mechanical impact sensitivity.

NOTE 4—Previous mechanical impact data in ambient pressure liquid oxygen may have been obtained following Test Method D2512 procedures. In 1997, Test Method G86 was updated to include a LOX impact

TABLE 3 Reaction Effect Assessment for Oxygen Applications

Rating		Effect on Personnel Safety	Effect on System Objectives	Effect on Functional Capability
Code	Severity Level			
A	Negligible	No injury to personnel	No unacceptable effect on production, storage, transportation, distribution, or use as applicable	No unacceptable damage to the system
B	Marginal	Personnel-injuring factors can be controlled by automatic devices, warning devices, or special operating procedures	Production, storage, transportation, distribution, or use as applicable is possible by utilizing available redundant operational options	No more than one component or subsystem damaged. This condition is either repairable or replaceable within an acceptable time frame on site
C	Critical	Personnel injured (1) operating the system, (2) maintaining the system, or (3) being in vicinity of the system	Production, storage, transportation, distribution, or use as applicable impaired seriously	Two or more major subsystems are damaged—This condition requires extensive maintenance
D	Catastrophic	Personnel suffer death or multiple injuries	Production, storage, transportation, distribution, or use as applicable rendered impossible—major unit is lost	No portion of system can be salvaged—total loss

test procedure that includes a more strict calibration procedure as an alternative to Test Method **D2512**. At a given plummet drop height the pressurized LOX mechanical impact system provides significantly lower impact energy than the ambient pressure LOX mechanical impact system; however, the relative ranking of materials was maintained.

NOTE 5—This test method was developed as a screening technique for selection of nonmetallic materials for use in liquid and gaseous oxygen service components and systems; the test has proven to be consistent in its rankings. For tests in liquid oxygen, since the material specimen is immersed in liquid oxygen prior to impact, and since the liquid oxygen surrounding the specimen is maintained at atmospheric pressure, two concerns must be stated. The first concern relates to the physical changes incurred in a specimen when the specimen temperature is reduced to cryogenic conditions. Sensitivity of selected materials may be significantly affected by this physical change. The second concern relates to test severity. Experience indicates that most materials are more sensitive to ambient or heated gaseous oxygen environments, as opposed to cryogenic oxygen environments. Also, experience shows most materials have a tendency to display increasing sensitivity with increasing oxygen pressure. As a result, tests in ambient pressure liquid oxygen may not be sufficiently severe to discriminate materials for use in ambient or elevated temperature, high-pressure gaseous oxygen systems.

6.3 Limiting Oxygen Index Test, Method **D2863**—This is a determination of the minimum concentration of oxygen in a flowing mixture of oxygen and nitrogen at 1 atm (0.1 MPa) that will just support flaming combustion from top ignition. The minimum oxygen concentration that will support combustion of materials in configurations that differ from the test configuration may be greater or less than the measured oxygen index value.

NOTE 6—Oxygen index data are reported as a volume percent oxygen (0 to 100). However, early work reported the volume fractional oxygen (0 to 1.0).

NOTE 7—Experience with oxygen index tests indicates that elevated temperatures enable combustion in lower oxygen concentrations and that passage of hot combustion products across an unaffected surface may preheat and promote combustion of materials in concentrations below the oxygen index value. In exploratory work to measure oxygen indices at elevated pressures up to 20 atm (2.0 MPa), it was found that the oxygen index decreased with increasing pressures, but that the ranking of materials was unchanged.

6.4 Autogenous Ignition Temperature Test, Test Method **G72**—This is a determination of the minimum sample temperature at which a material will spontaneously ignite when heated in an oxygen or oxygen-enriched atmosphere. Autogenous ignition (commonly called the autoignition temperature) should be measured at or above the maximum anticipated oxygen concentration. The test should be continued up to the ignition point or at least to 100°C above the maximum use temperature. The temperature that will produce autoignition of materials in configurations that differ from the test configuration may be greater or less than the measured autoignition temperature. System materials and contaminants may catalyze and lower ignition temperatures. Samples with large surface area to volume ratios (such as powders) typically ignite at lower temperatures. Flammable vapors that evolve at elevated temperatures may promote lower ignition temperatures, or if dissipated, result in higher autoignition temperatures.

NOTE 8—Pressure has its greatest effect on autoignition temperatures at lower levels. For instance, an autoignition temperature of a typical elastomer as measured by Test Method **G72** may decrease 80°C between 1.5 and 15 psig (10 and 100 kPa), but may only decrease 10°C between 150 and 750 psig (1000 and 5000 kPa). The autoignition temperature test

measures a highly behavioral property of a material, especially among polymers. Because it depends upon geometry, heating rate, temperature history of the material, trace contaminants and even catalytic effects of the environment, data collected on differing apparatuses using differing techniques may yield widely differing results. One should therefore not confuse the measured autoignition temperature minimum with the minimum temperature at which the material might ignite in actual hardware.

6.5 Gaseous Fluid Impact Test, Test Method **G74**—This is a test in which the material is subjected to a rapid oxygen pressure rise in a closed end tube. The procedure may be used as a fixed-pressure screening method or to measure a threshold pressure.

NOTE 9—This test method provides a reliable means for ranking nonmetallic materials for use in gaseous oxygen service components and systems. The test is configuration dependent and severe. Reaction threshold pressures obtained for most materials are below those pressures that would produce ignition in most common systems.

6.6 Additional Candidate Test Methods:

6.6.1 Thermal Analysis Tests—In these tests, a material's tendencies to undergo exothermic or endothermic activity are observed as temperature is raised. Pilot studies have been accomplished with Accelerating Rate Calorimeters (ARC) and Pressurized Differential Scanning Calorimeters (PDSC), and data have been published for autoignition temperatures measured by Differential Thermal Analysis (DTA). These tests indicate that material reactions occur at temperatures significantly different from those measured with the autoignition temperature Test Method **G72**.

NOTE 10—Although some thermal analysis tests report lower autoignition temperatures than Test Method **G72**, one should not infer that even these measurements represent the lowest levels at which ignition could conceivably occur in real systems.

6.6.2 Friction/Rubbing Test—The material is heated by friction and rubbing resulting from contact between rotating and stationary test specimens. This test method permits evaluation of materials under various axial loads while exposed to elevated pressure oxygen or oxygen-enriched environments.

NOTE 11—There is no standard friction rubbing test for polymers and no plans to develop test. Preliminary tests were conducted by NASA in the late 1970s, and polymers proved difficult to ignite. At that time, test development focused on the study of metals which are more likely to experience severe rubs in actual systems. In the case of polymers, in particular nylon, the polymers melted and flowed from the friction zone.

6.6.3 Particle Impact Test—The material is struck by particles while exposed to a flowing oxygen environment.

NOTE 12—There is no standard test method for studying the ignition of nonmetals during particle impact and none is planned. Preliminary tests conducted by NASA suggest that polymers may be more difficult to ignite than metals under particle impact, possibly due to their ability to cushion an impact.

6.6.4 Promoted Ignition Test—The material is heated by exposure to an electrically-ignited promoter material of known heat content. This test method is currently being developed and permits evaluation of materials while subjected to elevated-pressure oxygen or oxygen-enriched environments.

NOTE 13—Polymers have much lower autoignition temperatures than metals and tend to ignite in a range of 150 to 450°C. Further, the combustion temperatures of most polymers exceeds the autoignition temperature of virtually all polymers. Hence tests to evaluate the ability of

a promoter material or amount of promoter necessary to ignite polymers are not deemed meaningful and rather, the concept of a promoted ignition test is usually applied only to metals for which there are enormous ranges of ignition temperatures and for which the amount of polymer or metal necessary to cause ignition is more amenable to experiment.

6.6.5 Electrical Arc—This test is designed to evaluate the arc ignition characteristics of materials in pressurized oxygen or oxygen-enriched atmospheres.

NOTE 14—There is no standard test method for electrical arc ignition of nonmetals, and none is planned. Experience in oxygen and limited testing in air suggests that arc ignition of polymers as a result of static charge separation is unlikely at low pressures, perhaps also at high pressures. Further, reports on incident studies of NASA suggest that probable arcing at high pressures in oxygen did not produce ignition.

6.6.6 Special Tests—Depending on circumstances, a unique test may be required to qualify a material for a specific application, such as a resonance, internal flexing, or hot-wire ignition test.

7. Material Selection Method

7.1 Overview—To select a material for an application, first review the application to determine the probability that the chosen material will be exposed to significant ignition phenomena in service (7.2). Then consider the prospective material's susceptibility to ignition (7.3) and its destructive potential or capacity to involve other materials (7.4) once ignited. Next, consider the potential effects of an ignition on the system environment (7.5). Finally, compare the demands of the application with the level of performance anticipated from the material in the context of the necessity to avoid ignition and decide whether the material will be acceptable (7.6).

7.2 Ignition Probability Assessment—In assessing a material's suitability for a specific oxygen application, the first step is to review the application for the presence of potential ignition mechanisms and the probability of their occurrence under both normal and *reasonably* foreseeable abnormal conditions. As shown in the Materials Evaluation Data sheets, **Appendix X1**, values may be assigned, based on the following probability scale:

- 0—Almost impossible
- 1—Remote
- 2—Unlikely
- 3—Probable
- 4—Highly probable

This estimate is quite imprecise and generally subjective, but furnishes a basis for evaluating an application through helping to focus on the most important properties. These ratings may in some cases be influenced by the materials present in the system.

7.3 Ignition-Susceptibility Determination—The next step is to determine its rating with respect to those factors which affect ease of ignition (5.2.1), assuming the material meets the other performance requirements of the application. If required information is not available in published literature or from prior related experience, one or more of the applicable tests described in Section 6 should be conducted to obtain it. The application and materials present will play a strong role in defining the most important criterion in determining the ignition susceptibility.

NOTE 15—Until an ASTM procedure is established for a particular test, test results are to be considered provisional.

7.4 Post-Ignition Property Evaluation—The properties and conditions that could affect potential resultant damage if ignition should occur (5.2.3) should be evaluated. Of particular importance is the total heat release potential, that is, the material's heat of combustion times its mass (in consistent units). When available, other important postignition data of interest are the rate of resulting combustion and the oxygen index.

7.5 Reaction Effect Assessment—Based on the evaluation of 7.4, and the conditions of the complete system in which the material is to be used, the reaction effect severity should be assessed using **Table 3** as a guide. In judging the severity level for entry on the Material Evaluation Data Sheets, **Appendix X1**, it is important to note that the severity level is defined by the most severe of any of the effects, that is, effect on personnel safety *or* on system objectives *or* on functional capability. The materials present in the system can affect the reaction effect assessments.

7.6 Final Selection—In the final analysis, the selection of a material for a particular application involves a complex interaction of the above steps, frequently with much subjective judgment, external influences, and compromises involved. While each case must ultimately be decided on its own merits, the following generalizations apply:

7.6.1 Use the least reactive material available consistent with sound engineering and economic practice. Attempt to maximize autoignition temperature, oxygen index, mechanical impact ignition energy, and gaseous impact pressure threshold. Attempt to minimize heat of combustion and total heat release. Not every test need be conducted for every application, but it is best to base material selections on more than one test method.

7.6.1.1 If the damage or personnel injury potential is high (Severity Level C or D) use the best (least reactive) practical material available (see **Table 3**).

7.6.1.2 If the damage or personnel injury potential is low (Severity Level A or B) and the ignition mechanism probability is low (2 or less) a material with a medium resistance to ignition may be used.

7.6.1.3 If one or more potential ignition mechanisms have a relatively high probability of occurrence (3 or 4 on the probability scale, 7.2) use only a material which has a very high resistance to ignition.

7.6.2 The higher the maximum use pressure, the more critical is the resistance to ignition (see 5.3.1).

7.6.3 Prefer a material whose autoignition temperature in oxygen (as determined by 6.4) exceeds the maximum use temperature by at least 100°C. A larger temperature differential may be appropriate for high use pressures (see 7.6.2) or other mitigating factors.

7.6.4 Autoignition temperatures of 400°C or higher are preferred; 160°C or lower, unsuitable for all but the mildest applications (see 6.4).

7.6.5 Resistance to ignition by impact from drop heights of 43.3 in. (1100 mm) on repeated trials is preferred, while

susceptibility to ignition at 6.0 in. (152 mm) or lower would render a material unsuitable for all but the mildest applications (see 6.2).

7.6.6 Heats of combustion of 2500 cal/g (10.5 MJ/kg) or less are preferred; heats of combustion of 10 000 cal/g (41.9 MJ/kg) or higher are unsuitable for all but the mildest applications (see 6.1).

7.6.7 Materials with high oxygen indices are preferable to materials with low oxygen indices. For demanding applications, choose a material with an oxygen index above 55. Materials with oxygen indices below 20 are unsuitable for all but the mildest applications (see 6.3).

NOTE 16—With respect to guidelines 7.6.3-7.6.7, the use of materials that yield intermediate test results is a matter of judgment involving consideration of all significant factors in the particular application.

7.6.8 Experience with a given material in a similar application or a similar material in the same application frequently forms a sound basis for a material selection. However, discretion should be used in the extrapolation of conditions.

7.6.9 Since some materials vary from batch to batch, it may be necessary to test each batch for some applications.

7.7 Documentation—Table X1.1 (Appendix X1) is a materials evaluation sheet filled out for a number of different applications. It indicates how a materials evaluation is made and what documentation is involved. Pertinent information such as operating conditions should be recorded; estimates of ignition mechanism probability and reaction effect ratings filled in; and a material selection made on the basis of the above guidelines. Explanatory remarks should be indicated by a letter in the “Remarks” column and noted following the table.

7.8 Examples—The following examples illustrate the material selection procedure applied to three different hypothetical cases involving valve seats, and one case of a gasket:

7.8.1 High-Pressure Manifold Shutoff Valve:

7.8.1.1 Application Description—An ambient-temperature 1-in. (2.54-cm) stainless steel manifold requires a manual shutoff valve located 20 ft (6.1 m) from a primary 5000-psig (34.5-MPa) pressure source. The line is to be located outdoors but near attended equipment. A primary pressure valve upstream can be opened rapidly, hence the line might be rapidly pressurized to 5000 psig. A soft-seated valve is desirable to allow ease of operation.

7.8.1.2 Ignition Probability Assessment (see 7.2)—Due to a small contact area and small quantity of rubbing motion during operation, friction ignition is considered to be remote. Though the valve can be opened rapidly, the maximum velocity of the seat during closure would be negligible, hence mechanical impact ignition is also rated remote. Since the system is both clean and dry, neither particle impact nor static electricity is felt to be likely. There is no electrical apparatus in the equipment, so that arc ignition is thought to be almost impossible. Since sudden pressurization of the system to 5000 psig (34.5 MPa) might occur, the theoretical temperature achievable from heat of compression would be very high, and adiabatic compression ignition is thought to be a highly probable ignition source. No other ignition sources are identified, but their absence cannot be assumed. The summary of ignition probability ratings is:

Friction	1
Heat of Compression	4
Mechanical Impact	1
Particle Impact	2
Static Electricity	2
Electric Arc	0
Other	1

7.8.1.3 Prospective Material Evaluations (see 7.3)—Nonmetallic seat materials are reviewed, and polytetrafluoroethylene (PTFE) is found to be highly rated with regard to resistance to ignition (it has one of the highest ignition temperatures for plastics). A well-documented material, it has a very low heat of combustion of 1700 cal/g and impressive Liquid Oxygen (LOX) impact results of passing at a 10 kg-m energy level. Hence, PTFE is considered the best available plastic.

7.8.1.4 Post-Ignition Property Evaluation (see 7.4)—Though PTFE is found to have a low heat of combustion, the size of the seat required is quite large. Beyond this, PTFE is found to be a rather dense material. In consequence, ignition of the seat would be expected to release a small to moderate quantity of heat.

7.8.1.5 Reaction Effect Assessment (see 7.5)—Ignition of the seat might, in turn, ignite the stainless steel valve components and possibly release fire to the surroundings. Since such ignition would most likely occur while personnel are in the immediate area and since barricading is not feasible, the effect on personnel safety is rated high. Ignition would result in damage to the valve alone, which could be readily and inexpensively replaced. Interruption of the system for the required repair time is acceptable. Hence the following reaction assessment ratings are assigned:

Effect of Personnel Safety	D
Effect on System Objectives	B
Effect on Function Capability	B

Because of the importance of personnel safety, the overall rating is concluded to be a worst case D.

7.8.1.6 Final Selection (see 7.6)—In view of the overall Catastrophic Reaction Assessment Rating (Code D), only a valve seat that is very able to function successfully is concluded to be acceptable. Since there is a high probability (rating 3) that a PTFE seat would be exposed to temperatures due to heat of compression approaching the ignition point, even PTFE is concluded to be unacceptable in this application. As a result, a metal seat is selected instead (refer to X1.1).

7.8.2 Pipeline Control Valve:

7.8.2.1 Application Description—Automatic flow control is required in an 8-in. (20.3-cm), 650-psig (4.6-MPa) carbon steel above-ground pipeline at ambient temperature. High flow and tight shutoff are also required. The control valve is unattended in normal operation. The line was previously blast cleaned, and a strainer will be immediately upstream of the valve. A bronze-body globe valve is under consideration. A 10 diameter length of Monel pipe is present downstream to comply with CGA Pamphlet G-4.4 (6). A soft seat is under consideration.

7.8.2.2 Ignition Probability Assessment (see 7.2)—Friction is negligible between the plug and seat. Also the operational speed and load are low; frictional heating is unlikely. Rapid opening is likely to produce nearly adiabatic compression heating downstream of the valves and affect materials there.

Rapid closure could produce inertia ram pressurization against the valve by the large upstream mass; adiabatic compression ignition is a significant prospect. There can be only a low velocity impact of the plug on the seat during closure, and the presence of a strainer renders remote chances of mechanical impact or particle impact ignition. Since the pipeline is clean, dry, and remote from electrical equipment, arc and spark from associated equipment or static discharge are unlikely. The pipeline is grounded and subject to lightning strikes. However, in the event of so intense an ignition event, the role of valve seat would be relatively unimportant. No other ignition mechanisms are identified, but their absence cannot be assumed. The summary of ignition probability ratings is:

Friction	1
Heat of Compression	3
Mechanical Impact	1
Particle Impact	1
Static Electricity	1
Electric Arc	0
Other	1

7.8.2.3 *Prospective Material Evaluations (see 7.3)*—The probable exposure to heat of compression ignition requires a material with a high ignition temperature; PTFE has one of the highest autoignition temperatures capable of withstanding predictable temperatures. PTFE also has a low heat of combustion, and excellent mechanical impact test results. PTFE is also readily available and superior to the alternative of nylon. Hence PTFE is taken under consideration.

7.8.2.4 *Post-Ignition Property Assessment (see 7.4)*—Though PTFE has a low heat of combustion, the mass of PTFE present in the seat is large and PTFE is rather dense; complete combustion would represent a large heat release. In contrast, the PTFE is in excellent contact with a massive bronze body and the gas-wetted area is modest. As a result, the very compatible brass body should resist ignition and remain intact. Ignition of the downstream carbon steel piping is rated unlikely because of the 10 diameter isolation section of monel pipe.

7.8.2.5 *Reaction Effect Assessment (see 7.5)*—Ignition of the seat would be unlikely to produce a major release of fire nor to ignite the pipeline. Since the valve and neighboring pipeline are unattended, the effect of personnel safety is rated negligible (A). Combustion of the seat in the absence of penetration would not interrupt oxygen supply to the pipeline, nor would the combustion products force a long-term process problem. Combustion of the seat, when the valve is closed would supply oxygen to the pipeline, but the system can safely control this flow. Hence the effect on system objectives is rated negligible (A). Finally, since only the valve seat is expected to react, the effect on functional capability is rated marginal (B). The overall reaction effect rating is therefore the marginal (B) rating of the effect on functional capability.

7.8.2.6 *Final Selection (see 7.6)*—Among the materials available for valve seats, only PTFE rated acceptable relative to the probable exposure to heat of compression. The destructive potential of PTFE is acceptable and yields an acceptable reaction effect. As a result, PTFE is selected for the seat application.

7.8.3 *Reactor Butterfly Valve:*

7.8.3.1 *Application Description*—Several 12-in. (30-cm) remotely operated butterfly valves are required for controlling flow to a reactor. The piping is stainless steel. The temperature is essentially ambient. The operating pressure is 2 psig (13.8 kPa gage). The gas velocity is 40 ft/s (12.2 m/s). Elastomer linings for use as seats in cast steel valves with bronze disks are under consideration.

7.8.3.2 *Ignition Probability Assessment (see 7.2)*—A review of the operating conditions and the system indicates that no ignition mechanism is likely to be present. Valve breakaway and sealing torque are low, and the valve is slow-operating, so disk-to-seat friction and mechanical impact are rated as remote probabilities. The relatively low gas velocity and the cleanness of the stainless steel line minimize particulate impact and static electricity, which are rated unlikely and remote, respectively. Heat of compression is almost impossible at the low pressures involved. There is no electrical apparatus that could produce ignition, and therefore a remote rating is assigned. No other mechanisms of ignition are foreseen, but their absence cannot be assumed. Therefore a summary of the ignition probability assessment is:

Friction	1
Heat of Compression	0
Mechanical Impact	1
Particle Impact	2
Static Electricity	1
Electric Arc	1
Other	1

7.8.3.3 *Prospective Material Evaluations (see 7.3)*—For economy, it is desirable to use the manufacturer’s standard CR elastomer liner (chloroprene rubber), which also functions as a seat. Oxygen compatibility tests on the liner material give the following results:

Autoignition temperature in 2000 psig (13.8 MPa) O ₂ , °C	200
Impact, minimum drop height, in. (mm)	27 (680)
Heat of Combustion, cal/g (MJ/kg)	5800 (24.3)

7.8.3.4 *Post-Ignition Property Evaluation (see 7.4)*—The relatively high total heat release potential (5.8 kcal/g × 8.8 kg per liner = 51 000 kcal per liner) is substantial but is expected to be released at a fairly low rate in 2 psi (13.8 kPa gage) oxygen.

7.8.3.5 *Reaction Effect Assessment (see 7.5)*—Ignition of the seat would not likely ignite the cast steel valve body or the stainless steel piping; a release of flame would also be unlikely. Also, the valves are located on top of the reactor, isolated from personnel or other equipment. As a result, the effect on personnel safety is rated negligible. Damage in the event of an ignition would likely be less than \$1000 and the process upset would be minimal due to parallel manifolding. For these reasons, the effect on system objectives is rated negligible, and the effect on functional capability is rated marginal. The summary of the Reaction Effect Assessment is:

Effect on Personnel Safety	A
Effect on System Objectives	A
Effect on Functional Capability	B

The overall assessment is a marginal B rating.

7.8.3.6 *Final Selection (see 7.6)*—In view of the rather mild marginal rating resulting from modest repair costs alone, the CR elastomer with a medium resistance to ignition is justified,

consistent with 7.6.1.2. The judgment is buttressed by reference to Table X1.1 which indicates successful use of this material in a nearly identical situation.

7.8.4 Pipeline Gasket:

7.8.4.1 Application Description—A gasket is required for use between flanges in a 900-psig (6.2-MPa) centrifugal compressor discharge to a carbon steel pipeline. Gas temperatures of 150°C are possible. The flange is unattended and remotely located.

7.8.4.2 Ignition Probability Assessment (see 7.2)—There is no friction source in a flange system, therefore friction ignition is essentially impossible. Due to the inherent volume in the pipeline, pressure relieving devices, limited flow rate of the compressor, and the fact that the flange is not at a dead end, rapid pressurization is a remote possibility. In addition, there are no mechanical motions that might produce impact of the gasket. Particles might be produced and might be accelerated to the gas velocity, however, direct impact on the gasket is unlikely since the gasket will be installed by qualified mechanics and will, therefore, be properly and completely isolated between the steel flanges. The absence of associated electrical equipment and shielding indicate a remote chance of static electricity or electric arc ignition. No other sources are foreseen, but their absence cannot be assumed. The summary of ignition probability ratings is:

Friction	0
Heat of Recompression	1
Mechanical Impact	1
Particle Impact	1
Static Electricity	1
Electric Arc	1
Other	1

7.8.4.3 Prospective Material Evaluations (see 7.3)—A wide range of materials are available ranging from PTFE to rubber gaskets. Typical commercial gaskets of asbestos/SBR rubber are mechanically desirable and readily available. The autoignition temperature of PTFE and CTFE is found to be high, while asbestos/SBR gaskets have autoignition temperatures of roughly 200°C. Mechanical creep (cold flow) of PTFE is a mechanical concern.

7.8.4.4 Post-Ignition Property Evaluations (see 7.4)—Available gaskets have a wide range of heats of combustion. PTFE and CTFE are among the lowest and exhibit excellent results in other test types. The asbestos/SBR gaskets in many cases have heats of combustion as low as PTFE and CTFE. Rubber gaskets tend to have high heats of combustion. In addition, the total mass of gasket present tends to be quite small, and it is in excellent contact with massive metal flanges. In consequence, ignition of the gasket would tend to release a small quantity of total heat, and propagation would tend to be inhibited.

7.8.4.5 Reaction Effect Assessment (see 7.5)—Ignition of the gasket might produce ignition of the flange. Since the area is unattended, the effect on personnel would be negligible. The delivery of product would be interrupted but could be backed-up, yielding a marginal effect on system objectives. Similarly, limited damage that is rapidly repairable would result, yielding a marginal effect on functional capability. Hence the following reaction effect assessment ratings are assigned:

Effect on Personnel Safety	A
Effect on System Objectives	B
Effect on Functional Capability	B

As a result the overall rating is a marginal B.

7.8.4.6 Final Selection (see 7.6)—In view of the overall marginal reaction assessment rating, a gasket of moderate compatibility is acceptable. In the case of asbestos/SBR, the heat of combustion and total heat release compare favorably with highly acceptable PTFE. In addition, if ignition does occur, the asbestos matrix would likely remain in the thin seal region and act to interfere with the diffusion of oxygen to the flame zone, as well as combustion products away from the flame zone; this effect in combination with the thermal mass of the flanges might aid self-extinguishment. Finally, though the autoignition temperature of the asbestos/SBR is much lower than PTFE, and, indeed, is not the desired 100°C above the use temperature, there are no foreseeable mechanisms to produce brief temperature excursions that might approach ignition in a system with such a large thermal inertia. In this case, a 50°C margin between measured autoignition temperature and use temperature is felt to be acceptable and an asbestos/SBR gasket is chosen.

7.8.5 Gas Filters:

7.8.5.1 Application Description—Oxygen gas for electronics-industry microchip manufacture with a purity of 99.5 % has to be filtered at a maximum pressure of 200 psig (1481 kPa) and a maximum temperature of 200°F (93.3°C). The oxygen supply stream will contain no particles greater than 100 µm in size. The maximum expected gas velocity that may impinge onto the filter surface is 20 m/s. Several stages of progressively finer filtration will be used. Some of the filters will be located in areas close to personnel.

7.8.5.2 Ignition Probability Assessment (see 7.2)—Since there is no physical rubbing in a filter, the prospect of friction ignition should be almost impossible. The filter might be located at the end of a piping run of significant volume that will have to be occasionally pressurized. Guide G88 indicates that at a 200 psig final pressure, compression of ambient-temperature, atmospheric-pressure oxygen may produce final temperatures on the order of 344°C (653°F). If the initial temperature is 200°F, the final temperature may be 496°C (926°F). Therefore, depending upon filter material and the fact that filters tend to have high surface-area-to-volume ratios and tend to collect particles that may be easily ignited, heat of compression ignition is probable. The planned filters contain no moving parts, therefore mechanical impact ignition is almost impossible. The upstream systems will contain valves that might generate particles and depending upon other metallic materials present, might develop corrosion products. As a result, the prospect of particles striking the filter surface is great. The gas velocity is well below the maximum allowed by CGA Pamphlet G-4.4 which applies for carbon steel and stainless steel piping systems in nonimpingement circumstances; however, in this case, the particles will impinge on the filter surface itself. If the particles have been heated by impacts, they may be effective ignition sources upon contact with nonmetallics, and, since a filter is an inherent impingement site, compliance with CGA Pamphlet G-4.4 by virtue of the present velocity would be questionable even for a metal

filter surface. The likelihood of charge separation and electrostatic buildup is small in a metal system, although, because some filter media are excellent dielectrics, this possibility cannot be ruled out completely. There are no associated electrical services foreseen that might lead to arcing. No other ignition sources are identified but their absence cannot be assumed. The summary of ignition probability ratings is:

Friction	0
Heat of Compression	3
Mechanical Impact	0
Particle Impact (nonmetals media)	4
Particle Impact (metallic media)	3
Static Electricity	2
Electric Arc	0
Other	1

7.8.5.3 Prospective Material Evaluations (see 7.3)—Filter media are available in fully oxidized materials such as fiberglass or fired ceramics; these materials are virtually nonflammable in oxygen provided they do not incorporate binders. Media are also available in metals that have been sintered or spun for wire, and these typically exhibit a range of acceptabilities and all partial metallic materials such as bronze, Monel, nickel, and stainless steel have much higher ignition temperatures than nonmetals. Finally, media are available in polymeric materials including nylon, PTFE and others. These nonmetallic materials include the latest membrane-type filter media which exhibit the ability to filter to very fine particle size but that utilize very thin, high-surface-area components. Thin materials are likely to be very ignition-responsive to high temperature particle contact or elevated temperatures due to heat of compression. The desirability ranking of the assorted materials was in the order glass and ceramic first (on the basis of being nonignitable), metals second (with brass, bronze, nickel and Monel much preferred over stainless steel, in accordance with Guide G94), and polymers last (with PTFE and PFA preferred over nylon).

7.8.5.4 Post-Ignition Property Evaluation (see 7.4)—Since the fiberglass and ceramic materials are basically nonflammable, a fire of the media itself is not possible. In the case of metallic media, brass and bronze, Monel, Inconel 600, and nickel are shown to be highly propagation resistant 0.125-in. (0.31-cm) diameter rods by available data, while stainless steel is likely to propagate a fire under at least some conditions of expected operation (see Guide G94). The polymer materials are all likely to extensively combust under most of the anticipated system parameters. Polymers like PTFE and PFA are likely to produce much less heat release and damage than polymers such as nylon and polysulfone; however, in the case of membrane-type filters, the quantity of polymer present is very large, being on the order of kilograms, such that even a fire of PTFE may cause penetration or weakening with rupture of the system as well as ignition of other system materials including piping if metals such as carbon steel or stainless steel are used.

7.8.5.5 Reaction Effect Assessment (see 7.5)—The ignition mechanisms would be inconsequential with fiberglass or ceramic filters having light particle loadings. The ignition mechanisms are unlikely to ignite bronze, brass, Monel, Inconel, or nickel media. A prospect of igniting stainless steel media exists, and burning stainless steel would be a powerful ignition

source that may involve other materials such as carbon steel and stainless steel structural members. Burning stainless steel media, even within a copper, brass, Monel, Inconel, or nickel piping system, might melt through and release oxygen and burning metal slag. The relative ease of igniting the polymer membrane filters and their large mass also raises a likelihood of rupture, ignition or penetration of the metal piping with the release of fire. Although the filter membrane elements are large in comparison to typical polymers in an oxygen system, the overall filter assemblies are small in terms of system hardware. Therefore, replacement is possible in an acceptable time frame, however, debris released may pose a cleanup problem downstream. This debris may be irrelevant in many traditional oxygen systems, but could be unacceptable to ultraclean processes. The systems tend to be ganged, so that damage to one system would not be a major disruption. Hence the following reaction assessment ratings are assigned:

Effect on Personnel Safety:	
(fiberglass, ceramic media)	A
(brass, Monel, nickel, Inconel, media)	A
(stainless steel, polymer media)	C
Effect on System Objectives:	
(fiberglass or ceramic media)	A
(brass, bronze, Monel, Inconel, nickel media)	A
(stainless steel or polymer media)	B
Effect on Functional Capability	B

As a result, the overall rating is a critical “C” for stainless steel or polymer media based upon the personnel safety effect rating and is a marginal “B” rating for fiberglass, ceramic, brass, bronze, Monel, Inconel, or nickel media based upon the less demanding effect on functional capability.

7.8.5.6 Final Selection (see 7.6)—Since some of the prospective materials yield an overall critical reaction-effect-assessment fiberglass or ceramic media were highly preferred in combination with copper-based or nickel-alloy structural members. In this case, the requirements of the process dictate stainless steel structural members sized in general with the criteria of CGA Pamphlet G-4.4. As a result, the structural members are a conceivable participant in any significant internal fire. The desirability of the ceramic or fiberglass media are thus, accentuated. However, fiberglass media is unacceptable to the process, and ceramic filters have not been located to provide the required filtration levels. In turn, the next most desirable media was metallic with the copper-based and nickel-alloy media preferred to stainless steel. Here again, the copper-based options (including Monel) were unacceptable to the process, and, hence, nickel or Inconel are the preferred options. However, the filtration ability of available nickel-alloy mesh is inadequate to achieve the required submicrometre filtration, membrane filters were found to be required for mechanical reasons. Among the membrane filters, PTFE supported on PFA exhibits the best test results in oxygen index, ignition temperature, and heat of combustion tests (see Tables X1.2, X1.4, and X1.5), and was concluded to be the least flammable practical material. Because of the large mass and presumed susceptibility to ignition of the membrane configuration even with PTFE and PFA media, additional precautions were felt necessary. To mitigate against particle impact ignition, a prefilter of nickel mesh of 10–30 micron pore size was located immediately upstream of the filter. This serves to