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Spacecraft Fire Safety 1956 to 1999

An Annotated Bibliography

Robert Friedman and Gary A. Ruff
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September 2013

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Summary

Knowledge of fire safety in spacecraft has resulted from over 50 years of investigation and experience in space flight. Current practices and procedures for the operation of the Space Transportation System (STS) shuttle and the International Space Station (ISS) have been developed from this expertise, much of which has been documented in various reports. Extending manned space exploration from low Earth orbit to lunar or Martian habitats and beyond will require continued research in microgravity combustion and fire protection in low gravity. This descriptive bibliography has been produced to document and summarize significant work in the area of spacecraft fire safety that was published between 1956 and July 1999. Although some important work published in the late 1990s may be missing, these citations as well as work since 2000 can generally be found in Web-based resources that are easily accessed and searched. In addition to the citation, each reference includes a short description of the contents and conclusions of the article. The bibliography contains over 800 citations that are cross-referenced both by topic and the authors and editors.

1.0 Introduction

Living and working in space is a dangerous endeavor and will continue to be so for the foreseeable future. Our ability to survive in the harsh environment of space is a direct result of many experimental investigations, numerical analyses and simulations, and system evaluations. The current practices and procedures that allowed the safe operation of the Space Transportation System (STS) and are in place on the International Space Station (ISS) have been developed from these investigations and the experience gained through years of successful operation of manned space flight systems. This record of safe operation is testimony to the commitment and dedication of the individuals who have contributed to the space program.

As we once again expand the boundaries of manned exploration beyond low Earth orbit, we are sure to face new challenges on many fronts. Most of these relate to maintaining the crew health and safety during long-duration missions. The threat of an on-board fire has always been one of the more serious risks for a manned space flight. However, the most important factor distinguishing spacecraft from terrestrial fire protection systems is the unique atmospheric composition (%O_2 and pressure) and the low-gravity environment that dominates fire and particulate behavior and control in spacecraft. The substantial upward buoyant flow generated by large density gradients in fires in normal gravity is eliminated in an orbiting spacecraft, causing great differences in ignition and combustion processes. As a result, practically every aspect of fire prevention, detection, and suppression must be revisited and evaluated before fire protection of the crew and spacecraft can be assured. At the partial gravity levels that would exist in a lunar or Martian habitat, the effects of buoyancy, convection, and diffusion can combine to produce unique combustion results that are not simple interpolations between normal-gravity and microgravity results. Understanding these effects will require a significant number of investigations before crew safety can be ensured in these environments. A considerable number of research investigations have been and are being conducted to address these issues and unknowns related to combustion and fire protection in low gravity and partial gravity. Each investigation was defined and formulated on the results of previous research, each one adding a new piece to the puzzle of spacecraft fire protection. Future investigations will undoubtedly build on the past and current investigations.

The purpose of this bibliography is to document literature related to spacecraft fire safety produced during the second half of the twentieth century. The earliest reference is from 1956; the last from July 1999. In total, more than 800 references are included in this bibliography. In addition to the citation information, each reference includes a summary of the contents and findings of the investigation. Because of the rapid increase in the amount of literature in the late twentieth and early twenty-first centuries, some important contributions may be missing from this bibliography. However, most of the recent scientific literature can be found in Web-based resources that are easily accessible and searchable.

The citations in this descriptive bibliography are listed in chronological order to identify clearly the progression of the investigations. Each citation is identified by a sequential number to identify it in the two cross-reference lists presented in Section 2.0. The first of these is a topical cross-reference that lists each of the papers pertaining to a specific topic. Papers may be listed under multiple topics if they were particularly relevant to several of them. The second cross-reference is by author, with the papers listed under both primary authors and co-authors as well as editors of publications. A list of citations and their summaries is given in Section 3.0. Here, the citation numbers that are displayed with an asterisk (*) are those that are available in full text on the associated DVD, which accompanies the printed version of this report and is also available from the Center for Aerospace Information (www.sti.nasa.gov). The DVD contains the full-text articles of the selected citations as well as the electronic version of this report, where these citations are in blue font and are active links to their corresponding full-text article.

2.0 Cross-References to Bibliography

This section contains both topic and author cross-references to each of the numbered citations in this bibliography. Citations may be listed in multiple topic areas depending on their content. Also, primary authors as well as coauthors and editors are listed in the author cross-reference section.

2.1 Topics

The references contained in this bibliography have been grouped according to their topic and area of applicability. The topical cross-reference given below is in outline form to emphasize major topics and subgroupings within that topic. The numbers refer to the reference listing number in the chronological reference that follows. If multiple topics were addressed within a reference, the reference number is listed in each of the appropriate topics.

2.2 Authors

A cross-reference of the authors, co-authors, and editors of the publications listed in this bibliography is given below. For reports written by multiple authors, the reference number is listed adjacent to each author.

C

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3.0 Chronological Listing of the References

This section contains a chronological listing of the references included in this bibliography of fire safety in spacecraft along with a short summary of each. Note that the descriptions of the gravity environments are not necessarily consistent among the authors. Basically, normal gravity is the standard near-sea-level acceleration of 9.8 m/s^2 and may be denoted as 1g. Microgravity is the near-zero gravity encountered in free-fall and in unpowered orbiting and planetary mission spacecraft. It may be denoted by 0g or μg. Partial gravity is an environment with a finite acceleration less than the Earth g-level; for example, those on the lunar or Martian surfaces. Partial gravity is denoted by the fraction of normal gravity, such as 0.3g.

1. Kumagai, Seiichiro; and Isoda, Hiroshi: Combustion of Fuel Droplets in a Falling Chamber. Sixth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1956, pp. 726–731.

This is possibly the first reported results of 0g combustion research. The authors used a suspended combustion chamber with counterweight to study n-C_7H_{16} and C_2H_5OH droplets on filaments. Near 0g, droplets had spherical flame boundaries, which become oval at normal g. Evaporation rate measured as $D_0^2 - D^2 = Kt$ was about half the value at 0g compared with normal-g predictions. Ratio of flame diameter to drop diameter was not steady with time. Discussion after paper claims that flame diameter ≈ (droplet diameter)$^{1/2}$.

*2. Roth, Emanuel M.: Space Cabin Atmospheres. NASA SP–48, pt. II, 1964.

This is an excellent review of space cabin atmospheres for its time. Chapter I on definitions and theory gives a good background on combustion. Chapter 3 discusses O_2 and %O_2 effects on gas and liquid flammability. Chapter 4 on electrical hazards includes some of the material on the possible hazards of high-temperature Teflon. Chapter 6 on fire protection and extinguishment covers ignition sources, isolation, flame, heat, particle and pressure detectors, and physical and chemical flame extinguishment. Chapter 7 is a review on selection of spacecraft atmospheres presenting some arguments against 100 %O_2 (but not concluding that this should be avoided).

3. Bialecki, A.; and Laubach, G.E.; and Solitario, W.A.: An Approach to Trace Contaminant Control for a Spacecraft Atmosphere. Chemical Engineering Techniques in Aerospace, vol. 60, no. 52, Donald J. Simkin, ed., American Institute of Chemical Engineers, New York, NY, 1964, pp. 188–198.

This is a review comparing submarine with spacecraft (differences in inward versus outward leakage, gravity, and so forth). Contaminants are generated by materials, processes, and man. Various removal systems and total venting are discussed. The main contribution is a discussion of toxicology and a table of tentative limits for 2-week continuous exposure, supplied by R.H. Edgerly, a North American Aviation toxicologist. Spacecraft detectors, including gas chromatography, are briefly discussed.

3A. Huggett, Clayton; von Elbe, Guenther; Haggerty, Wilbert; and Grossman, Jay: The Effects of 100% Oxygen at Reduced Pressure on the Ignitibility and Combustibility of Materials, SAM–TR–65–78, AFSC, Brooks Air Force Base, TX, 1965.

This is an early experimental study investigating flammability of reference and spacecraft materials in 5 psia, 100-percent oxygen atmospheres, at normal gravity. In a theoretical section, the authors concluded that μg decreases but does not eliminate the fire hazard. They note that benefits of μg are lost in the case of ventilation flows. Experiments were conducted in a 90-liter chamber with viewing windows. Ignitibility was investigated using a 1200-W lamp source. Ignition for flame spread experiments was by a heated Nichrome wire. Obvious conclusions are that O_2 content has slight effect on ignitibility by radiation (energy requirement). However, flame spread rates are 1 to 3 orders of magnitude greater in O_2 than in air. Using materials such as fiberglass tape, which do not burn in air, burn in O_2 (sizing material in tape ignites, probably). Spread rates were measured for downward or horizontal flame spread. These are assumed to be applicable to the μg environment also.

*4. Kimzey, J.H.: Flammability During Weightlessness. Proceedings of the Institute of Environmental Sciences Annual Technical Meeting, Institute of Environmental Sciences, Mt. Prospect, IL, 1966, pp. 433–437.

Pioneer study in KC-135 aircraft at Wright-Patterson Air Force Base with combustion package to observe 0g flames in paraffin at conditions of 21 to 100 percent O_2 and 5 to 14.7 psi. Data are shown for rate of burning from photographs for practical solids (neoprene, Teflon, etc). Rate of burning is much less at 0g compared with that in normal gravity. Qualitative observations are that flames are spherical and the combustion zone changes from lean to rich as diffusion of O_2 is slow. Flames cool and are quenched in about 1.5 s, and steady state is not attained.

*5. Kimzey, J.H.; Downs, W.R.; Eldred, C.H.; and Norris, C.W.: Flammability in Zero-Gravity Environment. NASA TR–R–246, 1966.

This is an expanded version of the last paper, Reference 4.

6. Huggett, Clayton; Spurlock, Jack, M.; von Elbe, Guenther; Tobriner, Mathew, W.; Gift, Ralph; and Grossman, J.R.: Analytical Study of the Flammability of Spacecraft Materials. NASA CR–134192, 1967. Available from the NASA Center for Aerospace Information.

This report reviews growth of fire in Apollo space cabin deriving pressure rise as function of time and mass burned. The proposed Apollo material criteria are discussed, as well as the selection of material. For choice of atmospheres, a rate of combustion (filter paper, 45° at normal atmosphere) is approximately

$$\frac{P^{1/2}}{C_{PO_2} + nC_{Px}}$$

where P = total pressure (atm), Cp = heat capacity/mole of O_2 and diluent, and n = moles of inert/mole of O_2. If this parameter is 0.02 or less (corresponding to 1 atm, 14 percent O_2), flame spread falls to zero. Report also discusses chemical, optical, and thermal flame detection, as well as various extinguishing methods for spacecraft. The status of materials acceptance (MSC–A–D–66–3) is discussed, as well as that of early American Society for Testing and Materials (ASTM) procedure D–1230. Recommendations for the Apollo spacecraft are (1) inventory and control of combustibles and quantities, (2) compartmentalization to control fire spread, and (3) sealing and inerting of certain compartments. Recommendations for further study are (1) standardized material test methods, (2) material placement and size control criteria, (3) development of noncombustible substitutes, (4) fire dynamics in closed chambers, (5) zero-gravity combustion studies, (6) fire detection, and (7) fire extinguishment.

*7. Miller, L.G.: A Parametric Study on the Use of Diluent Gases as a Means of Extinguishing Spacecraft Fires in Flight. NASA CR–154993, 1967.

This is a simple set of gas law equations to demonstrate times for simultaneous evacuation and inert gas loading in the 5 psi-O_2 Apollo. Final total pressure is 3 psi, with O_2 partial pressure <0.8 psi. N_2 and He are both used, with various orifice sizes. Author recognizes that inert gas extinguishers in an O_2 atmosphere enhance combustion through forced convection but suggests concurrent depressurization and inerting are effective.

8. Botteri; B.P.: Fire Protection for Oxygen Enriched Atmosphere Applications. AFAPL–CONF–67–10, 1967.

This paper discusses background of initiation and combustion in O_2-enriched atmospheres. The main part of the paper presents calculations for Apollo (having an enclosed volume of 360 ft^3), maximum heat release, pressure ratios, and so forth and shows pressure-time plots. Fire detection and extinguishment are discussed briefly. Fire extinguishers for O_2-enriched atmospheres are evaluated qualitatively.

9. Haun, C.C.; Vernot, E.H.; Geiger, D.L.; and McNerney, J.M.: Inhalation Toxicity of Pyrolysis Products of Bromochloromethane (CH_2BrCl) and Bromotrifluoromethane ($CBrF_3$). Am. Ind. Hyg. Assoc. J., vol. 30, no. 6, 1969.

$CBrF_3$ was pyrolyzed in H_2-O_2 at 800 °C, and rats were exposed to 1700 to 4500 ppm. Assuming 55 percent decomposition, the standard 50% lethal dose (LD50) was 2300 ppm. Analysis showed that HF was the most likely toxin. Work is quite simplified.

10. Cook, Gerhard, A.: Combustion Safety in Burning Atmospheres, in above, pp. 139–145.

This paper presents results of burning rate tests on paper at an angle of 45° in various atmospheric pressures (to 10 atm) for N_2-O_2 and He-O_2. Except when O_2 was less than 20 percent, the burning rate in He is higher by up to 40 percent. The report notes classes of materials based on flammability in various %O_2 and various pressures. Interesting plots show burning rates for various %O_2 as function of total pressure.

*11. Bonura, M.S.; Nelson, W.G., et al.: Engineering Criteria for Spacecraft Cabin Atmosphere Selection. NASA CR–891, 1967.

The report reviews the effects of O_2, N_2-O_2, and He-O_2 on comfort zone, leakage, atmospheric supply, heat/mass transfer, life support systems, and fire prevention. For the latter, authors note ignition temperature is little affected by gravity or by the diluent. He-O_2 requires a higher ignition energy. Diluents reduced flame propagation rate for cotton cloth. Zero-gravity tests run in an AeroCommander showed larger flames for N_2-O_2 than He-O_2. Fire extinguishing by CO_2, cryogenic N_2, or vacuum purge was recommended.

12. Kimzey, J.H.: Freon 1301 as a Fire Fighting Medium in an Oxygen-Rich Atmosphere, NASA–TM–X–70164, 1967.

The author reviews Halon 1301 or DuPont 13B1 for weight effectiveness, corrosiveness, handling and toxicity. Decomposition products are toxic. A basic literature review cites space studies from the U.S. Air Force, Lockheed Martin Corporation, the U.S. Bureau of Mines, and Reference 2. For Apollo application, tests were conducted on a boiler plate model at several pressures and %O_2. Halon 1301and most other extinguishants are poor at 60+ %O_2—only water seems effective. A quick, explosive-release system may work with Halon 1301 in O_2.

13. McAlevy III, Robert F.; and Magee, Richard S.: A Criterion for Space Capsule Fire Hazard Minimization. J. Spacecraft, vol. 4, no. 10, 1967, p. 1390.

Simple tests with polystyrene and poly(methyl methacrylate) (PMMA) in oxygen-diluent atmospheres give $V = Y_{O_2}{}^m P^n$, where V is flame-spread velocity, Y_{O_2} is O_2 mole fraction, P is total pressure (4 to 415 psia), $m > 1$ and a function of the diluent, and $n < 1$ and constant. Flame-spreading rates were highest with He, then Ar, then N_2. Note that to increase the O_2 partial pressure while retaining fire safety, increase P rather than Y_{O_2}. The diluent of choice is N_2.

14. Botteri, B.P.: Fire Protection for Oxygen Enriched Atmosphere Applications. AFAPL–CONF–67–10, 1967.

Generally, the fire process consists of initiation, combustion, and extinguishment phases. For enriched atmospheres, the upper limit of flammability increases, ignition energy decreases, and flame spread increases. Total pressure has a similar effect. Fire detectors need fast response, and radiation detectors are most promising. Fire extinguishers seem limited to water or halons. This reference is based on Reference 8.

15. Kimzey, J.H.: Fighting Fires in an Oxygen-Rich Atmosphere. NASA TM–79891, 1968.

In a hyperbaric, oxygen-rich atmosphere, Halon and CO_2 are ineffective in fighting fires. Only a water deluge seems effective.

*16. Herrera, W.R.: Prototype Spacecraft Fire Extinguisher Evaluation. NASA CR–171801, 1968.

The Southwest Research Institute conducted evaluation tests of the foam extinguisher for Apollo. The foam consisted of 25 wt% Freon 12 and 75 wt% H_2O with gelling agents. Fire tests in a pressure vessel were used to extinguish samples of polyethylene in 100 percent O_2 at 6.2, 15.0, and 20.0 psia. Extinguishment was rapid. Gas chromatography analyses showed no decomposition of the Freon. Calculation of total discharge in Apollo cabin showed a maximum of 1.66 percent Freon, below any harmful concentration.

*17. Kimzey, John H.: Flammable and Toxic Materials in the Oxygen Atmosphere of Manned Spacecraft. NASA TN D–3415, 1968.

This is a primarily a literature review with excellent, early references. A table shows toxic atmospheric contaminants with levels defined for continuous 2-week exposure. Ignition requirements are reviewed in terms of a number of parameters: fuel composition, oxidant composition, pressure, surface area, mixing, catalyst, etc. Four approaches of fire extinguishment are discussed including isolation of fuel and/or oxidant, heat removal, flame zone disturbance, and radiation blockage. For 0g, the author feels that fires are self-extinguished after 0.8 to 1.2 s because of product buildup, but they may subsequently reignite. The dangers of aerosols may be great. The report also discusses prohibited items and what is needed in fire detection, coatings to suppress ignition, O_2 partial pressure, and so forth.

18. Stevens, M.R.; Fisher, H.D.; and Breen, B.P.: Investigation of Materials Combustibility, Fire, and Explosion Suppression in a Variety of Atmospheres, AFAPL–TR–68–35, 1968.

This is an early work dealing with (1) measurements of spontaneous ignition temperature of polyethylene, polyvinyl chloride, and nylon as function of O_2 content and flow rate; (2) ignition and burning rate of polyethylene and dacron in a chamber at 1g and 0g; and (3) burning rates of polyethylene influenced by extinguishants. In (1), the spontaneous ignition temperature generally increases as O_2 is reduced from 100 to 20 percent. In (2), 0g work was very limited—a NASA airplane (unspecified) was used. Experiments for a reference normal-gravity condition showed that, compared with N_2, He dilution decreases the burning rate for polyethylene, but increases it for dacron. Normal-gravity tests with Halon 1301 showed no suppression at 100 to 50 percent O_2 atmospheres. Where there was some slowing of burning, Br_2 was observed, and the test chamber was badly corroded. Water was ineffective as an extinguishant, but a protein foam agent did slow the burning rate. At 0g, burning rates of polyethylene were greatly reduced, but otherwise results were scanty and ambiguous. In (3), polyethylene and dacron burning rates were observed to establish an ignition-nonignition zone for Halon 1301 suppression. Ignition could be achieved for a maximum value of about 25 percent Halon at 760 mm Hg total pressure to 65 percent at 250 mm Hg.

*19. Atallah, S.; Bonne, U.; and de Ris, J.N.: The Flammability of Electronic Components in Spacecraft Environments. NASA CR–86106, 1968.

This Factory Mutual Research Company report focuses on theory to develop a model of flame spread in 0g using combustion reactions including radiation and conduction heat transfer. A critical condition is shown where a mass transfer number depending on density ρ, velocity V, diffusivity D, and time. This is used to show what fuels will burn in air and oxygen. Experimental work in airplanes and falling drops is quoted, but no comparison to theory is possible. It is mentioned that 0g may also be simulated by an electrostatic field. The Botteri work (Refs. 8 and 14) is quoted along with his plots for the Apollo accident. Final discussion is on theoretical flammability of wire bundles.

*20. Neustein, R.A.; Mader, P.D.; Colombo, G.V.; and Richardson, D.E.: The Effect of Atmosphere Selection and Gravity on Burning Rate and Ignition Temperature. McDonnell, Douglas Astronautics Company Report DAC–62431, 1968. Also Colombo, Mader, Neustein, and Richardson, NASA CR-106652.

This work continues that of Reference 11, adding more KC–135 0g studies plus Ne as a diluent. For 0g, burning rates were very low because of the accumulation of combustion products. Ne-O_2 at 5 psia and higher showed results intermediate to N_2-O_2 and He-O_2. Ignition energy was less than that of He, and burning rates were less. It was noted that He requires the highest ignition energy but has the highest burning rate. Zero-gravity ignition is accompanied by a flash because of the accumulation of combustibles. Work on minor preignition and combustion products of cotton (acrolein, acetaldehyde, etc.) is quoted for information on possible fire detection by infrared (IR) sensors.

*21. Jamison, H.H.: Evaluation of Bromotrifluoromethane as a Fire Extinguishing Agent for Apollo Hypergolic Propellants. NASA–TM–X–64349 (Internal Note MSF–EP–R–68–18), 1968.

Halon 1301 was tested in a cabinet against Aerozine-50 (A–50)/nitrogen tetroxide (N_2O_4) fires for application to Apollo lunar module adapter area fires. Tests results were visual and through gas analysis. The tests showed Halon 1301 is unaffected by aluminum, A–50, or N_2O_4. The hypergolic fires were extinguished by 1301 but not N_2. A polyurethane sponge, soaked in N_2O_4, does not ignite, but can be ignited with a spark and extinguished with 1301.

*22. Charno, R.J.: Evaluation of High Expansion Foam for Spacecraft Fire Extinguishment. NASA CR– 99580, 1969.

Reports on E.W. Bliss Company tests in a 400-ft^3 chamber using 95 percent water and 5 percent protein foam extinguisher at 20 to 100 percent O_2 at 5 to 16.5 psia. Polyurethane fires were always extinguished. Cotton fires usually were not extinguished.

*23. Callinan, J.; and Adelberg, M.: A Study of the Results of Tests Investigating the Effect of Acceleration on the Burning Rate of Spacecraft Materials. NASA CR–102067, 1969.

This reports on work done at the NASA Lyndon B. Johnson Space Center White Sands Test Facility, as summarized by the contractor, Adelberg Research and Development Labs of Sherman Oaks, CA. Specimens were mounted on a centrifuge for vertical burning in 16.5 psi, 100% O_2 up to 15g. Some materials would self-extinguish above 1g, such as Teflon, asbestos, Kel-F, and Beta cloth, probably because of convective cooling. Some materials showed reduced burning rates at about 1g to 3g, but then rates increased mildly with increasing acceleration, probably because of enhanced flow of melt preheating material faster than convection cooling. This group included Nomex, Al-Mylar, Al-Kaptan, and neoprene-coated nylon. Finally, Nylon Parapax showed a rapid increase in burning rate with g due to disintegration and melting. Horizontal burning of cotton cloth showed an increase in burning rate with increasing acceleration that leveled off above 5g.

*24. Kimzey, John Howard: Zero-Gravity Flammability. NASA TM X–66480, 1969.

A reprint of TM X–58001, (Ref. 4) except that it includes the proposed Skylab test requirements for the project M–479.

25. Radnofsky, M.I.: History and Development of Nonflammable Material for Apollo Spacecraft. Aerospace Med., vol. 40, 1969, pp. 1181–1185. (Nov)

This paper summarizes materials developed for spacecraft (Beta cloth, polybenzimidazole (PBI), metal cloth, Fluorel, etc.). Reference is made to MSC–A–D–66–3 and the later MSC–PA–D–67–13, the early NASA material standards.

26. Huggett, C.: Combustion Processes in the Aerospace Environment. Aerospace Med., vol. 40, 1969, pp. 1176–1180.

This paper deals mainly with oxygen-diluent effects. Increased oxygen affects combustibility in three ways: (1) wider flammability limits (more combustible materials), (2) reduced ignition energy, and (3) increased flame-spread rate. The hazards of the aerospace environment are noted. A rough correlation of flame spread rate with $C_p/P^{1/2}$ is noted, where C_p is the heat capacity/mole of O_2 and P is pressure, where high values of the parameter promote nonflammability. An analysis of the growth of the Apollo 204 fire in ΔP and O_2 consumed with time is shown to illustrate rapid exponential growth of fires.

27. Botteri, B.P.; and Manheim, J.: Fire and Explosion Suppression Techniques, Aerospace Med., vol. 40, 1969, pp. 1186–1193.

Fire protection involves prevention, overheat and fire detection, and extinguishment. Discussion of the latter is focused mainly on aircraft fuel tanks and crash fires, but some rate of hyperbaric oxygen-enriched chambers can apply to spacecraft. A table lists modes and compatibilities of various extinguishments. Most favorable agents are water and Halon 1301. Ternary diagrams are included for ignitibility of Mylar, cotton, and Teflon in air-helium-Halon 1301 mixtures.

28. Johnston, R.S.: Combustion Safety in the Spacecraft Environment. Aerospace Med., vol. 40, 1969, pp. 1997–1202.

This paper discusses atmospheres and notes that a 60-percent O_2 and 40-percent N_2 atmosphere for pad and launch operations is considered reference. Material Categories A to H as defined in Huggett, et al. (Ref. 6) and MSC–PA–D–67–13 are described. A retrieval system, Characterization of Materials (COMAT), for storage of material flammability data at the Manned Space Center (MSC) is described. Fire extinguishers for Apollo are potable water injectors.

*29. Callinan, J.; and Adelberg, M.: A Study of the Results of Tests Investigating the Effect of Acceleration and Gas Composition on the Burning Rate of Spacecraft Materials. NASA CR–102069, 1969.

This is a further statistical treatment of the Reference 23 data. For 13 various nonmetallic materials, burning rates were measured in the centrifuge for upward and downward combustion in 16.5 psia, 100 percent O_2; 16.5 psia, 60 percent O_2 and 40 percent N_2; and 6.2 psia 100 percent O_2. Acceleration range was to 15g, but 1g to 3g was ignored (decreasing range noted in Ref. 23). Overall upward burning rate increased by factor of 3.2 to 15g; downward by 2.6 to 15g. For upward burning, statistically for all materials, the pure O_2 atmosphere showed the greatest increase with acceleration level for downward burning, all three atmospheres showed nearly the same response. Again, the competing mechanisms, that is, convective heat transfer and the migration of melting particles, may explain differences. Absolute upward burning rates at 1g were about 3 times greater than for downward.

*30. Potter, Andrew E., Jr.; and Baker, Benny R.: Static Electricity in the Apollo Spacecraft. NASA TN D–5579, 1969.

Measurement of potential sparks from space-suited men in the Apollo showed spark energies up to 2 mJ could be generated. This is enough to ignite gas vapors and mists (minimum energies of 0.002 to 0.4 mJ, depending on atmosphere), but below the experimental minimum for log book paper and cotton underwear (ignition requires over 10 mJ). Any hazards are removed by grounding of sensors and other wiring.

31. Dorr, V.A.: Fire Studies in Oxygen-Enriched Atmospheres. J. Fire Flamm., vol. 1, 1970, pp. 91–106.

The paper cites experimental work on filter paper burning rate in 15 to 100 percent O_2 at 1 to 10 atm, in N_2 and He. The combustion process is accelerated in He. The plot cited by Knight (Ref. 286) for complete, incomplete, and noncombustion zones is presented. Additional data are shown for He. The paper rates a large number of types of fabric, elastomers, and so forth according to a scale of fire resistance of 0 (burns readily) to 9 (nonflammable in 100 percent 0_2). Experimental work confirms the acceleration of combustion with total pressure (constant O_2 concentration) and oxygen concentration.

32. Andracchio, Charles R.; and Aydelott, John C.: Comparison of Flame Spreading Over Thin Flat Surfaces in Normal Gravity and Weightlessness in an Oxygen Environment. NASA TM X–1992, 1970.

This is the first NASA drop tower combustion report, referencing only the Kimzey KC–135 experiments. The facility is the small tower, 27 m, 2.2-s free fall, with a drag shield. Two cellulose acetate and three 6.3- by 6.3-cm paper specimens 0.03 to 0.10 mm thick were used, in 100 percent O_2 at 5 psia (34 kPa). Wire ribbon ignition started 0.6 s after 0g for 0.5 s. Comparison to 1g showed 0g flame spread for all materials, and both horizontal and vertical orientation was 3 to 48 percent less than in 1g. Zero-gravity flame was rounded and spread nearly equally in all directions. Ignition was the same for 0g and 1g. The 0g flames were less visible and “quieter.”

*33. Cochran, Thomas H.; and Masica, William J.: Effects of Gravity on Laminar Gas Jet Diffusion Flames. NASA TN D–5872, 1970.

In the 2.2-s NASA drop tower, 24 tests were made with CH_4 flowing from a tube into air at ambient pressure. Ignition was 4 s before the drop, and just before impact, the CH_4 flame was turned off and a CO_2 purge started. In 1g, the visible flame length was linear with flow rate (1 to 6 cm for 0.1 to 0.6 cm^3/s) independent of nozzle size for three radii of 0.19 to 0.44 cm. For 0g, the flame initially decreased, became more spherical and then expanded until apparently extinguishing at 0.7 s. Zero-gravity flame colors were from yellow to rouge to orange (no blue). The fractional decrease in length $(L_1 - L_0)/L_1$, was correlated with $0.09\mathrm{Gr}^{0.37}\,\mathrm{Re}^{0.69}$ based on average properties between 21 °C ambient and 1875 °C adiabatic flame temperatures. The length at extinguishment was correlated with fuel Re only.

34. Anon., August 1970.

A concept for Skylab fire extinguishers is proposed. (probably related to Ref. 16). The Apollo fire extinguisher uses an emulsion of liquid Freon 12 droplets in an aqueous gel. The new concept will use a Halon in a pressure vessel, with a foam agent in a collapsible bellow in the vessel. The major unknown is the effect of 0g.

35. Kimzey, J.H.: informal notes, September 1970.

For an orbital space base, the author assumes 21 percent O_2 at 12.5 psia, compartmented structures, good storage of combustibles, and artificial gravity (0.7g). Fire detection is both passive and active (alarm turns on extinguisher). Gas, thermal, pressure, and other fire sensors are mentioned. Fire extinguishment can be by water spray, high expansion foam (see Ref. 50), gaseous extinguishers, and venting. The author mentions crew training, housekeeping, and so forth.

36. Kimzey, J.H.: Coolanol 15 Flammability, unpublished, September 1970.

Tests of flammability of Coolanol 15, a saturated alkyl silicone, in air and in 70% O_2 at 5 psia. Flashpoint, of course, is reduced at 5 psia. The Apollo foam extinguisher is effective at normal pressures but doesn’t work at 5 psia. Reduced pressure, such as that of venting, causes flare-ups of the quenched flame.

*37. Cochran, Thomas H.; Petrash, Donald A.; Andracchio, Charles R.; and Sotos, Ray G.: Burning of Teflon-Insulated Wires in Supercritical Oxygen at Normal and Zero Gravity. NASA TM X–2174, 1971.

This is the first combustion study in the NASA 143-m drop tower, 5.l8-s free fall. The tests were applicable to the Apollo 13 fire. Four drops were made with Teflon-insulated wires ignited in O_2 at 6.3 MPa and –118 °C. Differences were the shrink-tube types or an Al block. Normal-gravity flame spread was 1.4 cm/s. Zero-gravity wires also ignited, but flame spread was less, and combustion was less pulsating.

*38. Krupnick, A.C.: A Proposed Fire and Toxic Gas Caution and Warning System for Shuttle. Space Shuttle Technology Conference, Vol. 1: Operations, Maintenance, and Safety, NASA TM X–67264, 1971, pp. 261–276.

Author notes needs for fire detection in shuttle. The proposed system was an interferometer with gas filtering with an infrared sensor to detect pyrolysis and combustion products, principally COF_2 and SiF_4, with background monitoring of CO, CO_2, and H_2O. The breadboard model was produced as a spectrometer/interferometer but apparently never placed in service.

39. Kumagai, S.; Sakai, T.; and Okajima, S.: Combustion of Free Fuel Droplets in a Freely Falling Chamber. Thirteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1971, pp. 779–785.

An extension and improvement on the work of Reference 1. The droplet of hexane is suspended in a falling chamber. The drop is pulled free. The length of fall is not stated.

40. Cochran, Thomas H.; and Masica, William J.: An Investigation of Gravity Effects on Laminar Gas-Jet Diffusion Flames, 1971, pp. 821–829.

This report is identical to Reference 33 except that an indication of work in progress on smaller diameter tubes (Ref. 55) is given.

41. Bonne, Ulrich: Radiative Extinguishment of Diffusion Flames at Zero Gravity. Comb. Flame, vol. 16, 1971, pp. 147–159.

This paper attempts to model Kimzey's results, assuming that the 0g flame is extinguished by radiative heat transfer. Most of the work is mathematical showing that cooling to 900 K occurs in less than 1 s. Experimental work at normal gravity in a flat CH_3-air burner seems to contribute nothing.

*42. Downs, W.R.: The Combustion Process. NASA SP–5096, 1971, pp. 3–7. From the Manned Space Center (MSC) Conference, May 6–7, 1970.

The report presents a brief description of 1g and 0g flame zones.

43. Katsikas, C.J.; and Levine, J.H.: Manned Spacecraft Nonmetallic-Materials Flammability Selection Criteria and Requirements. NASA SP–5096, 1971, pp. 9–21.

This paper describes nonmetallic material and configuration selections using the MSC–PA–D–67–13 standard with illustration of some flame propagation rates as a function of O_2 partial pressure.

*44. Johnston, R.L.; and Pippen, D.L.: Development of Materials Screening Tests for Oxygen-Enriched Environments. NASA SP–5096, 1971, pp. 23–27.

The report describes the findings of an ad hoc committee on wire insulation to establish and formulate a test and development program for Apollo wire insulation. Early test procedures were proposed for high O_2 in 1963 when American Society for Testing and Materials (ASTM) and other tests proved inadequate. This need led to the NASA material-acceptance standard MS–PA–G7–13. Nine current tests are described, particularly upward propagation, downward propagation, combined thermogravimetric analysis and spark ignition, electrical wire insulation and accessory flammability, electrical setting and coating flammability, and determination of CO and odors.

*45. Bricker, R.W.; Crabb, J.P.; and Spiker, I.K.: Flammability Tests for Apollo Command Module and Lunar Module Mockup. NASA SP–5096, 1971, pp. 43–54.

Tests are described for flammability in cabin mockup in 100 percent O_2 at 5.8, 6.2, and 16.2 psia, and in 60 percent O_2 and 40 percent N_2 at 16.2 psia. An internal Nichrome wire igniter and external igniter were used. With certain material changes, the O_2-N_2, 16.2-psia atmosphere and the 100-percent-O_2, 6.2-psia atmosphere were found to be fire safe.

*46. Dawn, Frederick, S.: Nonmetallic-Materials Development for Spacecraft Applications. NASA SP–5096, 1971, pp. 57–63.

The report contains an evaluation of PBI and Kapton polyimide. It describes the first flammability tests of Astro Velcro with a Teflon pile and nylon hook at 1g, in 100 percent O_2 at 6.2 psia as well as in 60 percent O_2 and 40 percent N_2 at 16.5 psia.

*47. Fish, Richard H.: The Performance of Lightweight Plastic Foams Developed for Fire Safety. NASA SP–5096, 1971, 103–110.

NASA Ames work on plastic foams using principles of low conductivity, gas generation, and char formation. JP–4 fire tests show excellent performance (low back wall temperature for modified isocyanate and polyurethane rigid foams.) KBF_4 was added to the foam along with polyvinyl chloride for added fire resistance and quenching. It is noted that effectiveness of foam depends on internal gas generation, which may be toxic.

*48. Craig, Jerry, W.: Apollo Spacecraft Nonmetallic Materials Applications. NASA SP–5096, 1971, 129–135.

This report describes nonmetallic materials and protection for 100 percent O_2. Extensive use is made of Beta cloth (fiber glass) and Teflon. Velcro now uses Teflon pile backed by Beta. Only the hook is nylon. The portable fire extinguish is a water-based gelatin, pressurized Freon to form a foam.

49. Pearce, James P.; Kimzey, J. Howard; and Pippen, David L.: The Effects of Gravity on Flammability. NASA SP–5096, 1971, pp. 137–139.

This is a repeat of References 4 and 20, describing the KC–135 tests on neoprene, rubber, Teflon, and polyurethane combustion at 10 s of 0g. Results show slow propagation and a tendency toward self-extinguishment. High-gravity centrifuge combustion tests are described. These show higher flame temperatures and propagation rates compared to 1g.

*50. Kimzey, J. Howard: Fire Extinguishment in Hypobaric and Hyperbaric Environments. NASA SP–5096, 1971, pp. 163–169.

Tests on polyurethane foam shows that Halon 1301 is effective as an extinguishant only up to 77 percent O_2 (5 to 14.7 psia). All gaseous extinguishants are ineffective for the high O_2 concentration. Only water and water-based foam extinguished the flames. The thickness of the water foams necessary to extinguish a fire increases to over 1 inch at O_2 pressures of about 15 psia. A high-expansion foam is briefly described, based on gaseous O_2 and water-based foaming compound. The foam works by blanketing the fire, surrounding the flame with products of combustion. The foam is breathable—dogs have survived immersed for 90 min. For hyperbaric chambers, up to 105 psia with 27.5 percent O_2, Halon 1301 was better, but water was still more effective.

51. Sauers, Dale G.: Special Flammability Test Techniques. NASA SP–5096, 1971, pp. 179–185.

Describes tests for oxygen-enriched flammability (Apollo prelaunch conditions of 16.5 psia in 60 percent O_2 and 40 percent N_2 and at 6.2 psi in 100 percent O_2). The formal tests are those described in Reference 42 and MSC–PA–D–67–13 (Feb. 1968). The development and design verification tests precede the qualification tests. Those described are the flame-impingement tester, short-circuit ignition tester, polycarbonate drip-ignition tester, flash-point and fire-point testers and autoignition-point tester.

52. Dorr, Victor, A.: Compendium of Hyperbaric Fire Safety Research, ONR Final Report Contract N00014–66–C–0149, Feb. 28, 1971.

A compendium of three summary reports by Ocean Systems, Inc., an affiliate of Union Carbide and Singer, is largely an expansion of Reference 31. Ignition delay is increased by the high thermal conductivity of He diluent, but flame spread is increased by the high specific heat of He. Other conclusions and charts are the same as in Reference 31. An interesting proposal is the use of H_2 as a diluent at high pressures for submarines and diving. A mixture of 3.5 percent O_2 (0.21 atm O_2 partial pressure) in H_2 is nonflammable.

*53. Leger, L.J.; and Bricker, R.W.: Flammability Testing Conducted in Support of Apollo 13. MSC Cryogenics Symposium Papers, 1971, pp. 455–474.

In support of the Apollo 13 investigation, the authors measured Teflon insulation flame propagation upward, downward, and at 0g. At 6.5 MPa in a cryogenic O_2 atmosphere, downward rates were around 0.6 to 1 cm/s and at 30 °C, 1.1 to 1.6 cm/s. Corresponding upward rates were 5 to 10 cm/s and 9 to 11 cm/s. At 0g tests in the NASA Lewis Research Center 5.2-s facility (Ref. 37) at 6.3 MPa and –118 °C, the rate was 0.48 cm/s. Under these conditions, Teflon ignition promoted Al, steel, and Inconel combustion.

54. Canetti, G.S.: Systems Safety for Manned Operations in Earth-Orbital Missions. AIAA Paper 71–826, 1971.

This is an early study by Rockwell, predating the Peercy (Refs. 203 to 207) works evaluating 17 credible accidents including fire. Planning for fire safety criteria include design of isolated modules, escape paths, and unsafe condition detection. Proposed egress schemes include “ladder” closed configurations, flex-ports (deployable hatch tunnels between modules), and emergency volumes, internal and external.

*55. Cochran, Thomas H.: Experimental Investigation of Laminar Gas Jet Diffusion Flames in Zero Gravity. NASA TN D–6523, 1972.

This report covers additional studies and discussion of the work of Reference 33. The CH_4–air diffusion flame work is supplemented by three small burner radii (0.05, 0.08, and 0.11 cm) compared with 0.19 to 0.44 for Reference 33. For 1g, average flame length is linear with flow rate, but there is a small effect of Reynolds number Re. The smallest radius (highest velocity) gives the greatest flame length. For 0g, as before, flame minimized and then expanded. Again 0g flames were yellow with the tops poorly defined. However, not all flames were extinguished. Some were transient and growing, while others were steady state. In general, steady state was obtained at higher flow Reynolds number Re for the smallest radii and extinguished for large radii, and lower Re; the flames are transient in between. The author warns that these are estimates only. Extinguishment length as a function of Re agrees with Reference 33. Steady-state length can also be correlated with Re, and it is about 70 percent of the corresponding normal gravity length. Maximum flame radius is about 50 percent greater for 0g compared with 1g. However, the previous correlation for minimum length $(L_1 - L_0)/L_1 \sim 0.06\mathrm{Gr}^{0.37}\mathrm{Re}^{0.69}$ fits the new work poorly, especially at high flow rates. Steady-state flames at 0g were very stable.

56. Cholin, R.R.: How Deep is Deep? Use of Halon 1301 on Deep-Seated Fires. Fire Jour., vol. 66, no. 2, March 1972, pp. 19–23. (Abstract only).
Tests were conducted with Halon 1301 on Class A fires. For shallow fires, 3.6 percent 1301 is sufficient. For consistent extinguishment of deep-seated fires, 20 percent or more is required and 1301 is not recommended.

57. Haggard, John B., Jr.; and Cochran, Thomas H.: Stable Hydrocarbon Diffusion Flames in a Weightless Environment. Combust. Sci., Technol., vol. 5, 1972, pp. 291–298.
This is a continuation of the work of References 33 and 55, in the 2.2-s drop tower, with 0.05 and 0.08 cm nozzles, C_2H_6 and C_3H_8 fuels, and ignition 5 s before drop. Previous work for CH_4 showed axial flame length at 0g was linear with flow rate of fuel and 50 percent greater than at 1g. For C_2H_6 it was about 20 percent greater, and for C_3H_8 it was shorter. Note that C_3H_8 is more dense than air; CH_4 and C_2H_6 are less. Two types of stable 0g flames were observed: underventilated (spherical) and overventilated (distorted, without a finite width at the flame tip). The C_2H_4 and C_3H_6 flames at low flow rates were overventilated, and at high flow rates they were underventilated. All Reference 33 methane flames appeared overventilated. No self-extinguished flames were observed. Zero-gravity flames were yellow to orange-red. Flame length to tube inner diameter were correlated by $L_s/R_0 = 3.55\ Sc^{1/2}\ Re\ ln^{1/2}$ $(1/(1 - C_s)) + 5$, where C_s is the stoichiometric mole fraction. Correlation agreed with theory except for factor of 3.55 compared with 2.0.

*58. McAllister, Fred A.: Apollo Experience Report—Crew Provisions and Equipment Subsystem. NASA TN D–6737, 1972.
This report includes a brief description of the metering water dispenser that was adopted in the Apollo command and lunar modules for fire extinguishing.

*59. Lew, H.G.: Investigation of the Ignition and Burning of Materials in Space Cabin Atmospheres. NASA CR–128068, pt. I, 1972.
A General Electric analysis models the coupled solid and gas phase ignition process for burning plastic. Some discussion on Teflon and poly(methyl methacrylate) (PMMA) properties and combustion are given. The effect of gravity seems to be discussed only in terms of free convection.

*60. Lew, H.G.: Investigation of the Ignition and Burning of Materials in Space Cabin Atmospheres. NASA CR–128064, pt. II, 1972.
This is an analysis for Teflon monomer flowing over a hot horizontal cylinder with chemical reaction and diffusion. Ignition temperature decreases as gravity decreases, presumably as cooling of the cylinder is reduced.

61. Anon., "Report of Qualification Test of the Skylab Fire Extinguisher," Southwest Research Institute, 3366–QTR–1, July 1972.
This is a brief report on a shake test of the fire extinguisher of Reference 16, which is filled with an aqueous gel and Freon emulsion that expands to a foam.

62. Smith, Edwin E.: Measuring Rate of Heat, Smoke, and Torre Gas Release, Fire Technol, vol. 8, no. 3, Aug. 1972, pp. 237–45.
This report contains a discussion of the Ohio State University (OSU) combustibility apparatus, later adopted in ASTM E906. The apparatus measures combustibility in three ways: heat release measured through exhaust temperature and gas specific heat to give rate of heat release as a function of time, smoke release through an optical detector, and toxic gas release through sampling. A radiant panel in the apparatus permits flammability tests at room temperature or at elevated heat fluxes. Some experimental examples are given.

63. Auck, S.E.: Short History of Halogenated Fire Extinguishing Agents. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 7–12. TM 9338A6.

The first tested Halon extinguisher arose in 1911 with CCl_4 (Halon 104). In 1932, methyl bromide (CH_3Br) also made its appearance. Toxicity of these vaporizing liquids was recognized. During WWII, Germany also used Halon 1011. However, in the 1950s the liquefied gas extinguishant Halon 1301 was introduced. In 1962, 1301 was approved by recognized testing labs, and in 1967, Underwriters' Laboratories, Inc. withdrew recognition of all other Halons except 1301. This was made a law in 1970. Presently 1301 is the common Halon, although European systems use 1211 and 2402.

64. MacEwen, James D.: Toxicology of Pyrolysis Products of Halogenated Agents. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 53–59.

This report deals with high-temperature degradation products. At 800 °C, Halon 1301 produces (in mol%) 106% HF, 7.7% HBr, and 11.3% Br_2. A 50-percent mortality rate to animals (pulmonary hemorrhage) occurs at ≥4000 ppm preignition concentration (around 50 percent pyrolyzed). The paper notes a 15-min approximate lethal concentration of Freon 1301, nonpyrolyzed, of 14,000 ppm.

65. Reinhardt, Charles F.; and Reinke Ruth E.: Toxicology of Halogenated Fire Extinguishing Agents Halon 1301 (Bromotrifluoromethane). An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 67–78.

Halon 1301 acts in the central nervous system. For exposures of 5 min or less at 7 percent or less concentration, no harm has been reported.

66. Ford, Charles L.: Extinguishment of Surface and Deep-Seated Fires With Halon 1301. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 158–172.

Halon 1301 is shown to be effective against flammable liquids and solids. About 4 to 6 percent concentration is capable of extinguishing a variety of surface and deep-seated fires. Decomposition of 1301 occurs in proportion to the size of the fire. Fires large enough to produce substantial decomposition are in themselves a substantial hazard.

67. Gassmann, Julius J.; and Marcy, John F.: Application of Halon 1301 to Aircraft Cabin and Cargo Fires. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 173–187.

Although Halon 1301 systems had been specified since before 1960 for engine fire control, the use in cabin fire extinguishers is still being investigated. Paper describes FAA Tech Center tests on cabin mockup and cargo boxes. Results show that 5.8 percent Halon extinguishes urethane foam padding fires. Prolonged exposure to flames and heat may cause Halon pyrolysis. For chemicals containing oxygen, such as chlorates, the recommended concentration of Halon may not be effective.

68. Botteri, B.P.; Cretcher, R.E.; and Kane, W.R.: Aircraft Applications of Halogenated Hydrocarbon Fire Extinguishing Agents. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 215–238.

This report presents a table of selected properties and threshold effective level (TEL) of Halons. Some history is given of U.S. Air Force fire extinguishers. For engine fires, use of Halon 1301 is being introduced over older Halons. In fuel tank inerting and explosion suppression, the Halons are not as effective as N_2. For cabin fires, a foaming agent based on Halon 1211 and 1301 is being studied to replace 1011.

69. Carhart, Homer W.; and Fielding, George H.: Applications of Gaseous Extinguishants in Submarines. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 239–256.

The paper notes that a submarine atmosphere is 21 percent O_2 at 1 atm. The O_2 is produced by water electrolysis, venting H_2. Scrubbers remove CO_2; catalytic burners remove H_2 and organics; carbon beds remove organics and other vapors; and precipitators remove aerosols. Fire fighting is through $KHCO_3$, CO_2, water foam, and so forth. Paper notes that for inerting 7.2 percent Halon 1301, 42 percent N_2, and 29 percent CO_2 are needed. The Halon is the lightest and least toxic. About 3.7 percent Halon serves for most extinguishment. The N_2 offers a possibility for hyperbaric protection.

70. Kuchta, Joseph M.; and Burgess, David: Effectiveness of Halogenated Agents Against Gaseous Explosions and Propellant Fires. An Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, Washington, DC, 1972, pp. 257–277.

This paper presents U.S. Bureau of Mines charts of flammability of CH_4, gasoline, and A–50 as functions of %Halon 1202, 1211, and 1301.

*71. Linford, R.M.F.: Experiments With the Skylab Fire Detectors in Zero Gravity. NASA SP–298, 1972, pp. 41–55.

The tested fire detector, the first developed for spacecraft, uses the principle of ultraviolet (UV) detection, using a Geiger ionization tube. It responds to wavelengths less than 270 nm and at least 1 pW/cm^2 radiation. Honeywell and McDonnell-Douglas developed the tube. Tests were conducted in the KC135. Kimzey's combustion apparatus (Refs. 4 and 5) was used with various materials (cloth, epoxy, foam, etc.) in 22 free floats. Combustion was noted to be spherical, diminishing after initial flareup. The detector, located at a simulated 3 m distance, detected ignitions within 1 to 2 s.

*72. McHale, Edward T.: Habitable Atmospheres Which Do Not Support Combustion. NASA SP–298, 1972, pp. 331–335.

It is noted that flame spread is a strong inverse function of oxidant heat capacity per mole of O_2. Air heat capacity, for example, is 33 cal/°C mole O_2. Cotton burns three times as fast in O_2-He (27 cal/°C mol °C). This is in contrast to life support that requires sufficient partial pressure of O_2 (~2.5 psia) regardless of diluent. Three fluorinated hydrocarbons, CF_4, C_2F_6, and C_3F_8 are prepared as diluents. The paper does not cite test results.

73. McHale, Edward T., "Habitable Atmospheres Which Do Not Support Combustion," Atlantic Research Corp., May 1972.

In support of Reference 72, this describes actual testing of the fluorinated inert atmosphere. For tissue paper, up to 20 percent CF_4 is needed for suppression (Halon 1301 works with 5 percent). Analysis of pyrolysis products showed excessive HF, except for CF_4, which gives 6.6 ppm (Halon 1301 gives 50 ppm). Animal tests showed no toxicity at the usage levels of CF_4.

*74. Anon.: Systematic Control of Nonmetallic Materials for Improved Fire Safety. NASA SP–5109, 1972.

A technology utilization report covering concerns for Apollo. Designing for safety is discussed briefly along with hazard analysis, ignition, material selection, fire and smoke detection, fire extinguishment, and fire survival. Some references are made to work in the conference described in SP–5096 (Refs. 42 to 51).

75. Linford, R.M.F.: Integration of a Fire Detector Into a Spacecraft. J. Spacecraft, vol. 9, no. 9, 1972, pp. 697–701.

This article gives the background of the first Skylab ultraviolet (UV) flame detector, described in Reference 71. The various other devices considered, but rejected, are listed in a table. The Skylab fire detector uses a twin-tube reference detector scheme to reject radiation background from proton fluxes when crossing inside the South Atlantic anomaly. A system of 22 sensors with overlapping 120° fields of view are to be installed on Skylab.

76. Chianta, M.A.; and Stoll, A.M.: Fire Retardance of Mixtures of Inert Gases and Oxygen. Aerospace Med., vol. 44, 1973, pp. 169–173.

Tests on horizontal Nomex specimen with various O_2-He, O_2-N and O_2-Ar atmospheres showed that for slow heating, Helium retards combustion the most. This can be related to a Grashof number natural convection rate. With higher heating rates (igniter contacting specimen), destruction is mainly a function of O_2 flow rate.

77. Call, D.W.: Study of Halon 1301 ($CBrF_3$) Toxicity Under Simulated Flight Conditions. Aerospace Med., vol. 44, 1973, pp. 202–204.

Eight persons underwent a single-blind test exposed to 4 and 7 percent Halon 1301 at sea level and altitudes to 18 000 ft for 3 min. No changes in electrocardiogram were noted. Some decreases in reaction time were noted, although there was little difference between sea level and altitude performance.

*78. Haggard, John B., Jr.; and Cochran, Thomas H.: Hydrogen and Hydrocarbon Diffusion Flames in a Weightless Environment. NASA TN D–7165, 1973.

A continuation of the 2.2-s drop tower work of Reference 55. Four nozzles were used: 0.05, 0.08, 0.11, and 0.19 cm radii. Instead of CH_4, tests were conducted with H_2, C_2H_4, and C_3H_6. For 1g, flame lengths were approximately linear with flow rate, with a small dependence on nozzle radius. The 0g flames were all steady state except for transient flames with C_2H_4 and C_2H_6 on the 0.11- and 0.19-cm nozzles. Flame color was variable, pale yellow to red. Flame length was correlated this time with a (Schmidt No)$^{1/2}$Re function with the fuel stoichiometric mole fraction. A different fit was obtained for the hydrocarbons compared with H_2. For flame radius, a correlation with τ_F, which is the radius divided by the flow rate of fuel. This correlation combined with previous work of Edelman, Fortune, and Weilenstein could be stated in a form that includes g: $R_M/R_0 = 10.5e^{-0.603g}–3.7 \log \tau_F$, where R_M is maximum flame radius and R_0 is tube radius. Reasonable fit was obtained at normal and low gravity.

79. Huggett, Clayton: Habitable Atmospheres Which Do Not Support Combustion. Comb. Flame, vol. 20, 1973, pp. 140–142.

This paper summarizes Reference 72 from the same sources, although it is written earlier. The author points out that life support requires O_2 partial pressure with no concern for diluent, combustion requires feed back of energy from flame to unburned fuel. Atmospheres with a range of 40 to 50 cal/°C mole O_2 are inert. The suppression action of fluorocarbon is physical compared with the chemical action of bromocarbons.

80. Petrash, Donald A., and Corpas, Elias L.: Zero Gravity Facility for Space Vehicle Fluid Systems Research. Proceedings of the 19th Realism in Environmental Testing and Control Annual Meeting, Institute of Environmental Sciences, Mt. Prospect, IL, 1973, pp. 480–482.

This paper is a description of the 5.2–s drop tower, procedures, and experiment vehicles.

81. Tatem, Patricia A.; Gann, Richard G.; and Carhart, Homer, W.: Pressurization With Nitrogen as an Extinguishant for Fires in Confined Spaces. Combust. Sci., Technol., vol. 7, no. 5, 1973, pp. 213–218.

Submarine fire tests, based on Reference 69, showed the extinguishment of JP–4 pool fires (3 to 10 cm diameter) in 30 s by 0.35-atm N_2. Final O_2 was 15 mol%, CO_2 was 0.8 mol%, and CO was 150 ppm. The final composition for self-extinguished flames was 12 mol%O_2, 5 mol%CO_2, and 1100 ppm CO.

82. Chernyakov, I.N.: Safety of Life and Health of Crews of Spacecraft and Space Stations in Emergency Situations. NASA TT–F–14997 (Translated to English from the publication "Osnovy Kosmicheskoy Biologii I Meditsiny," Moscow Academy of Science), 1973.

This is a general discussion of space emergencies. For fire, the effects of low gravity and the enhancement by ventilation are noted. Fire dangers from meteorite penetrations are also noted. The paper cites the work of Johnson (Ref. 28) on the Apollo test atmospheres of 60 percent O_2 and Rodnofsky (Ref. 25) on nonflammable materials. The use of depressurization and inerting for fire fighting is noted. The paper also discusses briefly topics of surgical and medical treatment of burns.

83. Edelman, Raymond B.; Fortune, Owen F.; Weilerstein, Gertrude; Cochran, Thomas H.; and Haggard, John B., Jr.: An Analytical and Experimental Investigation of Gravity Effects Upon Laminar Gas Jet-Diffusion Flaws. Fourteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1973, pp. 399–412.

Presents work of References. 33 and 55 and develops correlations based on gravity and diffusion. Correlations fit normal gravity well, low gravity fairly well. Transient effects may be present in the drop tests at low Reynolds number.

84. Smith, Edwin, E.: Evaluation of the Fire Hazard of Duct Materials. Fire Tech., vol. 9, no. 3, 1973, pp. 157–170.

This is largely an expansion of Reference 62. More examples of the rate of heat release in the Ohio State University (OSU) apparatus are shown. The rate of heat release versus time assumes several stages, depending on whether the samples form a stable ash or not. With the apparatus, ignition is through a pilot flame releasing 12 Btu/min. Additional description of smoke release (in arbitrary particles/min-ft^2) and toxic gas released (HCl) are also included.

84A. Williams, F.A.: Unified View of Fire Suppression. J. Fire Flamm., vol. 5, 1974, pp. 54–63.

The Damkohler number $D \equiv \tau_r/\tau_c$ is introduced to define suppression conditions. The residence time, τ_r, can be based on a flame time or diffusion time (l^2/D). The latter is proposed. The author notes that while D can be based on the maximum flame temperature, D_a, a more constant value is based on surface conditions, D_b. The universal prescription for extinguishing a fire is lower D_b below the extinguishment value D_e. The latter is defined to give an explicit criterion of

$$\left(\frac{l^2}{\rho D}\right) C_{Fb}^{m} C_{Ob}^{m} A \exp\left(\frac{-E}{RT_{af}}\right) < k\left(\frac{RC_p T_{af}^2}{EQ_F}\right)^3$$

where C_{Fb} and C_{Ob} are local surface fuel concentrations and atmospheric O_2 concentrations, respectively; n and m are orders of the reaction rate, usually 1; A is a pre-exponential kinetics constant; E is activation energy, $k \sim 10^{-3}$; and Q_F is heat released per unit mass of fuel. All extinguishment strategies can be linked to changes in one of the coefficients of the unified relationship.

*85. Andracchio, Charles, R.; and Cochran, Thomas H.: Burning of Solids in Oxygen-Rich Environments in Normal and Reduced Gravity. NASA TM X–3055, 1974.

Circular specimens of cellulose acetate were burned in 100 percent oxygen at 34.5 and 101 kPa in the 2.2-sec drop tower in a package identical to that of Reference 32. Tests in a cylinder with a vertically burning specimen at 6.30 MPa were conducted in the 5.2-sec drop tower. In all cases, flame was pale orange. At the high supercritical pressure, spurting and bubbling were noticed. The flame spread rate was close to that in 1g for the very thin material but less than the 1g rate for thicker specimens. The effect of pressure on flame spread was on the order of $P^{0.1}$ at the lowest thickness, somewhat greater at thicker specimens (thicknesses were 25, 51, and 122 μm). Tests were also run with meshes of stainless steel, Inconel, copper, Al, and Ti. The metals ignited and burned too brightly for flame spread measurements.

86. Kimzey, J.H.: Venting a Spacecraft During or After a Fire. NASA JSC Internal Note, 1974.

This note consists of observations and comments on spacecraft fire safety. In low gravity, availability of O_2 is reduced and higher molecular weight species are released. Total oxidation is less likely than in normal gravity. For fighting fires, a pressurized zone may be vented. In severe fires, the skin may be damaged and the zone vented automatically. Depressurization should be reasonably slow. Afterwards repressurization should be undertaken with caution. It is better to overpressurize and drop back to 14.7 psi. It may be possible to vent to just 12.0 psi if burning items are present. Other recommendations are to have central control for detection and fans for mixing air and to perform gas sampling upon repressurization.

*87. Kimzey, J.H.: Skylab Experiment M479, Zero Gravity Flammability. Proceedings of the Third Space Processing Symposium on Skylab Results, vol. 1, 1974, pp. 115–130.

(N74–29890), later published as JSC 22293 (NASA TMX–70252), Aug. 1986. Report describes the one and only space experiment on combustion in a spacecraft. Specimens were mounted under covers in a container under 65 %O_2 at 5.2 psia with resistance wire ignition. Tests were on aluminized mylar, nylon, polyurethane foam, Teflon, paper, and others. Differential Thermal Analysis conducted on a paper specimen on the ground after the flight tests showed around 40 percent combustion. Rates of burning were almost half of that in 1g (in a separate test) for Mylar, 15 percent for foam, about 1/3 for nylon, and not determined for the others. Blue flames were noted for paper at 0g and was duplicated in 1g with minimum O_2. Extinguishment by evacuation was tried. Initial intensification of the flames before extinguishment was noted. Self-extinguishment was not noted, because (as estimated) shrinkage or boiling set up disturbances. Flashover between paper specimens in 0g was noted. Finally nylon was unique, showing continued burning for over 10 min and boiling.

88. Custer, R.L.P.; and Bright, R.G.: Fire Detection: The State-of-the-Art; A Description of Instruments for Detecting Outputs of the Combustion Process. NASA CR–134642 (NBS TN–839), 1974.

This is a review supported by the NASA Lewis Aerospace Safety Research and Data Institute (ASRDI). The report covers fire signatures, fire hazards, classification and operation of detectors, reliability, and code requirements, as of the date of the review.

*89. Berlad, A.L.; Huggett, C.; Kaufman, F.; Markstein, G.H.; Palmer, H.B.; and Yang, C.H.: Study of Combustion Experiments in Space. NASA CR–134744, 1974.

A study group, brought together under Public Systems Research, Inc., looked at basic experiments to be performed in space. The six experts presented their ideas plus those of outside respondents, reached via mail solicitation. The introduction notes that space gives the opportunity to study the effects of free convection (uncoupled), two-phase systems, and so forth. Various scientific areas are noted, including those of interest to fire safety: radiative ignition of solids and liquids, flame spread and extinction over solids, and smoldering. Report sections give rationale for studies on single droplet burning, porous body burning, large surface gas-solid combustion, droplet spray and particle cloud combustion, and liquid-gas combustion.

90. Trumble, T.H.: A Smoke Detection System for Manned Spacecraft Applications. AFAPL–TR–74–97, 1975.

This report describes preliminary development of hardware to use an open-beam 254-mm light-scattering smoke detector. Concept was tested with wood combustion at 1g, low pressure, and a 60-%O_2, 40-%N_2 atmosphere. An appendix describes catalytic bridge, ionization-chamber, and optical smoke detectors.

91. Prahl, J.; and Emmons, H.W.: Fire Induced Flow Through an Opening. Comb. Flame, vol. 25, no. 2, 1975, pp. 369–385.

By analogy to flow over a weir, authors derive the equations for heated gasses flowing out of a window, with cold air coming in below. A working equation for fire openings is shown, based on experiment, to give flow rate as function of density ratio, flow layer, and flow coefficient.

92. Botteri, B.P.: Aircraft Fire Protection Technology. AGARD–CP–166, 1975, pp. 18–1—18–17.

Hazard analysis in an aircraft compartment groups fire hazards into categories (zones). These are (1) an ignition zone, where an ignition threat is present but two failures are needed for fluid leakage, (2) a flammable zone, where flammable mixtures are present but two failures are needed for an ignition source, (3) a flammable leakage zone, where fluid leakage with one failure and an ignition source with one failure are present, and (4) a fire zone, where ignition source is present and one failure causes fluid leakage. Fire detection on Air Force planes is listed, including advantages and disadvantages of present types and proposed types. Fire extinguishing systems are generally limited to Halon 1301, 1202, and 1011. The paper also discusses flame arresters and inert gas generators for on-board generation in fuel tanks. This discussion after the paper covers Halon 1301 toxicity and smoke detectors.

*93. Downs, W. Richard: Apollo Experience Report: Detection and Minimization of Ignition Hazards From Water/Glycol Contamination of Silver-Clad Electrical Circuitry. NASA TN D–8177, 1976.

A flammability hazard occurs when a water-glycol solution contacts bare or defectively insulated silver-clad copper circuitry. Glycol can oxidize to glycolic acid, prevented by inhibitors of triethanolamine phosphate, or sodium mercurobenzothiazole. However, with or without inhibitor, the glycol spill is a hazard because of the electrochemical reaction of silver ions that are dissociating water. This is not true with pure copper or nickel circuitry. The recommended correction is rigorous spill cleanup or adding benzothiazole, a silver chelating agent, to glycol.

94. Kracklauer, J.; Sparkes, Charles; and Legg, Rod: New Smoke Test—Fast, Simple, Repeatable. Plastics Technology, vol. 22, no. 3, 1976, pp. 46–49.

This is a description of the Arapahoe smoke chamber, which is a cylindrical combustion chamber in which a sample is burned in a propane flame. In a chimney above the chamber, particles are gathered on a filter paper. After 30 s, the paper is weighed. Smoke weight, in mg/liter, correlates well with optical density measurements. The Arapahoe chamber can also be used to determine char production. The method may be the basis for ASTM D–4100.

94A. Barr, Laurence Gibson; Chuan, Raymond Lu-po; and Harkee, James Fredrick: Incipient Fire Detector. U.S. Patent 3,953,844, 1976.

This is the basic patent of the Brunswick smoke detector used on the Shuttle. This concept uses an angled internal tube to deflect flow to ensure that high-momentum particles (above approximately 3 μm) bypass the detector. The detector is a quartz crystal oscillator, whose frequency is a function of the mass impinging on the flat crystal. Zero-gravity application favors the rejection of large particles. Additional claims are made for the logic system that avoids false alarms by requiring buildup of particles for a predetermined time before actuation.

*94B. McKee, R.G.; and Alvares, N.J.: The Response of Smoke Detectors to Pyrolysis and Combustion Products From Aircraft Interior Materials. NASA CR–137949, 1976.

This is a Stanford Research Institute study under contract to NASA Ames. Gas sensor, photoelectric, and ionization commercial smoke detectors were tested in a chamber with pyrolysis, smoldering, and combustion products from a range of aircraft materials. Reported data included time to detector actuation plus light transmission, gas temperature, and sample mass loss. For radiant-heated pyrolyzing samples, no detector responded to pyrolysis products from cellulose fuels until the material ignited, and then only the ionization detectors responded to the cellulosic products. All detectors were sensitive to pyrolysis products of synthetic polymers. All were sensitive to smoldering products. Photoelectric detectors appear to have more tolerance in terms of coping with changes in velocity, pressure, and humidity, and they are recommended for aircraft for this reason.

95. Sauers, Dale G.: Effects of Forced Air Flow and Oxygen Concentration on Flammability, Smoke Density, and Pyrolytic Toxicity. J. Fire Flamm., vol. 7, no. 2, 1976, pp. 181–199.

This article summarizes NASA Johnson studies using a forced air flammability apparatus with epoxy-Kevlar laminate samples, a material marginally flammable using NHB 8060.1 upward flammability tests. The study was most concerned with regression analysis. Of interest are the remarks that shuttle ventilation is of the order of 8 to 20 cm/s and that 1g combustion is strongly enhanced by ventilation. In 1g with zero forced flow, buoyant flow was on the order of 60 cm/s. With the addition of forced flow, the combined flow increases nonlinearly. For example, the combined flow at 17 cm/s is almost 140 cm/s.

*96. Andracchio, Charles R., and Cochran, Thomas H.: Gravity Effects on Flame Spreading Over Solid Surfaces. NASA TN D–8228, 1976.

Experiments were conducted in the 5.2-s drop facility with the same cellulose acetate specimens as in Reference 85. In this study, tests were conducted at 100 $\%O_2$ and 276 kPa plus 40, 60, and 80 $\%O_2$ in He, Ar, and N_2, all at 34.5 kPa. Qualitative results show that flame spread velocity decreased as gravity decreases, as fuel thickness is increased, pressure is decreased (slightly), and O_2 mole fraction is decreased. Flame spread was greatest for He, then Ar, then N_2. General correlations were derived from these tests and those of Reference 85, using thin flow convection-conduction equations, the assumption that flame temperature is constant in all cases, and equality of inertia and gravity terms to give

$$\frac{V_{1g}-V_{0g}}{V_{0g}} \cong \left[\left(\frac{c_{p,g,0}M_o}{x_{ox,o}}\right)^2 \frac{\tau}{k_{g,0}}\right]^{2/3}$$

where V_{1g} = normal gravitational flame spread, V_{0g} = zero gravity flame spread, $C_{p,g,0}$ = ambient specific heat of gas, M_o = mean molecular weight of gas, $X_{ox,o}$ = mole fraction of oxygen, τ = sample thickness, and $k_{g,o}$ = thermal conductivity of ambient gas. Normal-gravity data correlate to

$$V_{1g} \cong B_1 \frac{k_{g,0}p^{0.1}x_{ox,o}^{1.3}}{c_{p,g,0}\tau}\left\{1+B_2\left[\left(\frac{c_{p,g,0}M_o}{x_{ox,o}}\right)^2 \frac{\tau}{k_{g,0}}\right]^{2/3}\right\}$$

where B_1, and B_2 are constants. Correlating plots of two equations with data give reasonable agreement ($B_1 \cong 0.0213$, $B_2 \cong 0.00177$).

97. Suminski, G.; Riemer, O.; and Hankey, F.: Integrated Fire and Overheat Detection System. AFAPL–TR–76–64, 1976.

This McGraw-Edison report describes an aircraft nacelle detector, which consisted of two ultraviolet (UV) sensors for flame detection plus an MgO thermistor cable for spot overheat detection. The thermistor became conductive at high temperatures. The dual UV detector requires radiation from both sensors for alarm unless a periodic test lamp check shows one head has failed.

98. Fish, Richard H.: Ames T–3 Fire Test Facility-Aircraft and Fire Simulation. J. Fire Flamm., vol. 7, no. 4, 1976, pp. 470–481.

This describes a NASA Ames chamber used to simulate pool fires to test materials. The method has an advantage over ASTM E119 in that initial high heat fluxes are correctly programmed. Heat fluxes are adjustable from 100 to 190 kW/m^2 and are 90 to 95 percent radiative. Test results are shown with JP–4 fires on protected and bare aircraft panels and foam materials.

*99. Junod, Thomas L.: Gaseous Emissions are Toxic Hazards Associated With Plastics in Fire Situations—A Literature Review. NASA TN D–8338, 1976.

The review, largely qualitative, discusses behavior of plastics, gases emitted through pyrolysis and combustion, toxicology, and laboratory studies. Conclusions are that gases—primarily CO— are the principal hazard in fires. Humans can survive with less oxygen than required to sustain the fire itself. Synergistic and autoignition effects of multiple gases may be encountered. Recommendations are for more laboratory and clinical studies, better standards, and improved statistics and analyses.

100. Frey, Alfred E., Jr.; and T'ien, James S.: Near-Limit Flame Spread Over Paper Samples. Comb. Flame, vol. 26, 1976, pp. 257–267.

Paper samples 3.7 and 7.5 mil (0.09 and 0.19 mm) thick were ignited in an aluminum holder, for horizontal and vertically downward combustion. Flame velocity for horizontal spread is found to follow (except near extinction) the relation $V \sim P^a Y_{ox}^b$ where the O_2 mole fraction exponent b = 1, and the total pressure exponent $a = 3.3\sqrt{\tau}/Y_{ox}$, where τ = thickness. Near extinction, V decreases rapidly with P. Thermocouple measurements show flame isotherms.

100A. Starrett, Philip S.: Factors Influencing Flame Spread Rates in Solid Materials. J. Fire Flamm., vol. 8, no. 1, 1977, pp. 5–25.

Analysis and experiments are described for sheet materials, based on flame spread rates for thin and thick fuel beds. The surface area available for burning per unit mass has the dominant influence on flame spread rates in thin materials. Normalizing factors used are total pressure to the 0.65 power, oxygen mole fraction to the 1.2 power, and atmospheric thermal conductivity to the 0.5 power. A full-scale test on an aircraft seat ignited by alcohol flame showed a decrease in flame intensity at 37 400 ft altitude for 6 min but continued burning. Extinction was at 50 000 ft. but re-ignited when altitude simulation was lowered. Note that in many cases, preheating the sample was necessary for ignition.

101. Dyer, J.H.; Marjoram, M.J., and Simmons, R.F.: The Extinction of Fires in Aircraft Jet Engines—Part III Extinction of Fires at Low Airflows, Fire Technology, vol. 13, no. 2, 1977, pp. 126–138.

This describes work conducted in England by the Graviner, Ltd, Co. and University of Manchester. Earlier studies covered methyl bromide carried in a high-flow wind tunnel to extinguish pool and spray-fed fires in nacelle models. This work studied methyl bromide, H1211, H1301, and N_2 in air. Airflows were of the order of 0.3 to 10 m/s. A thermal conductivity detector monitored the actual concentration of suppressant as a function of time to correlate with minimum extinguishment concentration. Extinguishment concentration decreased moderately with increasing airflow. Minimum necessary concentrations (at low airflows) were (in vol%) 7.8% methyl bromide, 5.8% H1301, 6.5% H1211, and 42.5% N_2. Thus with a safety factor, these are the lower concentrations of extinguishant for aircraft engine fire protection. The N_2 concentration corresponds to inerting with O_2 reduced to 12%.

102. Kumagai, S.: Survey of Research on Gravitational Effects on Combustion. Paper presented at the Combustion Institute, Spring Technical Meeting, Cleveland, OH, March 1977. (A78–12560).

This is a brief review by the author, now retired from the University of Tokyo. The earliest work on suspended 0g droplets (Ref. 1) was an investigation for diesel combustion. This is because low-gravity combustion research is divided into two categories: those of fundamental studies and those for space application. The paper discusses results on droplets, diffusion flames, and so forth. There is also a review of solid combustion in high gravity for understanding of rocket combustion.

103. Gibbons, H.L.: Carbon Dioxide Hazards in General Aviation. Aviat. Space Environ. Med., vol. 48, 1977, pp. 261–263.

A review of selected cases shows instances where passengers or crew had difficulty or even incapacitation because of CO_2 from dry ice or fire extinguishers. Toxicology results note that 2 %CO_2 increases respiration by 50 percent, while 5 %CO_2 increases respiration by 300 percent. Concentrations of 12% and greater may result in unconsciousness. Experiments showed that CO_2 extinguishers discharged in small aircraft could result in hazards, although stratification or turbulence may reduce local CO_2 concentrations.

104. Payne, G.C.: Aircraft Fire Detection and Suppressant Systems. Tech. Air, vol. 33, 1977, pp. 2–6.

This paper describes some Graviner (now marketed in the U.S. by HTL Industries) products. Included are continuous and discrete overheat detectors, as well as thermistor and ultraviolet (UV) sensing heads. A brief account of Concorde and 747 engine-nacelle systems and H1211 and methyl bromide fire extinguishers is included.

105. McKee, R.G.; and Alvares, N.J.: The Response of Smoke Detectors to Pyrolysis and Combustion Products From Aircraft Interior Materials. NASA CR–137949, 1976.

Seven smoke detectors (gas sensor, photoelectric scattering, and ionization) were tested with 40 materials (paper, fabric, and plastic) under pyrolysis, smoldering and flaming. Reference temperature, mass loss, and obscuration measurements were made. Preliminary results showed that ionization actuated before photoelectric in turn before gas sensors. Repeatability was a more useful criterion of acceptability than response time. No detectors responded to pyrolysis products from cellulose fuels until after materials ignited. (This report is basically the same as Ref. 94B.)

106. Barr, L.G.: Development of a Quartz Crystal Incipient Fire Detector. Proceedings of a Symposium on Fire Detection for Life Safety, 1977, pp. 210–226.

This is a description of the Celesco Industries gas sensing detector proposed for the shuttle. The design had an internal separator to concentrate particles in the 0.3 to 0.7 μm range. Impact on a quartz crystal caused a decrease in the resonant frequency, which was monitored as beat frequencies with respect to a reference crystal. Alarm corresponds to mass collection in excess of 1800 $\mu g/m^3$, as compared with the expected ambient of 4 $\mu g/m^3$ (typical dust particles are >1 μg). It is claimed that the design is insensitive to gravity and airflow changes.

107. Hirst, R.; and Booth, K.: Measurement of Flame-Extinguishing Concentrations. Fire Tech., vol. 13, no. 4, 1977, pp. 296–315.

For tests to support NFPA 12A and 12B, the authors used a cup burner with premixed extinguishant flows. The fuel supply (hydrocarbons, alcohols, etc.) was replenished after each test to avoid fuel contamination by the Halon products. Cup air flows were low, but extinguishment concentrations were constant above 10 cm/s. Tests for a variety of fuels, ambient and preheated, showed typical extinguishing concentration of 3.9 vol% for 1211 and 3.6% for 1301. The highest was for methanol, 7.3% 1301. The authors claim that extinguishant concentrations are higher for the cup test than for full scale; a small-scale exception is in the aircraft engine test results of Dyer (Ref. 101). Results for CO_2 and N_2 are included, and it is noted that CO_2 may show a slight chemical effect.

108. Berlad, A.L.: Gravitational Effects on Combustion. Leo Steg, ed., Materials Sciences in Space With Application to Space Processing, vol. 52, AIAA, New York, NY, 1977, pp. 89–110.

General discussion of flames, including flammability limits, quenching limits, and pressure limits. A review of gravity quotes experiments of Reference 78 and theory of Reference 96. A pitch for shuttle experiments is made.

109. Williams, F.A.: Mechanisms of Fire Spread. Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1976, pp. 1281–1294.

Literature survey reviews concepts of fire spread using an energy equation. Principal mechanisms noted are one-dimensional spread through conduction, diffusion, radiation, and ventilation control. Downward spread through solid fuels is controlled by mechanisms of conduction through gas, conduction through solid, radiation, and macroscopic fuel motion. The paper also discusses horizontal and upward spread.

110. Moussa, N.A.; Toong, T.Y.; and Garris, C.A.: Mechanism of Smoldering of Cellulosic Materials. Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1976, pp. 1447–1457.

An experimental investigation in a combustion tunnel studied ignited cellulose cylinders with diameters from 0.04 to 0.86 mm. A glowing char zone spread through the cylinders. Steady smoldering could be characterized through the O_2 partial pressure. At low values, smoldering extinguished. At high values, smoldering led to flaming combustion. Intermediate was a zone of steady smoldering. Smoldering speed and temperature appeared to be functions of the O_2 mole fraction only. Mathematical models are proposed to predict smoldering.

111. Lavid, Moshe; and Berlad, A.L.: Gravitational Effects on Chemically Reacting Laminar Boundary Layer Flows Over a Horizontal Flat Plate. Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1976, pp. 1557–1568.

This is a theoretical study of flat-plate combustion, facing upward (aiding flow) or downward (opposing flow). Gravity is considered through $Gr/Re^{5/2}$. Computer solution shows that flow velocity increases in the order: opposing flow < 0g < aiding flow. Flame height increases in the order: aiding flow < 0g < opposing flow.

112. Dressler, Donald P.; Robinson, Richard S.; Gann, Richard G.; Stone, Jack P.; Williams, Frederick W.; and Carhart, Homer W.: Biological Effect of Fire Suppression by Nitrogen Pressurization in Enclosed Environments. J. Combustion Toxicol., vol. 4, 1977, pp. 314–324.

Chamber tests were performed on rats exposed to 2 atm N_2 and 10 %O_2 (normal O_2 partial pressure). In some cases a pool of JP–4 was ignited at normal atmosphere, then extinguished with the N_2 pressurization. Total test times were up to 8 min. The chamber became very smoky. Results were preliminary, but animals were generally unharmed and showed little aftereffects or decrease in useful function (treadmill work).

113. Hilado, Carlos J.; and Cumming, Heather J.: Bibliography of Published Information on Combustion Toxicology. J. Combustion Toxicol., vol. 4, no. 3, 1977, pp. 425–429.

This is one of a continuing series of bibliographies covering 1975 to 1977.

114. Quintiere, James: Growth of Fire in Building Compartments. A.F. Robertson, ed., ASTM Special Technical Publication 614, 1976, pp. 131–167.

This is a review with many references on flame studies in compartments and modeling of fluid, mass, and energy transfer, with plots of illustrative results.

115. Schulze, N.R.; and Prichard, R.P.: Occupant Safety in the Space Shuttle. SAE Paper 780021, 1978. (A78–33362).

A general discussion of the space shuttle safety measures covers rescue, aborts, hazards, and so forth. For fire safety, a primary concern, the atmosphere was changed to 20 %O_2 with fuselage purging during prelaunch and monitoring of the effluent for leakage. Material controls and ignition-source minimization are mentioned. The shuttle has nine ionization smoke detectors, three built-in Halon 1301 extinguishers, and four hand-held extinguishers. Half-inch holes in the panels provide access for internal fire fighting. Spacelab, a cargo bay laboratory, has ionization smoke detectors, fixed fire extinguishers, and two hand-held extinguishers. Spacelab can be vented to vacuum if necessary.

115A. Ernsting, J.: Prevention of Hypoxia—Acceptable Compromises. Aviat. Space Environ. Med., vol. 49, 1978, pp. 495–502.

A review of clinical tests on high-altitude hypoxia notes that a partial pressure of O_2 equivalent to an altitude of 6000 ft is the maximum acceptable for an aircraft crew in routine flight.

116. Bukowski, Richard W.; Custer, Richard L.P.; and Bright, Richard G.: Fire Alarm and Communication Systems. NBS Technical Note 964, 1978.

This is similar to Reference 88, but this report focuses on hardware description, reliability, codes, and system selection.

117. Hilado, Carlos J.; Cumming, Heather J.; and Casey, Colleen J.: Toxicity of Pyrolysis Gases From Natural and Synthetic Materials. Fire Tech., vol. 14, no. 2, 1978, pp. 136–146.

NASA-sponsored tests of the toxicity of fire and decomposition products subjected mice to gas flows, Toxicity was rated in time to death. Products from wood, cotton, wool, silk, and so forth seemed as toxic as those from plastics and synthetics.

118. Gann, Richard G.; Stone, Jack P.; Tatem, Patricia A.; Williams, Frederick W.; and Carhart, Homer W.: Suppression of Fires in Confined Spaces by Nitrogen Pressurization: III Extinction Limits for Liquid Pool Fires. Combust. Sci. Technol., vol. 18, 1978, pp. 155–163.

This is the work of Reference 81, conducted in a 5000-liter horizontal chamber to investigate the effects of baffling, other fuels (C_7H_{16} and C_2H_5OH), and fuel temperature. For the large tank, N_2 addition for extinction was 0.60 atm compared with 0.35 atm for the Reference 81 tank. Pan size and baffling had no effect on extinction. For the preheated fuels, the final oxygen content at extinction was 10.9 percent, corresponding to about 0.9 %N_2 addition. Thus less than 2 atm of N_2 suppresses class B fires. The atmospheric heat capacity for JP–4 extinction was 45 cal/°C-mole O_2 in close agreement to the criterion of Huggett (Ref. 79).

119. Hilado, Carlos J.: Fire Response Test Methods for Aerospace Materials. J. Fire Flamm., vol. 9, no. 2, 1978, pp. 217–228.

This paper reviews various fire test methods, noting need for one-directional heat flux. For comparability, the vertical sample test Federal Aviation Regulation FAR 25.853 is most widely used even though it is not strictly one dimensional or high heat flux. The American Society for Testing and Materials (ASTM) fire spread tests in a tunnel (E84) and with a radiant panel (E162) are not considered appropriate for aerospace applications. For heat release, the Ohio State University (OSU) apparatus (a chamber with a pyramidal top and radiant heating) is best. The apparatus described by E. Smith (Ref. 62) in Fire Technology, measures the change in air temperature. An Ames T–3 Fire Test Facility (Ref. 98) measures containment, the time a given heat flux applied to exposed face produces a specified effect on the unexposed face. For smoke testing, the author prefers the OSU test to ASTM methods. For toxic products evolution, the author compares some animal tests and cites his literature bibliography.

120. DeWitt, Richard L.: Preliminary Concept, Specifications, and Requirements for a Zero-Gravity Combustion Facility for Spacelab. NASA TM–78910, 1978.

A design for a low-gravity chamber, 0.6 m outer diameter by 1.5 m high, is described for installation on Spacelab. The chamber will be supplied with liquid or gaseous fuels, O-N or He atmospheres to 2 atm pressure, internal gas distributors, venting, and so forth. (See also DeWitt, R.L.: Combustion Experimentation Aboard the Space Transportation System in Ref. 150, pp. 245–258.)

121. McGunigle, R.D.; Jackson, H.W.; and Beavers, R.R.: Applicability of Fiber Optics to Aircraft Fire Detection Systems. AFAPL–TR–78–84, 1978.

This report from HTL Industries reviews ultraviolet- (UV) -conducting fiber optics at wavelengths >280 nm for aircraft fire-signal transmission. It also gives an assessment of costs and weight.

122. Russo, D.M.: Behavioral Technology and Its Application to Fire Toxicology Research. Conference on Fire Resistance Materials (Firemen), Demetrius A. Kourtides, ed., NASA TM–78623, 1978, pp. 159–179.

A paper from a midterm project review notes that traditional toxicity tests are necessary but not sufficient to evaluate pyrolysis and/or combustion products. Some products may be relatively nontoxic but behaviorally disabling and impeding escape. Tests with mice in wheels and shock chambers show significant behavioral impairment but considerable variation between tasks.

123. Sibulkin, Merwin; and Little, Michael W.: Propagation and Extinction of Downward Burning Fires. Comb. Flame, vol. 31, 1978, pp. 197–208.

Experimental studies were conducted on a 1.3-cmdiameter rod of poly(methyl methacrylate) (PMMA) in an upward flow cylinder, burning like a candle. The gas mixture varied from 20.6 to 23.2 vol.% O_2. The burning surface assumed a conical shape having an angle ϕ with respect to the axis. As %O_2 decreased, ϕ increased (i.e., the surface became flatter). Thus the flame propagation decreases, but the rate of the surface regression remained constant as $u/v = \sin\phi$, where u = surface regression and v = flame propagation. Relating this behavior to the limiting oxygen test ASTM D–2863 showed that the cause of extinction is not reduction of heat transfer from flame to burning region. Rather it is the inability to propagate below the burning cone. Tests just below the limiting index show a flame consuming the cone but extinguishing when the cone is flat ($\sin\phi = 1$).

124. Bukowski, R.W.; and Mulholland, G.W.: Smoke Detector Design and Smoke Properties. NBS Technical Note 973, 1978.

Ionization and photoelectric smoke detectors are discussed, in both theory and design. The ionization type is most sensitive to particles >0.3 μm in diameter; photoelectric detectors are most sensitive to larger particles. Aerosol instrumentation for calibration is discussed.

125. Tesoro, Giuliana C.; and Moussa, N. Albert: Materials for Fire Resistant Passenger Seats in Aircraft. J. Consumer Prod. Flamm., vol. 5, no. 4, 1978, pp. 201–216.

Tests of several materials were conducted for the NASA Ames FIREMEN project, using a concentrated radiant heat source of 5 (approximately equivalent to a single match) to 21 W/cm^2. As expected, the time to smoke, char, or ignite decreases with increasing heat flux. Only cotton and a wool-nylon blend ignited; phenolic and PBI did not. At low fluxes urethane or neoprene backings influenced ignition, urethane promoting ignition and neoprene inhibiting it.

*126. Williams, F.A.: Droplet Burning at Zero-g. NASA CR–158160, 1978.
Also in Reference 150, pp. 31–60.

Zero-gravity droplet experiments are justified by the need to achieve spherical symmetry of the flame, where time to extinction (10 s for 1 mm droplet) and positioning-release delays demand the long-term exposure of Spacelab. Feasibility studies were conducted at the NASA 2.2-s drop tower (Ref. 140). These studies were largely qualitative although they showed a droplet diameter decrease greater than theory. A third phase of the study was the conceptual design for Spacelab installation of the DeWitt chamber (Ref. 120). The proposed design includes description of a syringe system, electrostatic positioning, retractable spark system, and motion picture instrumentation. Proposed fuels include C_7H_{16}, $C_{10}H_{22}$, CH_3OH, kerosene, heavy fuel oils, 10 percent H_20 in C_{16} H_{34}, and mixtures.

127. Summerfield, M.; Messina, N.A.; and Ingram, L.S.: Definition of Smoldering Experiments for Spacelab. PCRL–FR–79–001 (NASA CR–159528), 1979.

Smoldering is a low-temperature (~500 °C) combustion wave in porous materials. The authors discuss the possibility of a canister experiment for Spacelab. A thorough review of density, physics, and design is included. (See also Summerfield, M. and Messina, N., “Smoldering Combustion in Porous Fuels,” in Ref. 150, pp. 129–194.)

*128. Berlad, A.L.; and Killory, J.: Combustion of Porous Solids at Reduced Gravity Conditions. NASA CR–3197, 1979.

This report discusses the need and difficulty of particle cloud combustion. An experimental apparatus is proposed for Spacelab. Work in progress includes a lycopodium powder-in-air test in the NASA 2.2-s drop tower. Particles are dispersed by upward flow 10.5 s before drop. At 1 s before the drop, the flow ceases. The igniter is turned on at 0.65 s after drop, off at 1.15 s. Comparison of 0g results with upward propagating 1g shows the 0g post reaction zone disturbance and luminosity are less than at 1g. For the same particle concentration of 130 mg/L, 1g flame propagation was 17 cm/s. The agreement with previous 1g downward results was only fair. (See also Berlad, A., “Combustion of Particle Clouds,” in Ref. 150, pp. 91–127.)

*129. Russo, D.: Recent Advances in Materials Toxicology. Conference on Fire Resistant Materials: A Compilation of Presentations and Papers, NASA CP–2094, 1979, pp. 27–42.

This is a collection of viewgraphs from the final review, updating Reference 122. Results of three experiments on animal survivability with CO, HCN concentrations are shown.

130. Fewell, Larry L.: Fire Resistant Aircraft Seat Program. Conference on Fire Resistant Materials: A Compilation of Presentations and Papers, NASA CP–2094, pp. 135–166.

This program consists of Phase I—Initial tests, limiting oxygen index, performance, and toxicity; Phase II—in-service full-scale tests; and Phase III—processing and value decisions. A large number of candidate materials were considered. Illustrations show the seat construction, highlighting the multilayer cushion, fire block, and fabric cover. The Ohio State University (Ref. 62) apparatus tested heat release of multilayer cushions at 1.5 and 3.5 W/cm^2 heat flux. The paper notes the large quantities of paper and trash found in aircraft.

130A. Abduragimov, I.M.; Androsov, A.S.; and Krylov, E.V.: Flame Propagation Over the Surface of Thin Polymeric Materials. Combust. Explos. Shock Waves, vol. 15, no. 4, 1979, pp. 470–472.

Normal-gravity work in Russia for horizontal 0.05-mm-thick paper shows that the flame above the paper is bright and heats the fuel only by radiation, whereas the flame below the paper is transparent, premixed, and heats fuel by conduction and radiation. With forced concurrent flow, upper flame spread increases to a maximum at 7 cm/s, and the lower flame spread decreases with velocity. If CO_2 is blown into the chamber, upper surface spread decreases with flow while the lower surface extinguishes.

131. Ortiz-Molina, Marcos G.; Toong, Tau-Yi; Moussa, N. Albert; and Tesoro, Guilian C.: Smoldering Combustion of Flexible Polyurethane Foams and Its Transition to Flaming or Extinguishment. Seventeenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1978, pp. 1191–1200.

This continues the work of Reference 110 with proprietary polyurethane bricks and cylinders, some covered with cellulosic materials (cotton). Results are shown by plots of O_2 partial pressure against O_2 mole fraction to define zones of extinguishment, smoldering, and flaming combustion. Heat flux to sustain smoldering was computed as $g = \rho cv\ (T_{\text{interface}} - T_{\text{initial}})$. This was plotted as log(heat flux) versus $1/T$ to rate the various polyurethanes.

*132. Kanury, A. Murty: Feasibility Study of Liquid Pool Burning in Reduced Gravity. NASA CR–159642 (Notre Dame TR No. 79–1), 1979. Also in Reference 149, pp. 195–244.

This study presents justification and theoretical background for combustion study in pool burning for Spacelab, in a tray about 300 to 40 cm long by 2.5 cm deep and wide. Normal-gravity experiments with n-butanol and other fuels show flame spread rate as a function of pool temperature. The author discusses the data and a conceptual design for Spacelab.

133. Reuther, James J.: Measures of Effectiveness and Mechanisms for Chemical and Physical Inhibition of Quenched and Adiabatic Premixed Flames. NBS SP 561, Characterization of High Temperature Vapors and Gases, vol. 2, 1979, pp. 1281–1313.

This is a review and discussion of data, covering adiabatic (Bunsen burner) and quenched (metal screen) combustion inhibition. Criteria for inhibition can be based on normalized flame velocity change (adiabatic) or maximum temperature change (quenched or adiabatic). Self-inhibition is discussed where fuel or oxidant inhibits combustion (i.e., off-stoichiometric combustion). Study of inhibition shows that all inhibitors possess a chemical and physical component, with one dominating. Halogenated hydrocarbon inhibition is via a neutral mechanism and not through ions.

134. Brzustowski, T.A.; Twardus, E.M.; Wojcicki, S.; and Sobiesiak, A.: Interaction of Two Burning Fuel Droplets of Arbitrary Size. AIAA J., vol. 17, no. 11, 1979, pp. 1234–1242.

Theoretical work (first two authors) was performed at the University of Waterloo, Canada; the experimental work (last two authors), at the Technical University of Warsaw. The mathematical model, useful for pollutant studies, yielded the change in burning rate and flow changes with the relative size and separation of two drops. Touching drops of equal size experience a burning rate of $\ln 2$ (0.6931) that of an isolated drop. The burning rate approaches 1 as the separation increases. The flame envelops both drops until a certain separation distance is obtained. Drop tower studies used the Warsaw 1.4-s facility (Ref. 193), which used downward air jets to reduce drag and a braking cable for decelerations. Schlieren photographs resemble the theoretical analyses, but more experimental work is needed. Droplets were suspended on a wire and then released. Only one droplet was ignited and the flame propagated to the second drop.

*135. Horrigan, D.J.: I. Atmosphere. The Physiological Basis for Spacecraft Environmental Limits, NASA RP–1045, 1979, pp. 1–15.

Oxygen limits are shown on a physiological basis, calculated as minimum alveolar oxygen pressure. On this basis, an acceptable transient partial pressure limit is 18.1 kPa (equivalent to the partial pressure at 4000 ft.), but a contingency limit is 16.5 kPa (6000 ft.). A table gives the time of useful consciousness at altitudes above 617 m. Carbon dioxide limits are 0.5 kPa partial pressure for indefinite exposure, 1 kPa for limited duration, and 2 kPa for immediate correction. Relative humidity is recommended in the range of 40 to 70 percent.

*136. Kaplan, H.L.: II. Contaminants. The Physiological Basis for Spacecraft Environmental Limits, NASA RP–1045, 1979, pp. 17–56.

Contaminants detected in Apollo flights are discussed. Toxicological factors are derived from several relationships: absolute concentration (probably very rare), (concentration) × (time), rate of concentration change with time, and (concentration – constant) × (time). CO is the major toxin in fires. Carboxyl hemoglobin above 10 percent impairs performance with long-term exposure to about 70 ppm CO in the atmosphere. Tests indicate a tolerance to slow accumulation of CO up to 400 ppm, probably due to increase of red cell mass. Some 90-day limits for contaminants from Navy submarine and space cabins (also 1000 days) are given based on National Academy of Science recommendations.

137. Affens, W.A.: The Effect of Halon 1301 Fire Extinguishing Agent on the Response of Combustible Gas Indicators. NRL–MR–4150, 1980.

After some review of combustible gas indicator techniques, tests are described in which a heated-filament indicator is exposed to pentane-air vapors with 0, 3.7, and 7.4 percent Halon 1301. Response decreases (indicator reads low) about 30 percent with 3.7 percent Halon and 45 percent with 7.4 percent Halon. There is also a sensitivity loss (like a hysteresis) of about 9 percent after previous exposure to Halon.

138. Lugar, J.R.: Water Mist Fire Protection. David Taylor Naval Ship R&D Center, unpublished letter report, January 1980.

A water mist system with five nozzles was demonstrated on diesel fuel and hexane fires in a chamber. Potable water at 1.3 atm, delivered through a small orifice (0.032 in. diam.), showed rapid extinguishment within 24 s and rapid temperature reduction. Practical application needs more study.

*139. Altenkirch, R.A.; Eichhorn, R.; and Shang, P.C.: Buoyancy Effects on Flames Spreading Down Thermally Thin Fuels. Comb. Flame, vol. 37, 1980, pp. 71–83.

Experiments are described on the burning of thin paper and cardboard samples mounted on an aluminum plate in a centrifuge. Buoyancy effects were investigated for "downward" spreading flames. Gravity, at levels from 1g to 4g, decreased flame spread. Most of the work is on the correlation of nondimensional spread to Damkohler number, the ratio of residence to reaction time.

*140. Knight, Brian; and Williams, Forman A.: Observations on the Burning of Droplets in the Absence of Buoyancy. Comb. Flame, vol. 38, no. 2, June 1980, pp. 111–119.

This paper describes experiments in the NASA Lewis Research Center 2.2-s facility, where droplets of C_7H_{16} and $C_{10}H_{22}$ were ignited in atmospheres of 20, 25, 30, 50, and 80 %O_2 in N_2 at 0.5 and 1 atm. The only quantitative data shown are plots of d^2 versus time, where droplet diameter d decreases more rapidly than predicted by theory. Some independent motion of the drops complicated the assessment. The authors propose that thermal diffusion increased heat transfer and evaporation. A "flash extinction" was noted with decane in 50 %0_2, attributed to hot carbon particles.

141. Waldman, J.J.: Aircraft Fire and Overheat Detection and Extinguishment. SAE Paper 800622, 1980.

This brief historical review covers fire detection and extinguishment devices for aircraft. Current fire detection is described. Thermal detectors consist of spot and line (continuous) types. The latter consists of thermistor or pneumatic-averaging types and discrete types (eutectic materials). Set points for averaging-type detectors are dependent on the length of sensor. Optical (ultraviolet and infrared) sensors are also described. For future applications, fiber optic bundles transmitting to a common sensor and integrated or multiple-decision systems add benefits and redundancy. Present extinguishing methods described include limited active (tank inerting) or manual and automatic Halon 1301 systems. Most extinguishing systems are individually sized to yield 15 vol% of Halon in 0.5 to 0.9 s in a limited volume. Automatic systems are one-shot Halon 2402 for wing surge or vent boxes. For future applications, nitrogen-generating systems using hollow-fiber permeable membrane to separate N_2 from O_2 in air are promising.

142. Huggett, Clayton: Estimation of Rate of Heat Release by Means of Oxygen Consumption Measurements. Fire Mater., vol. 4, no. 2, 1980, pp. 61–65.

The author shows that in general heat of combustion of organic materials is quite uniform on the basis of oxygen consumed, about 13.1 kJ/g. Corrections for experimental measurements are discussed, such as incomplete combustion (CO) and detection factors (moles gaseous products per mole of oxygen). Measurements require only volumetric flow rate and vol% O_2 in exhaust to determine the rate of heat release. A precise technique could run a dedicated MS monitoring Ar as an internal standard. The new Factory Mutual Research Center installation of 60,000 m^3 for fires up to 10 MW at West Gloucester, RI, is cited.

142A. Boccio, J.L.; Asp, I.; and Hall, R.E.: Acceptance and Verification for Early Warning Fire Detection Systems. NUREG/CR–1798, Brookhaven Report BNL–NUREG–51296, May 1980.

A review of detection for nuclear plant protection, covering selection, location, fire signatures, and so forth. Most of the report is based on References 88, 116, and 124. Some discussion covers optical density of smoke related to particulate concentration.

143. Roux, H.J.: A Discussion of Fire Risk Assessment. Fire Risk Assessment Symposium, G.T. Castino and T.Z. Harmathy, eds, ASTM Special Technical Publication 762, 1980.

Risk is defined as a potential for harm or the realization of unwanted, negative consequences of an event. Risk = (expected frequency of event) × (expected degree of exposure) × (potential for harm). If all factors are weighted equally, then

$$\frac{\text{loss}}{\text{unit time}} = \frac{\text{event}}{\text{unit time}} \times \frac{\text{exposure}}{\text{event}} \times \frac{\text{loss}}{\text{exposure}}$$

However, all factors are not viewed equally; that is, often the potential for harm (nuclear meltdown, for example) is regarded as more anxiety provoking than the frequency. A hazard is defined as a level of risk. Thus safe is not necessarily zero risk.

144. Rowe, W.D.: Assessing the Risk of Fires Systemically. Fire Risk Assessment Symposium, ASTM Special Technical Publication 762, 1980.

General treatment of fire risks, in steps of risk identification, risk estimation, risk aversion, and risk acceptance. A diagram shows risk estimation in terms of causative events, outcome, exposure, consequences, and consequence values. Risk acceptance and cost effectiveness are also discussed.

145. Enders, J.H.; and Wood, E.C.: Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee. FAA–ASF–80–4, vol. 2A, 1980.

This 13-month study reviewed in-flight and crash hazards. Findings confirmed that the Ohio State University calorimeter is most promising test method to evaluate material flammability, and much work needs to be done on toxicity standards. Recommendations are to expedite ASTM F–501 and accelerate toxicity testing. The report notes the presence of much uncontrolled paper and material onboard aircraft. A chapter discusses toxicity and smoke, use of animals versus chemical analysis, and incapacitation versus mortality. It is stated that for materials to be rated as toxic hazards, their specific use condition and other properties should be considered rather than solely the specific toxicity of thermal decomposition products. Additional discussion urges further evaluation of anti-misting kerosene.

145A. Melikhov, A.S.; and Potyankin, V.I: On Limiting Conditions of Solid Material Combustion in Weightlessness. Combustion of Condensed and Heterogeneous Systems, Proc. VI All-Union Symposium on Combustion and Explosions, Alma Ata USSR, 1980, pp. 40–51.

Results are reported from tests on paper, cardboard, and polymethyl methacrylate (PMMA) samples in 0g in the Levin Institute 0.725 (~3 m) drop tower. A drag shield assured that the residual gravity was $<2\times10^{-4}$ g. Tests were conducted with O_2 from 15.5 to 35 percent and velocities of 0 to 25 cm/s for paper 0.05 mm thick. Quiescent paper did not propagate when O_2 concentration was below 35 percent. For forced flow of 25 cm/s, paper continued to burn. Limiting flow velocities were also obtained for cardboard (0.5 mm thick) and PMMA (1 mm thick). Photographs showed cardboard propagation at 0.9 cm/s, but not at 0.7 cm/s. For PMMA, results are shown as a flammability map of limiting velocity versus O_2 concentration. At 15.5 %O_2, V_{lim} was around 25 cm/s, and at 35 %O_2 it was 0.9 cm/s. The airplane studies of Kimzey are cited.

*146. Strehlow, Roger A.; and Reuss, David L.: Effect of a Zero g Environment on Flammability Limits as Determined Using a Standard Flammability Tube Apparatus. NASA CR–3259, 1980.

Report summarizes a 3-year precursor and design study for CH_4-air lean limit determination in space. The lean limit is possibly dependent on gravity. The proposed method uses a 51-mm-diameter combustion tube designed for the DeWitt combustion facility (Ref. 120). The gases are seeded for use of laser doppler anemometry or holographic techniques. The authors justify the need to conduct experiments in space. Limited results from the NASA Lewis Research Center 2.2-s facility on flame front propagation velocity versus %methanol are shown to compare 1g and 0g behavior for prediction of lean limit of combustion. (See also Strehlow, R.A. and Reuss, D.L., "Flammability Limits in a Standard Tube," in Ref. 150, pp. 61–89.)

147. Bukowski, Richard; and Istvan, Sharon M.: A Survey of Field Experience With Smoke Detectors in Health Care Facilities. NBSIR 80–2130, 1980.

A questionnaire survey of hospitals and nursing homes in the United.States produced over 1000 usable responses on real and false alarms. Overall ratio of false alarms to real was about 14:1. The false alarms averaged about 0.04/device-year, while real alarms averaged about 0.003/device-year. Survey included coded data on manufacturers. There appeared to be little difference in false alarm frequency between ionization and photoelectric detectors.

*148. DeWitt, R.L.: Requirements and Preliminary Concept of a Zero Gravity Combustion Facility for Spacelab. AIAA Paper 81–0165, 1981.

A condensation of the design material of Reference 120, with expanded background and references.

149. Mehaffey, J.R.; and Harmathy, T.Z.: Assessment of Fire Resistance Requirements. Fire Tech., vol. 17, no. 4, 1981, pp. 221–237.

Several parameters of fire spread in compartments are reviewed. The authors considered fire spread through conduction rather than convective spread. A normalized heat load H is defined as $\frac{1}{\sqrt{k\rho c}}\int_0^{\tau} q\,dt$, where $k\rho c$ = thermal inertia, q = heat output by the flame, and τ = duration of fire exposure. A semi-empirical expression is derived for H, in terms of inertia, heat load, ventilation, and so forth.

150. Cochran, T.H., ed.: Combustion Experiments in a Zero-Gravity Laboratory. Progress in Astronautics and Aeronautics, vol. 73, AIAA, New York, NY, 1981.

Background of the NASA Lewis interest in combustion experiments, which led to the Public Systems Research report (Ref. 89). The study justified zero-gravity research to improve analysis of coupled equations and to provide a "clean" experimental system. The value of the research for spacecraft fire safety is also stated.

*151. Haggard, J.B., Jr.: Forced and Natural Convection in Laminar-Jet Diffusion Flames; Normal-Gravity, Inverted-Gravity and Zero-Gravity Flames. NASA TP–1841, 1981.

Additional research was conducted in the 2.2-s Drop Tower to extend the methane studies of References 55 and 78. For the current studies, the fuel nozzle was coaxial with forced air in the outer annulus. Tests were conducted with the 0.05-, 0.19-, and 0.305-cm fuel nozzles at normal gravity, inverted gravity, and microgravity. For no air flow, normal gravity flame length depended on fuel flow rate and slightly on radius, and inverted gravity flame length depended strongly on radius and flow rate. Normal-gravity flames were always longer than those for inverted gravity. The normal gravity flame radius is correlated by $R_M/R_0 = 5.75 - 3.7 \log \tau_f$, where R_M = maximum flame radius, R_0 = nozzle radius, $\tau_f = R_0/V_f$. The flame radius for inverted gravity is correlated by $R_M/R_0 = 8.55 - 3.7 \log \tau_f$; for zero gravity, the correlation $R_M/R_0 = 10.5 - 3.7 \log \tau_f$. For forced air, zero gravity extinguishment at large R_0 was prevented by minimum air flow of 10 cm/s. The correlation of flame radius with forced convection for zero gravity was $R_M/R_0 = 2.4 + 4.75 \log(\tau_A/\tau_f)$, where τ_A = air nozzle radius/air flow. For normal gravity, the authors found the correlation to be $R_M/R_0 = 1.5 + 3.0 \log(\tau_A/\tau_f)$.

152. Kubicki, Dennis J.: Fire Protection and Rescue Planning for the NASA Space Shuttle. Fire J., vol. 75, no. 4, 1981, pp. 34–40.

First, the NHB 8060.1A classification of materials usage and required tests is reviewed. Then shuttle ground escape modes are described. A diagram shows the nine ionization-type detectors in the air and crew compartment. Fixed Halon 1301 extinguishers are discharged by "arming" and pressing the discharge button to provide 6 percent within 2 s. Four portable extinguishers can be aimed into 1/2-in. "fire holes" in the panels. A mission is terminated if an extinguisher is discharged because of toxicity concerns. There are three launch abort modes: return to launch site after 60 km; abort-once-around, ~270 s; and abort-to-orbit, >270 s.

153. Brzustowski, T.A.; Sobiesiak, A.; and Wojcicki, S.: Flame Propagation Along an Array of Liquid Fuel Droplets at Zero Gravity. Eighteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1981, pp. 265–273.

This continues the experimental work of Reference 134. The Technical University of Warsaw experiment package for the 1.3-s drop tower with its drag-reducing jets is shown. Most work was done with double drops of C_6H_6, n-C_8H_{18}, and n-C_7H_{16}. A spark was discharged at the drop, igniting one droplet. Time to ignite the second drop, for a given fuel, seemed to be a function of the spacing to the third power and a mild inverse function of droplet direction or volume. It was noticed from Schlieren photographs that the thermal wave reached second droplet before it ignited, because of physical and chemical delay times. However, ignition seemed "contactless"; that is, the droplet ignited before visible flame reached it. In low gravity, the flame spread is spherical until the flame is quenched by lack of fuel or O_2. Hence, the second droplet can always be ignited if time allows. Under normal gravity, however, heat convection may sweep the thermal plume upward, limiting lateral spread to adjacent droplets.

154. Ballal, D.R.; and Lefebvre, A.H.: Flame Propagation in Heterogeneous Mixtures of Fuel Droplets, Fuel Vapor and Air. Eighteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1981, pp. 321–328.

The drop tower at Cranbrook Institute of Technology is 10 m high (1.4-s free-fall time) with guide rods and automobile tires as decelerators. The apparatus is a 7-cm square tube with blackened interior. Fuel mixtures of isooctane, diesel, or heavy fuel oil are atomized to produce mixtures of droplets, vapor, and air. A screen upstream of the spark electrode produces flat flames, as observed by an open shutter camera with chopped light. Results show that at 1 atm, flame spread decreases from a laminar value (23 to 43 cm/s, depending on fuel and equivalence ratio, ϕ) as the fraction of nonvaporized fuel is increased. For small droplets, the decrease is slight; that is, the mist acts like vapor. For subatmospheric pressures, flame spread is proportional to P^{-x}, where $x = 0.5$ for droplets and 0.3 for vapor. Results agree well with prediction based on equating the quench time to the sum of the reaction and evaporation times.

155. Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials in Environments That Support Combustion. NASA TM–84066, 1981.

This is the revised NASA handbook on material acceptance testing.

155A. Feoktistov, K.P.; and Markov, M.M.: Evolution of ‘Salyut’ Orbital Stations. USSR Report Space No. 15, JPRS–80424, 1982, pp. 1–11. (Translation of Zemlya i Vselennaia (Earth and Universe) no. 5, Sept.-Oct. 1981, pp. 10–17).

Description of innovations in Russian space station indicates that Salyut 6 has a fire detection system and special fire extinguishers. No other details are given.

155B. Mulholland, G.W.: How Well Are We Measuring Smoke? Fire Mater., vol. 6, no. 2, 1982, pp. 65–67.

Photoelectric extinction detectors can have calibration errors of 25 percent or more from forward scattering and white light effects.

156. Quintiere, J.G.: Smoke Measurements: An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program. Fire Mater., vol. 6, no. 3 and 4, 1982, pp. 145–60. (Also NBSIR–82–2508–PT–1, 1982.)

This is a literature review on equations and measurements of smoke particle size and spatial density. Comparisons of full-scale and laboratory test data are shown. Test methods are described and evaluated.

157. Williams, S.J.; and Clarke, F.B.: Combustion Product Toxicity—Dependence on the Mode of Product Generation. Fire Mater., vol. 6, nos. 3–4, 1982, pp. 161–162.

Rat lethality data (at DuPont) show large differences depending on whether combustion is in a cup furnace or supported on a wire mesh above CH_4 (high water in products) or C_2H_2 (low water) flames. Differences are seen with polytetrafluoroethylene (PTFE) or Douglas fire reference fires. Polyacrylonitrile, which produces thermally generated HCN, showed less difference in lethality between combustor types.

158. Reichelt, Eric F., Walker, Joseph; Vickers, Richard W.; and Kwan, Anthony J.: Report of Test Results: Halon 1301 Versus Water Sprinkler Fire Protection for Essential Electronic Equipment. ESL–TR–82–28, 1982.

Halon 1301 at 5.6 percent concentration is highly effective and showed no harm to magnetic tape or other electronic equipment. It is felt that Halon 1301 is ineffective on deep-seated fires, but electronic fires are not of this nature. Water from a sprinkler head did not discharge until there was a high temperature rise. Water has the drawbacks of corrosion and staining.

159. Berlad, A.L.: Combustion Under Microgravity Conditions. AIAA Paper 82–0880, 1982.

A very generalized review cites three areas for continued microgravity studies: (1) kinetic oscillations in combustion, (2) radiative ignition of solids, and (3) flame propagation and ignition at high pressure.

160. Quintiere, J.G.: An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program. NBSIR–82–2508–PT–1, 1982. (Avail. N83–19727).

In this review, only light attenuation by smoke, not toxicity, is considered. The key parameters are α, the particle optical density, or σ/C_s, where σ = extinction coefficient (m^{-1}), and C_s = mass of particulates per unit gas volume, X, the ratio of particulate mass to total mass loss. For α and X independent of time, $D_s = \alpha Xm''$, where D_s = optical density per unit path length, and m'' = mass lost per unit area and time. These parameters form a basis for comparing the scaling of tests (like the Ohio State University test and ASTM E–906) up to full scale. The discussion covers the effects of time, heat flux, O_2 concentration, and so forth on these parameters. Various data are compared. The correlations deviate as the full-scale fire becomes more complex.

161. Quintiere, J.G.: An Assessment of Correlations Between Laboratory and Full-Scale Experiments for the FAA Aircraft Fire Safety Program, Part 2: Rate of Energy Release in Fire. NBSIR–82–2536–PT–2, 1982. (Avail. N83–19728).

This review deals mostly with equations of calorimetry to derive flame spread and heights. The key parameters are heat of combustion ΔH_c, the equivalence ratio ϕ, and heat of vaporization ΔH_{vap}. Flame spread is derived from these parameters and a Spalding mass transfer number to give some limited comparisons to experiments. Flame spread will be small (no propagation) if $\dot{m}'' + \left(\dot{q}_e''/\Delta H_{\text{vap}}\right)$ is small, where $\dot{m}''$ = mass loss/(time-area) and q_e''= external heat transfer/(time-area).

162. Apostolakis, G.: Data-Analysis in Risk Assessments. Nucl. Eng. Des., vol. 71, no. 3, 1982, pp. 375–381.

Some background material on probability risk assessment later proposed for application to fire safety. Bayes theorem relates the effect of evidence (information as opposed to data) on probability distribution. A distinction is made between measured frequencies and unmeasurable probabilities. Paper discusses and gives examples of generic distributions, dependence on human factors, among other factors.

162A. Tsuchiya, Yoshio: Methods of Determining Heat Release Rate—State-of-the-Art. FSJOD, vol. 5, no. 1, 1982, pp. 49–57.

Author, from the National Research Council, Canada, gives a review of thermal and oxygen consumption methods to measure the rate of heat release. Thermal methods, such as American Society for Testing and Materials (ASTM) and the Ohio State University test suffice because of thermal inertia; that is, the time delay of thermocouples, for example, give a reduced rate of heat released compared with the real surface-wave response (about 60 percent). Corrections, such as constant-temperature methods, are mathematical manipulations that can compensate for those flaws. Highly radiative flames also cause errors. Oxygen consumption methods assume a constant heat release (419 kJ/mole O_2 or 13.1 kJ/g). The paper lists combustion sources that deviate from this constant. Incomplete combustion to CO can be corrected, if the CO/CO_2 ratio is known or estimated. The change in number of moles of fuel gas requires a small correction. Improvements in the accuracy of O_2 determination by paramagnetic susceptibility or diffusion through a membrane can help. In general, O_2 consumption methods are more rapid and accurate. Tables show deviations for CO concentration, unusual organic fuels, and others.

162B. Melikhov, A.S.; Potyankin, V.I.; and Flankin, E.V.: Limiting Conditions of Polymer Combustion at Reduced Pressures. Fizika Goreniya i Vzryva, vol. 18, no. 3, 1982, pp. 44–47. Combustion, Explosions, and Shock Wave, vol. 18, no. 3, Nov. 1982, pp. 297–300.

Test of cotton, poly(methyl methacrylate) (PMMA), polyimide, fluorocarbon, and other materials established curves of limiting total pressure versus oxygen concentration. Most of the attention focused on PMMA. This had flammability limit of ~16 $\%O_2$ that is constant down to about 100 mm Hg. At the lower pressures, the flammability limit increased to high O_2 concentrations. At 100 $\%O_2$, the limit was 9 mm Hg. Flame pictures show pale spherical flame (blue) near the minimum pressure with the flame standing well off the fuel. Temperature measurements confirm that the gradient in the flame region is lower near the minimum pressure. Convection appeared with the lowest pressure.

163. Beene, David E., Jr.; and Richards, Robert C.: Extinguishing Deep-Seated Cargo Hold Fires With Carbon Dioxide. CG/D–09/83, 1983. (AD–A–127977).

Tests were conducted with corrugated cardboard bales in a 5.7-m^3 test chamber and in a 1050-m^3 cargo hold in a test vessel in Mobile, AL. The cardboard was ignited by a charcoal igniter until visible flames were seen. The deep-seated fires were treated with CO_2. A concentration of 25 percent (per free volume) was seen to control the fire to the extent that the steel structure is cool and the ship can return to port. A true extinguishment requires over 60 $\%CO_2$ and soak times of 15 hr, requiring quantities of CO_2 unlikely to be carried onboard ships.

164. Quintiere, J.G.; and Tanaka, T.: Some Analysis of the FAA Post Crash Aircraft Fire Scenario. Fire Tech., vol. 19, no. 2, 1983, pp. 77–89.

A model of pool fires at cabin doors is assessed using various equations of Emmons and Prahl (Ref. 91). Results are shown on plots of predicted cabin temperatures for various fuel quantities, intensities (kW), and wind speeds. One figure also shows a prediction of smoke layer height.

165. Bankston, C.P.; and Back, L.H.: Pool Fire-Ventilation Crossflow Experiments in a Simulated Aircraft Cabin Interior. J. Aircr., vol. 22, 1985, pp. 861–868.

A review of the literature discusses briefly full-scale and reduced-scale aircraft cabin tests. No data are given. Jet Propulsion Laboratory results show that despite crossflow, a reverse ceiling flow occurs, spreading smoke and toxic products against ventilation.

166. Desmarais, L.A.; and Tolle, F.F.: Integrated Aircraft Fuel Tank Inerting and Compartment Fire Suppression System. AFWAL–TR–83–2021–VOL–2, 1983.

A large matrix of tests were conducted in simulated nacelles with and without forced convection and with JP–4 and other fuel fires. Extinguishment was deemed successful if it suppressed the fire within 4 s. The maximum agent requirements (worst scenarios) were (in vol%) 6% H1301, 34% CO_2, 34% LN_2, 58% GN_2, and 72% NEA9 (inferred from GN_2). On a mass basis, spread between agents is reduced to a factor of 3. Nitrogen-enriched air to a maximym of 9 vol% O_2 (NEA9) looks more promising as an inerting agent.

167. Eklund, Thor I.: Analysis of Dissipation of Gaseous Extinguisher Agents in Ventilated Compartments. DOT/FAA/CT–83/1, 1983.

Previous sources give acceptable dosages of extinguishers as Halon 141 = 4% x minutes; H1301 = 10% x minutes; and CO_2 = 25% x minutes (latter is far too conservative at lower concentration). The author devises simple, perfect mixing calculations to produce nomograms of maximum extinguisher weight for aircraft, for air change and compartment volume. The governing equation for Halon 1301 is $W = 0.02850v/\tau$, where W = maximum stored water (lb), v = compartment volume (ft^3), and τ = air charge time (min). Results, based on perfect mixing, are claimed to be conservative.

168. Judd, M.D.; and Meehan, J.: Flammability Testing. ESA Bulletin—European Space Agency, vol. 34, 1983, pp. 28–32.

For Spacelab materials, generally NHB 8060.1B tests (Ref. 155) are used. The prime screening test is upward propagation; the criterion being self-extinguishment for less than 15 cm of the 30-cm sample and less than 10 min burning and no dripping or spattering. For materials that fail Test 1, a configuration test based on Test 10 of Reference 155 or a wire overload test, Test 4, as appropriate, are performed. Examples of test results are shown by photographs. Configuration tests are essential.

169. Witcofski, R.D.: Space-Station Crew-Safety Requirements. Presented at the Conference and Workshop on Mission Assurance, paper no. 10, Los Angeles, CA, 1983. (A83–36408).

The paper presents an introduction to the forthcoming Rockwell study (Refs. 203 and 207) The Rockwell contract assessed space station safety through identification of threats, time constraints, strategies, costs, and so forth. For fire, three lines of defense are indicated: design to preclude, design to control (this includes detection, suppression, evaluation of hatches, etc.) and retreat to a "safe haven."

170. Desmarais, L.A.; Tolle, F.F.; and Allen, T.D.: Evaluation of Advanced Airplane Fire Extinguishants. AIAA Paper 83–1141, 1983.

Paper is largely a condensation of Ref. 166 with some additional tests and comments on MONNEX ($KC_2N_2H_3O_3$) and dawsonite powder extinguishants.

171. Altman, R.L.: Extinction of In-Flight Engine Fuel-Leak Fires With Dry Chemicals in Flames, Lasers, and Reactive Systems. Progress in Astronautics and Aeronautics, J.R. Bowen, N. Manson, A.K. Oppenheim, and R.I. Soloukhin, eds., vol. 88, AIAA, New York, 1983, pp. 273–290.

Tests were conducted with JP–4 dripping on a heated trough. Effectiveness of dry chemicals was assessed by the time to reignition; that is, the time after initial extinguishment to ignition after continued fuel drips. Commercial carbonates and MONNEX ($KC_2N_2H_3O_3$) were the best in delaying fuel-leak fires, superior on a weight basis to Halon. Additional tests in an air flow apparatus also showed the effectiveness of powders. Some experimental formulations of potassium dawsonite ($KAl(OH)_2CO_3$) and KCl or KI show great promise.

172. Webb, Murray & Associates, Inc.: Literature Survey With Bibliography to Accompany the Evaluation of a Condensation Nuclei Fire Detector. Unpublished report to NASA Johnson Space Center, June 1983.

This survey was prompted by tests of the Environment One Corp. condensation nuclei fire detector. The bibliography covers smoke and condensation nuclei properties and generation, smoke detector technology, and particle counter technology. None of this may be applicable for spacecraft fire safety.

173. Williams, F.A.: Studies of Experiments on Droplet Burning at Reduced Gravity. Proceedings of the 4th European Symposium on Materials Sciences Under Microgravity, ESA SP–191, 1983, pp. 191–196. (N83–31667).

This is largely a repeat of References 125 and 139 on the 2.2-s droplet results and an expanded introduction.

174. Alexander, J.I.; Bogan, D.J.; Carhart, H.W.; Eaton, H.G.; Kaplan, C.R.; St. Aubin, H.J.; Sheinson, R.S.; Stone, J.P.; Street, T.T.; Tatem, P.A.; White, T.M.; and Williams, F.W.: Submarine Hull Insulation Fire Test IV. NRL FR–8727, 1983.

Tests were conducted on a hull with open hatch using a n-heptane fire pan. Results showed a maximum chamber temperature of 450 °C after 2.3 min, maximum radiation of 0.2 W/cm^2, and maximum concentration of CO of 0.43 percent at 8 min. Comparisons with the first three tests with closed hatches showed the much slower buildup of temperature (closed hatch reached 770 °C in 1.2 min).

175. Ballal, D.R.: Flame Propagation Through Dust Clouds of Carbon, Coal, Aluminum and Magnesium in an Environment of Zero Gravity. Proc. R. Soc. Lond., sec. A, vol. 385, 1983, pp. 21–51.

In the 1.4-s drop tower of Cranfield Institute of Technology (Ref. 154), the test section was modified to produce and ignite clouds of coal and metal powders. Photography showed results of burning velocities in the range of 5 to 25 cm/s for coals and up to 40 cm/s for Al and Mg. For coal, velocity increases with volatile content and with equivalence ratio ϕ and decreases with particle size (12 to 47 μm). Oxygen enrichment increases velocity but also increases heat losses by radiation. The technique of Reference 154 (equating quench time to evaporation and reaction times) is also applied to dust clouds to derive flame thickness and burning velocity. Selected velocities for solids and liquids can be plotted as functions of a mass-transfer number.

176. Ikeda, G.K.: Oxygen Index Tests to Evaluate the Suitability of a Given Material for Oxygen Service. ASTM Special Technical Publication 812, B.L. Werley, ed., 1983, pp. 56–67.

The oxygen index (OI) is the minimum percentage of O_2 in O_2-N_2 required to sustain candle-like burning at equilibrium (Test ASTM D 2863, used in G63 for evaluation of materials for oxygen service). In general, increasing ΔH_{comb} corresponds to decreasing OI. The OI is also lower for higher temperature gas mixtures and for upward burning. An arbitrary acceptability index is quoted as $(\mathrm{OI})^2 T_i/\Delta H_{\mathrm{comb}}$, where T_i is the autoignition temperature (deg R) in 100 $\%O_2$. Shortcomings of D2863 are the lack of temperature controls and lack of strict criterion for flammability.

177. Monroe, R.W.; Bates, C.E.; and Pears, C.D.: Metal Combustion in High-Pressure Flowing Oxygen. ASTM Special Technical Publication 812, 1983, pp. 126–149.

This paper covers metal combustion in oxygen and presents a table of metal combustion properties. A burn ratio (BR) for metals is proposed, which is $\Delta H_{comb}/\Delta H_{phaschg}$, where $\Delta H_{phaschg}$ is the heat of fusion if BR is at the melting point (mp), or the heat of vaporization if BR is at the boiling point (bp). A $(BR)_{mp}$ below 5 for some metals shows that they may not sustain combustion in the liquid phase, and a $(BR)_{bp}$ below 1 shows that combustion is difficult in the gas phase. The paper cites experimental work in which a metal rod is heated and fractured in a stream of oxygen. Plots of ignition as a function of oxygen pressure and specimen temperature confirm that low-BR materials (e.g., Al and steel) burn readily, whereas high-BR materials (e.g., copper-nickel alloy and silver) do not. Hence, the burn ratio establishes a criterion for oxygen service.

178. Slusser, J.W.; and Miller, K.A.: Selection of Metals for Gaseous Oxygen Service. ASTM Special Technical Publication 812, 1983, pp. 167–191.

In this paper on metal-oxygen compatibility, the authors recommend promoted ignition tests. They quote previous results with neoprene "pills" to ignite metals. Their own work at Air Products and Chemicals uses an apparatus with compressed steel wool-Al wool pills. Results show that of the materials tested, Monel was the best, then 304 SS. Material selection for valves with O_2 contact and a "fire triangle" for metals was also discussed.

*179. Bond, Aleck C.; Pohl, Henry O.; Chaffee, Norman H.; Guy, Walter W.; Allton, Charles S.; Johnston, Robert L.; Castner, Willard L.; and Stradling, Jack S.: Design Guide for High Pressure Oxygen Systems. NASA RP–1113, 1983.

This volume reviews O_2 testing and materials selection, recommending metallic and nonmetallic materials. An interesting discussion covers component design problems (thin walls, feathered edges, blunt passages, etc.), systems design, cleaning procedures, and inspections.

180. Berlad, A.L.: Multiphase Combustion Experimentation in Microgravity. IAF Paper 83–141, 1983. (A83–47288).

This paper is largely an analysis and survey, expanding on the chapter in Reference 150. The emphasis is on particle clouds, where gravitational settling prevents systematic experimental studies of large particles and even makes small-particle-size studies difficult. Several designs for shuttle-based particle cloud zero-gravity studies proposed under a TRW, Inc., contract are shown. The importance of these studies to safety is noted because present dust flammability measurements are poorly defined in normal-gravity apparatus.

180A. National Behavior Systems: Space Station/Nuclear Submarine Analogs. Boeing Aerospace Company, IR&D CC0271 (Proprietary), Oct. 13, 1983.

Review and interview case study of submarine human factors and operations for analogy to space stations. Safety is discussed only in terms of safe havens and attitudes.

181. Clarke, F.B., III: Toxicity of Combustion Products—Current Knowledge. Fire J., vol. 77, no. 5, 1983, pp. 84–101.

This is a thorough review of toxicity testing. Statistics in Maryland indicate that CO may be responsible for 48 percent of fire deaths (carboxyhemoglobin, COHb > 50 percent) and contribute to 16 percent more (COHb > 30 percent). Burns are responsible for 18 percent. Several test methods for toxicity are discussed. Combustion and pyrolysis can be in a tube furnace, cup furnace, or radiant heater, and the exposure chamber can be static or dynamic. Lethality is determined as an LC50 (lowest concentration for 50% mortality) or a time to lethality. Several test methods are reviewed. Among them is the Hilado USF–NASA method with a tube furnace, dynamic measurements, and time criteria.

Comparative data are shown for the National Bureau of Standards (NBS) method, using static-cup furnace and time criteria. Checks for interlaboratory reproducibility are given relative lethality for common materials. It is noted that many plastics are less toxic than woods. Pyrolysis just below the ignition temperature may generate as many products as combustion. The author also compares NBS results with dynamic calorimeter tests, finding order-of-magnitude discrepancies. The paper notes that the static tests expose animals to all products at once; the dynamic tests expose them to varying products. Toxicity of products may be completely different for dynamic and static tests. In summary, no "correct" methods are available yet.

181A. Melikhov, A.S.; Potyankin, V.I.; Ryzhov, A.M.; and Ivanov, B.A.: Limiting Polymer Combustion Regimes in the Absence of Free-Convection. Combust. Explos. Shock Waves, vol. 19, no. 4, 1983, pp. 393–395.

Tests at the Moscow Aviation Institute investigate the combustion of poly(methyl methacrylate) (PMMA) over concentrations from 16 to 100 %O_2, pressures from 30 to 760 nm Hg, and imposed concurrent velocities from 0.2 to 150 cm/s. Low velocities (to 20 cm/s.) were produced by moving the sample (1 by 8 by 50 mm). Higher velocities are produced by a forced flow. The data are summarized in a flammability curve of %O_2 versus velocity limit. In the absence of free convection, the minimum O_2 was about 16%. The curve had a minimum with two increasing branches. In normal gravity, the minimum O_2 was 15%. Results above were at 1 atm. A correlation produced a set of curves at decreasing pressure, where the limit of flammability increased as pressure decreased. This has implications for depressurization. The pressure data were probably taken at normal gravity.

182. Mniszewski, K.R.; Waterman, T.E.; Campbell, J.A.; and Salzberg, F.: Fire Management/Suppression Systems/Concepts Relating to Aircraft Cabin Fire Safety. IITRI–J06532/C06554, 1982.

This is a comprehensive literature review by Illinois Institute of Technology Research Institute and Gage-Babcock for the Federal Aviation Administration on aircraft fire management, considering post-crash and in-flight fire scenarios. Some items are of interest to spacecraft safety. The crash fire section presents charts of melt-through time and internal temperatures for various Al skin thicknesses and insulation. Inside the cabin, fires are classified as rapid, developing <1 min; moderate, 1 to 5 min; or slow, >5 min. The review discusses smoke visibility and presents optical density equations. Limiting optical density for escape is stated as 6%/ft. Experiments show that polymeric materials generate more smoke in flaming than smoldering combustion (acrylic sheets are an exception); cellulosic materials generate more when smoldering. Generally, polymers generate more smoke than cellulosics. Toxic gases are also discussed. The limiting value of CO blood hemoglobin (COHb) for human judgment impairment is 35 percent, and Pesman (NACA TN 2996, 1953) recommends a relation COHb (%) = 8 × CO (%) × τ, where τ = exposure time in minutes). Plots also show air temperatures for fire sizes and times. Long-term human exposure is limited to 70 °C; although 130 °C can be endured for 15 min escape time. The report covers suppression agents and notes the unsuitability of foams (psychological), dry agents (dispersal), and CO_2 (suffocation) in aircraft. Automatic sprinklers and Halon systems are promising in aircraft. Halon 1301 is considered acceptable to 7 percent, although the corrosiveness of products is recognized. Comparatively, Halon 1211 is considered more toxic in enclosed spaces. Aircraft decompression to fight fires is noted, but work of Starrett (Reference 100A) shows that decompression itself is insufficient. For passengers, ambient condition above 14 000 ft may not be tolerable. The Federal Aviation Regulation FAR (1974) requires fire detection in aircraft in cargo and powerplant volumes, but not passenger cabins. The use of cross zone detectors, preferably of different species, is recommended. An "OR" gate could warn, and an "AND" gate could alarm or suppress. Suggestions are noted to reduce sensitivities at busy times—day or meal time in galleys, for example—in order to reduce false alarms (15- to 25:1 in structures). Blocking smoke by overpressure is noted; a12-Pa (0.05 in H_2O) differential may be sufficient.

183. Helgeson, W.C.; and Schultz, H.E.: A Method for Evaluating Smoke Control on Ships Using SF_6 Tracer Gas. CG/D–23/84, 1983.

SF_6 was discharged to check airflow patterns in a Coast Guard cutter, as detected by an electron capture device, sensitive to 1 ppb. The method is useful in evaluating hatch closures, dampers, and so forth, with the SF_6 simulating smoke. Flows are of the order of 4.5 m/min. The gas is 5 times denser than air. How well it would simulate the convective flow of smoke or the behavior in the closed environment of space is questionable.

184. Materials Branch, Structures and Thermal Division: "Materials Branch Procedures for Conducting Flammability, Offgassing, Fracture Control, Outgassing, and Stress Corrosion Payload Reviews," NASA JSC–19614, Jan. 1984.

This presents review policies for STS–10 and later. Flammability evaluations are shown by logic diagrams (yes-no decisions). An appendix shows a vented container design and assessment philosophy. The assumption is that fire can occur, thus for acceptance as fire-safe, fires resulting from ignition of test materials or components will either self-extinguish or at least not propagate. It is not a requirement that equipment be in operating condition after the fire is out. Various configuration requirements are included, such as flammable materials should be more than 6 in. away from an ignition source or other flammable materials and should not exceed 20 in.^{2}

185. Quintiere, James: A Perspective on Compartment Fire Growth. Combust. Sci. Technol., vol. 39, nos. 1–4, 1984, pp. 11–54.

This is a comprehensive review on fire modeling, covering fluid mechanics, heat transfer, smoke layers, fire growth scenarios, fire spread, and so on.

186. Sibulkin, Merwin; and Malary, Steven F.: Investigation of Completeness of Combustion in a Wall Fire. Combust. Sci. Technol., vol. 40, nos. 1–4, 1984, pp. 93–106.

In an apparatus similar to that of Reference 123, poly(methyl methacrylate) (PMMA) is burned as a diffusion flame. Combustion is far from complete: about 40 percent of carbon formed CO. As the concentration of O_2 decreases toward extinction, combustion becomes more complete. Incomplete burning leads to a 20-percent reduction in ΔH_{comb}, a 10-percent reduction in ϕ_{stoich}, and a 10- to 18-percent reduction in modeled burning rates.

*187. Greider, Herbert R.: Atmospheric Composition. Space Station Medical Science Concepts, J.A. Mason and P.C. Johnson, Jr., eds., NASA TM–58255, 1984, pp. 39–42.

This early work recommends an intermediate pressure in the space station to avoid the bends in preconditioning for extravehicular activity (EVA). This pressure is 7.4 psi, corresponding to 18 000 ft. If the partial pressure of O_2 is to be at sea-level values, the O_2 concentration must be 44 percent; for 5000 ft, the O_2 concentration must be 37 percent; and at 8000 ft, it must be 33%. Airplanes fly with 8000-ft pressurization, and even higher altitude levels can be acclimated. Suit pressure for EVA is assumed to be 4.3 psi. Advantages of structures and reduced leakage for low-pressure in the space station is noted. A pitch for Lewis Research Center fire hazard work is noted.

188. Ewing, C.T.; Hughes, J.T.; and Carhart, H.W.: The Extinction of Hydrocarbon Flames Based on the Heat-Absorption Processes Which Occur in Them. Fire Mater., vol. 8, no. 3, 1984, pp. 148–156.

The authors develop a heat balance equation for flame temperatures, which gives a limiting temperature as the minimum temperature to avoid extinction. This is then used to calculate minimum quantities of extinguishants. For thermally stable gases (N_2, CO_2, etc.), extinction temperatures are of the order of 1700 to 2000 K depending on molecular weight and whether the flames are premixed or diffusion-controlled. The interesting result is if heat absorption sinks due to vaporization, dissociation, and decomposition are considered, minimum quantities of "chemical" extinguishants, solids, liquids, and gases (including H1301) can be calculated. Hence, the heat-absorption process for these extinguishants may be more important than the "chemical" effects.

189. Warren, D.E.; Faughnan, K.A.; Fellows, R.A.; Godden, J.W.; and Seck, B.M.: Aircraft Thermal Detection Utilizing Metal Hydrides. J. Less Common Met., vol. 104, 1984, pp. 375–383.

The Systron Donner pneumatic fire detector, in use since 1962 in aircraft, is described. The tube is filled with He, which of course has a linear *p-T* response. Hence, at a preset average temperature, the He pressure activates a switch. In addition, a core of Ti, Ti-alloy, or Pb hydride (depending on application) releases H pressures nonlinearly with temperature to sense a high local heat. The actuator works on combined He-H pressure, and the action is reversible. A second switch is closed by the normal tube pressure and activates upon a leak or pressure loss. Typical range is 2.1 atm normal and 3.7 to 5.8 atm for actuation.

189A. Hall, J.R., Jr.; and Stiefel, S.W.: Decision Analysis Model for Passenger-Aircraft Fire Safety With Application to Fire-Blocking of Seats. NBSIR 84–2817, 1984.

This is an analytical study supported by the Federal Aviation Administration. Historic data are analyzed for fatal airplane crashes with fires. The analysis is a cost-benefit calculation, attempting to match the economic impacts of lives saved against marginal costs of seat blocking materials. Lives saved are estimated from additional escape time afforded for low, medium, and high (optimistic) scenarios, with value ($500,000) assigned to lives and avoided property damage. Injuries are neglected as negligible to the model. Expenses include seat material and operating costs for the low, medium, and high assumptions. Seat blocking materials are aluminized fiberglass and neoprene plus some hypothetical materials. For U.S. airlines, costs generally exceed benefits, except for some high-level comparisons with fiberglass. For world airlines, benefits may be feasible. Results are very sensitive to assumed costs. The report has descriptions of airplane crashes used in analysis, some economic data, and annotated literature references on aircraft fires.

190. Space Station Requirements for Materials and Processes: General Processes. NASA JSC No. 20149, 1984.

A general handbook on material use, treatment, fabrication, testing, and documentation for the space station, without particular reference to flammability.

191. Kim, Hyung T.; and Reuther, James J.: Temperature Dependence of Dry Chemical Premixed Flame Inhibition Effectiveness. Comb. Flame, vol. 57, no. 3, 1984, pp. 313–317.

Premixed flat-flame CH_4-air tests were used to determine the effectiveness of dry chemicals added to the flame as inhibitors. An inhibitor index was defined as $\Delta T_{inhib}/[In]$, where T_{inhib} is decrease in flame maximum temperature, and $[In]$ is mole concentration of inhibitor. Surprising results were that the index was flame temperature dependent with different slopes; that is, the comparative ranking of dry chemicals at one flame temperature would not necessarily agree with that at another temperature.

192. Okajima, S.; Kanno, H.; and Kumagai, S.: Combustion of Emulsified Fuel Droplets Under Microgravity. IAF Paper 84–153, 1984.

Single droplets of hydrocarbon were burned in air in a 1-s Tokyo drop tower. Paper is almost identical to a later Acta Astronautica paper, Reference 212.

193. Klemens, R.; Wojcicki, S.; and Gieras, M.: Ignition and Combustion of Coal Particles at Zero Gravity. IAF Paper 84–155, 1984. (A85–13093).

Results are presented for coal-particle cloud combustion tests in Warsaw 1.4-s drop tower. The paper is almost identical to a later Acta Astronautica paper, Reference 213.

*194. Ronney, P.D.: Effect of Gravity on Halogenated Hydrocarbon Flame Retardant Effectiveness. IAF Paper 84–156 (NASA TM–83761), 1984. (A85–23199).

Flammability studies of premixed hydrocarbons with Halon 1301 in the Lewis Research Center 2.2–s facility. Paper is almost identical to a later Acta Astronautica paper, Reference 225.

195. Sacksteder, K.R.: Microgravity Combustion Science and Applications Program at the NASA Lewis Research Center. Space Operations: Problems, Issues, and Programs Related to Man in Space, Chemical Propulsion Information Agency Pub. 415, 1984, pp. 265–286.

Paper is a description of ongoing shuttle and ground experiments in combustion (solid surface, particle cloud, and droplet burning). Spacecraft fire safety is briefly mentioned as a topic for an upcoming Johnson Space Center workshop.

196. Sarkos, C.P.; Filipczak, R.A.; and Abramowitz, A.: Preliminary Evaluation of an Improved Flammability Test Method for Aircraft Materials. DOT/FAA/CT–84/22, 1984.

The fire resistance of a scale test model of an aircraft cabin was tested with a propane burner. Protective materials were Nomex honeycombs with various facings. Four small-scale tests were conducted: a vertical Bunsen burner (ASTM F 501), limiting oxygen (ASTM D 2863), radiant panel (ASTM E162), and the Ohio State University (OSU) calorimeter recommended by the SAFER Committee (Ref. 135), ASTM E906. In the scale-model tests, only two phenol Kevlar and graphite-facing panels showed no flameover. However, in the small-scale tests all passed the 60-s F501 and showed oxygen indices of 31 to 44 percent. Results with the other two tests were closer to the scale model ranking. The researchers particularly liked the OSU apparatus operated at 5 W/cm^2 for heat release and O_2 depletion. The OSU apparatus gives lower results than a reference test with the National Bureau of Standards (NBS) cone calorimeter.

197. Peercy, R.L., Jr.; and Raasch, R.F.: The Threat-Strategy Technique—A System Safety Tool for Advanced Design. AIAA Paper 85–0397, 1985. (A85–19723).

A discussion of strategies to meet space station threats, emphasizing fire. The paper is nearly identical to the later Journal of Spacecraft and Rockets paper (Ref. 229).

*198. Noe, K.A.; and Strehlow, R.A.: Behavior of the Lean Methane-Air Flame at Zero Gravity. NASA CR–175586, 1985. (N85–21283).

Lean combustion limits for premixed CH_4-air mixtures were determined in the NASA Learjet facility, as an extension of the 2.2–s work (Ref. 146). Lean limits at 0g were 5.10 percent compared with 5.27 percent for 1g upward propagation and 5.85 percent for downward. The 0g flame front resembled the 1g downward propagation. Flame tip propagation speeds in 0g were 2 to 3 times less than corresponding 1g speeds. Interesting tests were also conducted with ignition at 0g, downward propagations as the gravity levels were increased toward one. Methane composition for extinction increased from 5.27 to about 5.80 percent at gravity levels of 0g to 0.43g, although the actual gravity at the extinction point could be lower than that observed.

199. Williams, F.N.; St. Aubin, H.J.; Stone, J.P.; Alexander, J.I.; Bogan, D.J.; Brandow, S.L.; Carhart, H.W.; Eaton, H.G.; Litz, C.E.; Lustig, S.R.; Maday, M.G.; Neilon, R.M.; Sheinson, R.S.; Simmons, M.B.; Street, T.T.; Tatem, P.A.; White, T.M.; and Kaplan, C.R.: Submarine Hull Insulation Fire Test VII. NRL–FR–8872, 1985.

This is another test in the series described in Reference 174, this time with a closed hatch and paper, cotton, and polyurethane fuels with maximum heat output of 233 kW corresponding to 0.13 W/cm^2 after 300 s. Maximum temperature was 336 °C after 306 s; and maximum CO was 1.1 percent. Smoke particles reached a maximum of 1.9×10^6 particles/liter for size range ≥1 μm. An overall plot of temperature versus time shows higher temperatures but slower rates of temperature rise than test of Reference 174.

*200. Bricker, Richard W.: Test Results From a Comparative Evaluation of a Condensation Nuclei Fire Detector. NASA CR–3874, 1985.

Webb, Murray & Associates, Inc., tested a condensation nuclei fire detector (CNFD) made by Environmental One Corp., Schenectady. The unit had a pyrolyzer to break up particles from smoldering fires. For 138 tests with smoldering polyvinyl chloride (PVC) cable insulation and flaming computer paper, the CNFD was far more sensitive than comparable photoelectric or ionization detection. However, more refinements are needed in the pyrolyzer and the CNFD. For 0g, a substitute for the free-water humidifier is needed. The sensitivity of the apparatus was set at 30 000 particles/cm^3. Typical particle counts show that 50 000/cm^3 (the space station criterion) is attained almost instantly for flaming fires and within 1.5 to 9 min for smoldering fires.

201. Chung, G.; Siu, N.; and Apostolakis, G.: Improvements in Compartment Fire Modeling and Simulation of Experiments. Nucl. Technol., vol. 69, no. 1, 1985, pp. 14–26.

A Univresity of California, Los Angeles, work describes the use of a compartment fire modeling program COMPBRN II, which determines convection and flame radiation. Results were checked with Underwriters Laboratory, Inc., experiments conducted by Sandia National Laboratory, which used a chamber, heptane fire, and cable tray. Results agreed well when using parameters for the doorway coefficient (≈ 0.7), combustion efficiency (≈ 0.7), and a log-normal uncertainty factor. The latter is the ratio of the actual propagation time to the predicted propagation time.

202. Fire Detection and Suppression System for Space Shuttle Orbiter and Spacelab. Brunswick Defense Report 0855–251, 1985.

This report presents diagrams of the smoke detector and extinguisher assemblies in the shuttle and Spacelab. It also has sketches and schematics of systems and brief descriptions of design concepts, hardware, and performance capabilities.

*203. Peercy, R.L., Jr.; Raasch, R.F.; and Rockoff, L.A.: Space Station Crew Safety Alternatives Study—Final Report. NASA CR–3854, 1985.

In Volume I of a five-volume contractor's final report from Rockwell International, the philosophy is given for meeting space station crew safety threats and some open issues for resolution.

*204. Raasch, R.F.; Peercy, R.L. Jr.; and Rockoff, L.A.: Space Station Crew Safety Alternatives Study—Final Report. NASA CR–3855, 1985.

In Volume II of the final report, eight major threats are considered. For the fire threat, the authors note that catalytic reactions, for example with hydrazine, are often overlooked. Many metals catalyze hydrazines. The authors define two strategies for fire safety: (1) design to preclude (low O_2, material control, grounding, ignition control, etc.) and (2) design to control (compartmentalization, detectors, extinguishers, etc.). Kimzey is quoted on handling hydrazines. For the explosion threat, the conventional fire triangle has two added elements: pressure and temperature. For the depressurization threat, minimum O_2 partial pressure limits of 110 mmHg (9000 ft) could be tolerated (the optimum sea-level partial pressure is 160 mmHg). Undetected hypoxia is another cause for concern. An extensive set of tables lists various safety related threats. Also listed are topics for further study. Noted in these is the need to study combustion in microgravity.

*205. Rockoff, L.A.; Raasch, R.F.; and Peercy, R.L., Jr.: Space Station Crew Safety Alternatives Study—Final Report. NASA CR–3856, 1985.

In Volume III of the final report, the authors discuss human factors. The Space Station human factors are reviewed with analogies to Antarctic Research Station, submarines, and Skylab 4. Other chapters cover crisis management, isolation, safety violations, and so forth.

*206. Peercy, R.L., Jr.; Raasch, R.F.; and Rockoff, L.A.: Space Station Crew Safety Alternatives Study—Final Report. NASA CR–3857, 1985.

The appendix to the final report lists literature—mostly Kimzey's work. A summary of crew safety guidelines is included. In the summary, relevant items include those referring to credible single failure (Item A–1), no dual failure (A–2), isolation (A–8), safe haven (A–9, B–1), repressurization (B–7), atmospheric monitoring (B–10), detection of fire hazards (B–21), storage of hazards (B–23), flammable components (C–1, C–2), and personal items (C–15).

*207. Mead, G.H.; Peercy, R.L., Jr.; and Raasch, R.F.: Space Station Crew Safety Alternatives Study—Final Report. NASA CR–3858, 1985.

In Volume V of the final report, the authors present risk assessment charts, safety philosophy, and an example of a threat assessment for fire. Safety guidelines and hazards are repeated from Volume IV.

208. Quintiere, J.G.; Babrauskas, V.; Cooper, L.; Harkleroad, M.; Steckler, K.; and Tewarson, A.: The Role of Aircraft Panel Materials in Cabin Fires and Their Properties. FAA–CT–84–30, 1985.

This is a compilation of fire-test results on aircraft panels of Fiberglass, phenolic, Kevlar, and others conducted by the NBS–CFR (National Bureau of Standards, Center for Fire Research) and Factory Mutual Reseach Corporation (FMRC). Tests of interest are the NBS ignition-flame spread apparatus (also shown in the NASA Fire Safety Workshop report, Ref. 286), the cone calorimeter, and FMRC apparatus.

*209. Gibb, John W.; McIntosh, M.E.; Heinrich, Steven R.; Thomas, E.; Steele, Mike; Schubert, Franz; Koszenski, E.P.; Wynveen, R.A.; Murray, R.W.; Mangialardi, J.K.; and Schelkopf, J.D.: Other Challenges in the Development of the Orbiter Environmental Control Hardware. Space Shuttle Technical Conference, NASA CP–2342, Norman Chaffee, ed., pt. 1, 1985. (N85–16924).

This paper deals with problems and solutions with the shuttle ammonia boiler system, smoke detectors, water/H_2 separator, and waste collector. The smoke detector furnished by Brunswick Corp. (Thomas and Steele) was changed from a quartz crystal microbalance concept to an ionization detector. The nine assembly locations, plus three extinguishers, are shown in a sketch. Other information includes the rationale for adapting particular designs, altitude operation tests, and internal pump and motor designs.

210. Bricker, R.W.: Fire Safety for Manned Orbiting Space Stations. Draft Preliminary Report, NASA Johnson Space Center, 1985.

The report is a general survey on the subjects of minimizing ignition sources and material selection. A very brief review of detection, extinguishment, and 0g effects is included. The detection discussion is based on the condensation nuclei detector, a concept not adopted on the shuttle. The extinguishment discussion notes the development of sticky smothering agents and fire barriers as well as the possibility of flareup and reignition in extinguishing procedures.

211. Berlad, A.L.; and Joshi, N.D.: Gravitational Effects on the Extinction Conditions for Premixed Flames. Acta Astronaut., vol. 12, no. 7/8, 1985, pp. 539–545.

Extinction conditions encompass three limits: <u>flammability</u> based on stoichiometry for a standard vessel (say 5 cm), <u>quenching</u> based on minimum apparatus size, and <u>pressure</u> based on minimum pressure for a given stoichiometry and apparatus. The paper is mainly theory but includes some limited data with premixed lycopodium powder-air flames from the NASA 2.2-s drop tower. For these flames, heat losses appear to be smaller than those for upward and downward 1g flames. Future work is to cover freely propagating and burner-stabilized gaseous flames and also freely propagating and stabilized two-phase flames.

212. Okajima, S.; Kanno, H.; and Kumagai, S.: Combustion of Emulsified Fuel Droplets Under Microgravity. Acta Astronaut, vol. 12, no. 7/8, 1985, pp. 555–563.

This work is analogous to the University of Tokyo work (Refs. 1 and 39). This time, a 0.9-s drop tower is used. The combustion package is in a drag shield, and deceleration is by impact on a cushion at the bottom. The fuels are 90 percent n-C_7H_{16}, i-C_8H_{18}, n-$C_{11}H_{24}$, n-$C_{13}H_{28}$, n-$C_{15}H_{32}$, n-$C_{16}H_{34}$ in water, using a patented Japanese method for creating stable emulsions of fuel in water or water in fuel. Ignited drops, ~1 mm in diameter, show microexplosions in 1g and more steady "puffing" in 0g. Burning rate is about 30 percent less in 0g and increases with carbon number.

213. Gieras, M.; Klemens, R.; and Wojcicki, S.: Ignition and Combustion of Coal Particles at Zero Gravity. Acta Astronaut., vol. 12, no. 7/8, 1985, pp. 573–579.

A study at the Technical University of Warsaw used a 10-m, 1.4-s drop tower, with a cable-guided platform. Four air turbines on the platform balanced the cable and air resistance. Breaking at the bottom used a 5-g cable system. Coal particles were mounted on quartz needles and ignited. The maximum spacing for propagation was determined for a range of particle diameters, for 21 to 100 %O_2, and for coal volatility from 2 to 48 percent. For 21 %O_2, maximum spacing was about twice the particle diameter, increasing slightly with diameter. Maximum spacing increased greatly with increasing O_2 content and increasing coal volatility.

214. Vedha-Nayagam, M.; and Altenkirch, Robert A.: Gravitational Effects on Flames Spreading Over Thick Solid Surfaces. Acta Astronaut., vol. 12, no. 7/8, 1985, pp. 565–572.

This is a theoretical work, but it illustrates downward flame spread over poly(methyl methacrylate) (PMMA) with reference to previous experiments.

215. Kuchta, J.M.; and Clodfelter, R.G.: Aircraft Mishap Fire Pattern Investigations. AFWAL–TR–85–2057, 1985.

This manual is dated, but it has much information from various sources. The authors promise to update the manual in 4 years, but the project was apparently never continued. Contents include investigative procedures, air properties, fuel properties and thermal characteristics, plastics combustion properties, hydrogen properties, explosive tables, fire extinguishant and inerting, and various facts of fire and explosion damage analyses.

215A. Opfell, J.: Fire Detection and Fire Suppression Trade Study. Allied-Signal Aerospace Co. 85–22472, rev. 1, 1985.

This work is part of the Allied-Signal subcontract for fire protection of the space station. It presents candidate detection and suppressant means. Seventeen fire situations are proposed. The detection and suppression tradeoffs are based on 23 attributes for both fire-safety elements. Only methods, not designs and hardware, are compared, eliminating safety, performance, and cost (reducing the attributes to 18). Weights and scores are given to (1) smoke detection and fire detection methods and (2) CO_2, Halon 1301, water, and nitrogen for fire suppression. Both fire detection methods got the same score. For fire suppression, numerical scores (10 is the highest) were 8.19 for CO_2, 8.16 for H_2O (not a Boeing candidate), 7.95 for N_2, and 7.54 for H1301. The CO_2 was assumed to be provided as saturated liquid. Recommendations are therefore for smoke and radiation detection, CO_2 suppression, plus water for deep-seated Class A fires.

216. Edelman, R.B.; and Bahadori, M.Y.: Effects of Buoyancy on Gas Jet Diffusion Flames—Experiment and Theory. IAF Paper 85–288, 1985.

The paper reviews results of 0g diffusion flame tests conducted in the NASA 2.2-s drop tower by Science Applications International Corporation. The authors have also devised a reference 1g downward burning test, with an air annulus to maintain a downward burning flame. No current test results are availiable.

217. Dosanjh, S.; Peterson, J.; Fernandez-Pello, A.C.; and Pagni, P.J.: Buoyancy Effects on Smoldering Combustion. IAF Paper 85–289, 1985.

Smoldering combustion of α cellulose was studied at low density difference, reducing (ρ_{cell} - ρ_{air}) to near zero to remove buoyancy forces. Measured flame spread and maximum temperature were in fair agreement with theory. Extinction occurred at low air flow-rates, implying that diffusion may be insufficient to maintain 0g smoldering.

218. Quintiere, J.G.; and Harkleroad, M.: New Concepts for Measuring Flame Spread Properties. NBSIR–84–2943, 1984.

This is a description of the National Bureau of Standards radiant-heater test to determine ignition times over a range of radiant fluxes from 1.5 to 7 W/cm^2 and to calculate thermal properties of thick solids. The apparatus can also be used for evaluating flame spread as a function of time, yielding plots of spread rate (and time to ignition) versus irradiance in W/cm^2.

*219. Ronney, Paul D.; and Wachman, Harold Y.: Effect of Gravity on Laminar Premixed Gas Combustion I: Flammability Limits and Burning Velocities. Comb. Flame, vol. 62, no. 2, 1985, pp. 107–119.

Experimental work is described on premixed combustion of CH_4-air at 50 to 1500 torr (6.7 to 200 kPa) in a 25 by 25 cm cylindrical vessel test in the NASA 2.2-s drop tower. Comparison with 1-g tests shows that lean flammability limits at low-g lie between those of upward and downward 1-g limits. Burning velocities at the lean limit in low-g approached zero. Conclusions are that the 1-g downward lean limits result from the inability of the flame front to propagate downward against buoyant forces; the 1-g upward lean limit is where burning velocity approaches zero. This could correspond to the limit at zero-g, except that at low gravity, self-extinguished flames near the limit occur.

*220. Ronney, Paul D.: Effect of Gravity on Laminar Premixed Gas Combustion II: Ignition and Extinction Phenomena. Comb. Flame, vol. 62, no. 2, 1985, pp. 121–133.

This paper reports on additional tests on ignition energy using the same apparatus as Reference 219. In 1g, the minimum ignition energy increases with fuel concentration near the lean limit. This rise is finite; however, in 0g, the rise is near infinite. Various flame radii of self-extinguished flames were noted. These tests produced a diagram where the spark energy versus fuel concentration curve for 0g could be superimposed within the parabola of the 1g curve. The region between the curves corresponds to self-extinguished flames at low energy and nonignitions at high energies.

*221. Aydelott, John C.; Carney, Michael J.; and Hochstein, John I.: NASA Lewis Research Center Low-Gravity Fluid Management Technology Program. NASA TM–87145, 1985.

The paper covers results of several years of low-gravity fluids work. Of interest is a brief description of the capabilities of the NASA Lewis 2.2- and 5.2-s drop towers and the Learjet airplane.

222. Plugge, Martin A.; Wilson, Christopher W.; Zallen, Dennis M.; and Walker, Joseph L.: Fire Extinguishing Agents for Oxygen-Enriched Atmospheres. ESL–TR–85–26, 1985. (AD-A766967). N85-30890.

This project, conducted by the New Mexico Engineering Research Institute, studied simulated aircraft crack hazards with O_2 leaks. Flow cup tests (similar to Ref. 107) and small-scale static tests show that Halon 2402 is a more effective suppressant than H1301, which in turn is more effective than H1211. Tests with heptane, JP–4, and cotton show that H1301 suppresses fire at around 3 vol% for air, but the necessary concentration increases 5 fold for 40 %O_2. Other tests were conducted in a medium-scale chamber, large-scale cabin, and an actual fuselage. Large-scale results showed that slightly less Halon than in the cup tests is effective, probably due to poorer combustion efficiency. Full-scale fires were difficult to extinguish, and cooling is necessary to prevent reignition when the Halon flow diminishes. For cooling, water or aqueous film-forming foam is effective. A bibliography with a brief literature survey on oxygen-enriched fires is appended.

223. Sarkos, Constantine P.: New FAA Regulations Improve Aircraft Fire Safety. ASTM Stand. News, vol. 13, 1985, pp. 33–39.

The review covers Federal Aviation Administration aircraft regulations for seat cushion flammability to be adopted in 1987, floor proximity emergency lighting to be adopted in 1986, smoke detectors for lavatories and automatic extinguishers in trash receptacles to be adopted in 1986, and cargo chamber protection and improved flammability testing using the Ohio State University apparatus (Ref. 196). For the fire extinguishers, H1211 is required and decomposition products are shown to be rapidly diluted (Ref. 167). Cargo compartments of fiberglass resist burn through, compared with Nomex or Kevlar.

224. Nelson, Gordon L.: Perspective on Transportation; Relative Fire Risk Potential for a Range of Public Transportation Vehicles; a Delphi Study. ASTM Stand. News, vol. 13, no. 12, 1985, pp. 50–55.

The results of the American Society for Testing and Materials (ASTM) Committee E-S Delphi interview study are summarized. Risk factors relating to death and injury, property loss, and ignition potential are evaluated by 61 experts to get a quantitative rating for mass transportation modes. Aircraft rate high; taxis and people-movers rate low. A breakdown of the results is shown in the paper.

225. Ronney, Paul D.: Effect of Gravity on Halocarbon Flame Retardant Effectiveness. Acta Astronaut, vol. 12, no. 11, 1985, pp. 915–921.

In the NASA Lewis Research Center 2.2-s drop tower, flame spread and ϕ (equivalence ratio) at the lean limit were measured for CH_4, C_2H_6, and C_3H_8 diffusion flames with 0 to 6 %Halon 1301 added to the combustion air. The action of the Halon was not much different in 0g compared with 1g. At 6 %Halon, combustion was suppressed. Halon turned the 0g flame yellow. Self-extinguished flames were noted only with CH_4.

226. Anderson, C.L.: Vulnerability Methodology and Protective Measures for Aircraft Fire and Explosion Hazards. AFWAL–TR–85–2060–VOL–3–PT1, 1986.

Since 1978, the United States Air Force has been evaluating two onboard inert gas generator systems (OBIGGS). The Air Research system uses a hollow-fiber permeable membrane for separation of O_2 from air to yield an O_2-deficient inerting atmosphere. The Clifton Precision Co. separation approach uses a molecular sieve (Zeolite). Both systems are to produce 3 lb/min flow at 5 %O_2 for climb and cruise and 8 lb/min at 9 %O_2 for descent. The permeable membrane requires an air cycle machine. The molecular sieve can operate on cooled bleed air at lower pressures and higher temperatures, but it is noncontinuous, requiring multiple chamber purging and sequencing. The report presents results only from reference ground tests.

226A. Siu, N.; and Apostolakis, G.: Modeling the Detection Rates of Fires in Nuclear Plants: Development and Application of a Methodology for Treating Imprecise Evidence, Risk Anal., vol. 6, no. 1, 1986, pp. 43–59.

The analytical study discusses fire detection times. This time is the result of competition of three modes: $T_{D1,}$ the automatic detection time by instruments specifically placed to detect the fire (if there are such instruments); T_{D2}, the local detection time by personnel at the local site; and T_{D3}, the remote detection time by abnormal instrument or control indications. Generally, the actual time required to detect a fire is the minimum of the three. Some mathematics are shown for subjective (Bayesian) formulations. The authors use published data to show the range of each time as it affects the frequency of fire detection. Sensitivity analysis shows that use of the minimum of a set of random variables works very well.

226B. Potyankin, V.I.; Melikhov, A.S.; and Ivanov, B.A.: Spherical Flame Under Gravitational Acceleration. Combustion of Heterogeneous and Gaseous System, Proceedings of the 8th All- Union Symposium on Combustion and Explosions, Tashkeat, U.S.S.R., 1986, pp. 85–88.

Combustion of spherical 8 to10-mm poly(methyl methacrylate) (PMMA) balls on a 1-mm ceramic fiber was shown to be spherical if started in 1-atm 100 %O_2 and then reduced in pressure to 8 to 11 mmHg. When dropped in the Russian 0.72-s tower, the flame remained spherical. At standard air conditions, the normal-gravity flame had a typical plume. Hence, it was shown that where natural convection is suppressed, spherical flames are possible. Flame zone temperatures increase until about 1 diameter away from PMMA surface, then they decrease at greater distances.

227. Egawa, T.; Kawakami, T.; and Okajima, S.: Pressure Effects on Combustion of Fuel Droplets Under Zero Gravity. ACOME, vol. 6, no. 1, 1986, pp. 51–59. (A87-28289).

Experiments are reported for the combustion of single droplets of ethanol and n-C_7H_{16} in a Hosei University 1-s drop tower. The facility used a drag shield and a cushion decelerator. Droplets were suspended on a quartz fiber. They were ignited.and the igniter retracted in 0.1 s. Results showed that the D^2-law applies at 0.1 to 1.2 MPa pressure. The K factor $\left(\frac{\mathrm{d}D^2}{\mathrm{d}t}\right)$ increased slowly with pressure. Flame diameter was also measured. For both fuels, the researchers observed carbon shells between the droplet and flame, which increased with pressure.

228. Kimura, M.; Ihara, H.; Okajima S.; and Iwama, A.: Combustion Behaviors of Emulsified Hydrocarbons and JP-4/N_2H_4 Droplets at Weightless and Free Falling Conditions. Combust. Sci. Technol., vol. 44, nos. 5+6, 1986, pp. 289–306.

This is an extension of results reported in Reference 212, including work on droplets of water-emulsified fuels like JP–4. At 0g, droplets show spray-like dispersions of fine droplets but no microexplosions as observed earlier in 1g. Heavier (C_9+) hydrocarbons show mild microatomization in 0g.

229. Peercy, R.L., Jr., and Raasch, R.F.: Threat-Strategy Technique: A System Safety Tool for Advanced Design. J. Spacecr., vol. 23, no. 2, 1986, pp. 200–206.

This paper is based on spacecraft-safety concepts covered in the final reports from Rockwell (Refs. 203 to 207). Hazard reduction has four approaches: design to preclude, design to control, provide protective devices with operational work-arounds, and define risks and conditions for acceptance. For the example of fire, causative factors and strategies are listed. For design to preclude, specific elements (hazard-reduction approaches) are two-gas systems, materials control, ignition source control, and so forth. For design to control, elements are compartmentalization, smoke detection, vent systems, fire extinguishers, and so forth. The summary notes that hazards must be dealt with on a total system perspective. The general philosophy is that hazards are to cause no damage or injury that result in a complete of suspension of operation (baseline). The highest level of safety is no damage at all; the lowest level is crew survival at the expense of the space station.

230. Ohlemiller, T.J.: Smoldering Combustion. NBSIR 85–3294, 1986.

A review of smoldering combustion notes that smoldering history proceeds from pyrolysis to a char with high surface area per mass (this step may be exothermic) to oxidation. An idealized approximation is one-dimensional smolder spread. Reverse propagation (O_2 flow opposite to reaction movement) implies a rate proportional to the square of the fuel thickness. With forced air flows of up to 1 cm/s (greater flow may fluidize the bed), smolder velocities are always very low, on the order of 10^{-2} cm/s. CO production is estimated. Smoldering aerosols consist of large particles, around 2 to 3 μm, which are 10 to 200 times larger than those of flaming combustion. Solids in the fuel bed act as filters; hence smolder smoke may not be detectible until the combustion zone nears the ambient surface. Less common forward propagation is noted. Practical situations are multidimensional, combining forward and reverse smolder.

231. Bukowski, R.W.: An Introduction to Fire Hazard Modeling. NBSIR 86–3349, 1986.
Predictive models for fires can include hazard models (scenario dependent) and risk models (hazards weighted by probabilities). Categories of models are field models (volume cells with fine resolution), zone models (small number of volume layers), and network models (uniform “compartments”). The paper discusses general features of models and the use of models to determine extent of fire spread, smoke and gas levels, and evacuation and alarm response times. A table gives material property data, (ΔH_c, ignition temperature, toxicity) for use in predictions.

232. Steckler, K.D.; Baum, H.R.; and Quintiere, J.G.: Salt Water Modeling of Fire Induced Flows in Multicompartment Enclosures. NBSIR 86–3327, 1986.
Scaling equations are presented for salt-water representation of smoke and air flows in fires. The equations aim to match Re, Pr, and height-to-source length ratio. In practice, it is impossible to match all quantities. However, salt water diffusivity scales hot gas thermal conductivity (ρD compared with k/c_p). Salt water modeling tries to match buoyant effects, which swamp out initial momentum. Results are shown for 1/20-scale room models (scale is based on model not source dimensions), with 10 wt% NaCl/water (specific gravity = 1.07). A defined interface height (10 percent of temperature rise above ambient) agrees well with previous thermal studies. Photographs of 1/20-scale complex ship models are also included.

233. Babrauskas, Vytenis: Comparative Rates of Heat Release From Five Different Types of Test Apparatuses. J. Fire Sci., vol. 4, 1986, pp. 148–159.
The paper compares the following fire-test apparatuses or techniques: (1) adiabatic or insulated box (Ohio State University (OSU) type), (2) isothermal type (National Bureau of Standards (NBS) II calorimeter), (3) O_2 consumption, open (cone calorimeter), (4) CO-CO_2 evolution (Factory Mutual Research Corporation (FMRC) original), and (5) flame height (new technique). Heat release rates for the various apparatuses are compared for the standard peak rates generated in the Federal Aviation Administration panel test. Correlation of these rates divided by ignition time separates the good and bad panels, consistent with results of full-scale tests. The OSU-O_2 and OSU-thermopile methods give peak heat release rates about half those determined by the cone calorimeter, FMRC, and flame-height methods.

234. Anon.: Detoxification of Halon Fire-Extinguishant Products. NASA Tech Briefs, vol. 10, no. 2, 1986, pp. 82–83.
The addition of $(NH_4)_2CO_3$, (powder) or NH_3 (gas or liquid) to Halons produces nontoxic, less corrosive ammonium halides for extinguishment. The article cites tests conducted by Eric L. Miller of LEMSCO (Lockheed support) at NASA White Sands Test Facility, with 5.6 wt.% $(NH_4)_2CO_3$ added to H1301.

235. Bukowski, Richard W.: Engineering Applications for Fire Related Prediction Tools. NBSIR 86–3360, 1986, pp. 19–24.
This is a cursory summary of available models and data sources, with references, and essentially a condensation of Reference 231.

236. Bukowski, Richard W.: Fire Detection and Alarm Systems. NBSIR 86–3360, 1986, pp. 25–38.
This is a brief review of fire signatures, type of detectors, selection of detectors, and detector systems.

237. Ferguson, R.E.; and Chewning, E.M.: Space Station ECLSS Integration Analysis. McDonnell Douglas Astronautics Co. Report MDC W5088–1, 1986.

This report describes the computing program for an air temperature control and flow distribution model. The model uses finite elements and finite differencing. It neglects viscous and momentum effects. The application is then used to represent the Spacelab airflow and flow short-circuit patterns. An example is included.

238. Ramsden, J.M.: The Fire-Hard Airliner. Flight Int., vol. 129, no. 4011, 1986, pp. 27–30.

Recent Federal Aviation Administration and international rules are discussed. Fire-resistant materials for aircraft interior panels are accepted through the results of a Bunsen burner test. The Federal Aviation Regulation FAR 25.853 vertical fire test requires sample to burn less than 15 s and char less than 20 cm after removal of a Bunsen burner. Tests show that phenolic fiberglass is a preferred material for aircraft panels. The advantages of treated wool for fabrics are also noted.

239. DeMeis, Richard: Safety in the Space Station. Aero. Amer., vol. 24, no. 5, 1986, pp. 26–29.

This article is a brief review of safety concerns by the “Aerospace America” Engineering Editor. The author quotes Kimzey, noting differences between the space station and previous human-crew flights; for example, introduction and expansion of such activities as soldering, repair shops, laundry, cooking, garbage, and waste disposal. Kimzey and Pinkel are cited as recommending infrared flame detectors. Pinkel also mentions coaxial wire overheat sensors. The sources note the possibility of venting to extinguish fires and purge residues. They also note the advantages of deionized water sprays for extinguishing. Kimzey feels that metal combustion work should continue: the solid oxide does not have the self-extinguishing potential. Sacksteder is quoted on the 0g solid and particle cloud combustion experiments.

240. Vedha--Nayagam, M.; and Altenkirch, R.A.: The Shape of Low-Gravity Flames Spreading Across Solid Combustible Surfaces. Paper presented at the Central States Section Spring Technical Meeting, The Combustion Institute, Cleveland, OH, May 1986.

Experiments were conducted with burning filter paper at 30 and 50 %O_2 and 1.5 and 2.0 atm total pressure in the NASA Lewis 5.2-s drop tower. A finite difference routine was used to calculate flame shapes and flow fields. Agreement with experiment appears good. The flame size decreases as O_2 concentration changes, but there is little effect with total pressure. Prediction of the flame size by the routine is based on bracketing and assuming a paper temperature to get a best fit.

241. Altenkirch, R.A.: The Use of a Low-Gravity Environment in Combustion Research. Paper presented at the Central States Section Spring Technical Meeting, The Combustion Institute, Cleveland, OH, May 1986.

This is a good review of zero-gravity experiments. The author states that the impetus for doing low-gravity combustion experiments comes from a desire to (1) remove buoyancy to expose other effects, (2) provide an experimental environment to match assumptions of theory, (3) create and maintain unique conditions (clouds, droplets), and (4) establish experiments of a scale suitable for investigation. The author mentions fire safety for spacecraft only briefly. The facilities available and spacecraft accommodations are described. Ronney is cited as defining combustion limits for three cases (normal up, normal down, low gravity). He also found that the low-gravity limit for lean CH_4-air is near the normal-gravity upward limit. Self-extinguished flames are found in low gravity, as well as darker, cooler flames. Occasionally “extinguished” flames reignite at the end of a test. Particle cloud studies show that the temperatures of low-gravity flames are higher than those of normal gravity.

242. Gat, Nahum: Design Considerations for Shuttle Borne Microgravity Combustion Experiments. Paper presented at Central States Section Meeting, The Combustion Institute, Cleveland, OH, 1986.
This is a good description of the requirements for design and accommodations in the shuttle, with examples for the Droplet Burning Experiment and the Particle Cloud Combustion Experiment. There is a brief discussion of the space station and many references.

242A. Breen, David E.: Improved Life Safety Through More Reliable Smoke Detection Systems. New Technology to Reduce Fire Losses and Costs Conference, S.J. Grayson and D.A. Smith, eds., Elseiver, New York, NY, 1986, pp. 227–234.
Analysis of Harvard University dormitory photoelectric smoke detectors, set at 1.5 percent smoke obscuration/ft (shuttle is 0.5 percent/ft (Ref. 262)) shows a 46:1 ratio of false to real alarms. Each detector thus had a probability of an alarm every 4 years. Statistics showed a strong reduction in false alarms for (1) desensitized setting to 2.2 to 2.5 percent/ft (7.2 to 8.2 percent/m), (2) "hardened" smoke detectors with dust and humidity resistance set at 1.5 percent/ft, or (3) detectors with 60-s verification delays set at 1.5 percent/ft.

242B. Holker, J.R.; and Lomax, G.R.: Sensory Early Warning Systems in Fire Detection. New Technology to Reduce Fire Losses and Costs Conference, Elseiver, New York, NY, 1986, pp. 248–255.
Laboratory studies on trace compounds for odor warnings on overheated fabrics show excellent results for volatile and sulfide compounds. Odors are detected at concentrations as low as 0.1 ppb. Work is preliminary, and the objective is sensory not instrumented detection. Agents are treatments rather than microencapulants. Drawbacks may be residual odor at room temperature, excessive response (too stimulating).

243. Salyer, Ival O.; Griffin, Charles W.; and Duvall, Donovan S.: Intumescent Fire Extinguishing Solutions. U.S. Patent 4,588,510, University of Dayton, May 13, 1986.
This invention is an aqueous solution that can be sprayed onto Class A or B fires, surface or deep-seated, to extinguish them through an expansion that creates a foam barrier that extinguishes through wetting, cooling and O_2 exclusion. A preferred composition is (in wt%) 15.1% $(NH_3)_2HPO_4$ to furnish phosphoric acid, 26.9% sucrose to form a polymer foam, 1.6% cyanoguanidine to generate N_2 gas, 9.1% urea to control the viscosity between 200 to 1000 cP, 2.2% Witconate AOS as a wetting agent for Class B fires, and 44% water. Other soluble polyols such as glycerin may substitute for sucrose.

244. Joshi, N.D.; and Berlad, A.L.: Gravitational Effects on Stabilized, Premixed, Lycopodium-Air Flames. Combust. Sci. Technol., vol. 47, nos. 1+2, 1986, pp. 55–68.
This article presents the same results as Reference 211 with a little more description of the apparatus and the 2.2-s drop tower tests.

245. Horton, J.C.: Guidelines for the Implementation of Required Materials Control Procedures. NASA MSFC–PROC–1301, 1986.
This document defines terms and identifies categories for space material acceptance, including an assessment of flammability by material and by subassembly.

246. Tewarson, Archibald: Fire Hazard Analysis of Dielectric Materials—A New Approach. Conference Record of the 1986 IEEE International Symposium on Electrical Insulation, 86CH2196–4–DEI, 1986.
Several criteria for acceptance of insulating materials are proposed. First is ignition, where heat flux determined by Factory Mutual combustibility apparatus (see Ref. 208), Ohio State University (OSU), or National Bureau of Standards (NBS) cone calorimeter is equal or less than 20 kW/m^2. Next is fire growth defined as a heat flux of 40 kW/m^2 or less. Next is the ratio of heat of combustion to heat of vaporization of 5 or less. Also discussed qualitatively were criteria for toxic compounds, corrosive compounds, and smoke generation.

*247. Wherley, B.L.; and Strehlow, R.A.: The Behavior of Fuel-Lean Premixed Flames in a Standard Flammability Limit Tube Under Controlled Gravity Conditions. NASA CR–177132, 1986. (N86–28139).
Experimental studies were conducted to measure lean limits, flame speed, and flame propagation of premixed CH_4-air and C_3H_8-air in standard tubes at normal, zero, and partial gravity in the NASA Lewis Lear jet. Results were largely qualitative. Gravity affected the C_3H_8 flame speed; and possibly CH_4. Normal-gravity flames were very unsteady.

248. Johnson, Gary; Wolbers, Harry L., Jr.; and Miles, William L.: Habitation Module for the Space Station. Proceedings of 16th Intersociety Conference on Environmental Systems, SAE Paper 860928, 1986, pp. 161–174.
The Habitation and Space Station Operations Module architecture is described. A four-standoff system (fairings between racks) permits efficiency and best use of interchangeable components. This paper serves as a background for related safety issues. The "safe haven" bay has a kit with supplies to support the crew if one of the other pressurized modules is abandoned.

249. Ray, C.D.; and Humphries, W.R.: Status of the Space Station Environmental Control and Life Support System Design Concept. Proceedings of 16th Intersociety Conference on Environmental Systems, SAE Paper 860943, 1986, pp. 297–308.
This paper gives the basic designs and assumptions for the Environmental Control and Life Support System (ECLSS) for an eight-person space station crew. The ECLSS has seven subsystems: (1) temperature and humidity control, (2) water recovery and management, (3) atmospheric control and supply, (4) waste management, (5) atmospheric revitalization, (6) extravehicular activity support, and (7) fire detection and suppression. The latter is undefined, although it is assigned a maximum mass of 386 kg and an average heat rejection of 222 W.

250. Rossier, Robert N.: Nuclear Powered Submarines and the Space Station: A Comparison of ECLSS Requirements. Proceedings of 16th Intersociety Conference on Environmental Systems, SAE Paper 860945, 1986, pp. 321–329.
This paper from Martin Marietta has a system-by-system comparison of submarines and the space station in resource and mission requirements, subsystem design, and so forth. The author notes that fires pose a severe threat in the closed environments of both submarines and the Station. The paper discusses fire detection and suppression needs. Passive design features and active systems are noted. Submarines have advantages in avoiding fire hazards because the large crew makes it easier to observe fire precursors and atmospheric cleanup is more frequent.

251. Anon.: FAA Issues Rules on Seat Impact, Cabin Material Flammability. Aviat. Week Space Technol., vol. 125, no. 5, 1986, p. 52.
This is a news article, confirming the regulations discussed in Reference 223.

252. Beene, David E.; and Schultz, Harry E.: Evaluation of SF_6 as a Tracer Gas for Determining Smoke Movement in Shipboard Fires. CG–D–27–86, 1986.
This report continues the work of Reference 183. Simulation by SF_6 provides a correlation of SF_6 concentration with temperature and smoke density. Test results show that a 0.25 optical density of smoke obscured a lamp 92 in. away. The SF_6 tests are useful to rank ventilation systems. However, a quantitative correlation of SF_6 concentration and smoke quantity is not found.

*253. Uhran, M.L.; Youngblood, W.W.; Georgekutty, T.; Fiske, M.R.; and Wear, W.O.: Equipment Concept Design and Development Plans for Microgravity Science and Applications Research on Space Station: Combustion Tunnel, Laser Diagnostic System, Advanced Modular Furnace, Integrated Electronics Laboratory. NASA CR–179535, 1986.

This is a Wyle Labs report on four concepts for space station laboratories: combustion tunnel, laser diagnostics system, advanced modular furnace, and integrated electronics laboratory. The combustion tunnel definition is a preliminary design, showing the flow system and certain concepts for sampling, gas mixture blending, and so forth. The laser diagnostics section describes conceptual designs that include holography, classical optical techniques, laser doppler velocimetry, and laser induced fluorescence systems for space. Treatment of the first two relevant concepts is rather elementary.

254. Babrauskas, Vytenis; and Parker, William J.: Ignitability Measurements With the Cone Calorimeter. Fire Mater., no. 1, 1987, pp. 31–43.

The report is a good—although not the earliest—description of the cone calorimeter (ASTM Proposal P190). The calorimeter, usable for horizontal or vertical combustion modes, employs a spark plug plus radiant heating. Some estimate of thermal thickness limits is given. Test results are shown for wood and poly(methyl methacrylate) (PMMA), in terms of time to ignition at radiance levels of 25 to 100 kW/m^2. In general, data show that time is proportional to radiance (kW/m^2) to the –1.5 to –2 power. However, empirical ignition-time models show poor agreement with experimental results.

255. Babrauskas, Vytenis; Levin, Barbara C.; and Gann, Richard G.: New Approach to Fire Toxicity Data for Hazard Evaluation. Fire J., vol. 81, no. 2, 1987, pp. 22–23, 27–28, and 70–71.

This is a preliminary description of the N-gas model for combining LC_{50} (rodent lethality) data of toxic gases along with O_2 deficiency in fire products. The linear addition of HCN and CO is shown in a table; the nonlinear synergy of CO_2 + CO is shown in a graph.

256. Fletcher, James C.: Space Station 1986—Now More Than Ever. Aerospace America, 1986, pp. 24–27.

“Kickoff” paper on the space station states that the station will serve its users not its designers, will reflect its civil character, will press forward new technologies, and will remain affordable.

257. Carlisle, Richard; and Nolan, Mark: Space Station 1986—Frontier of Technology. Aerospace America, 1986, pp. 48–51.

The paper discusses the new 8-psi-glove extravehicular activity suit and also improvements in water electrolysis and CO_2 removal for the Environmental Control and Life Support System.

258. Ishida, Hiroki; and Iwama, Akira: Some Critical Discussions on Flash and Fire Points of Liquid Fuels. Fire Safety Science, Proceedings of First International Symposium, Cecile E. Grant, and Patrick J. Pagni, eds., Hemisphere Publishing Corporation, Washington, DC, 1986, pp. 217–226.

Flash points and fire points (sustained 5-s diffusion flames) of several alcohols and n-paraffins were measured in an open cup system. Flash points were 4 to 7 °C higher than those calculated from vapor pressure curves for conditions of a spark electrode for ignition placed 3 mm above the liquid surface. Standard closed-cup tests with pilot ignition flames further away from the liquid surface gave slightly lower results, but still above the theoretical. The prediction of flash points of mixtures was unreliable.

259. Kazarians, Mardyros; Siu, Nathan; and Apostolakis, George: Risk Management Application of Fire Risk Analysis. Cecile E. Grant, and Patrick J. Pagni, eds., Fire Safety Science, Proceedings of First International Symposium, Hemisphere Publishing Corporation, Washington, DC, 1986, pp. 1029–1038.

This is a paper on probabilistic risk assessment, showing levels of risk decomposition (analogous to a Work Breakdown Structure). Some examples are given, based on the assumption that a frequency of occurrence per year can be estimated.

260. Hartzell, G.E.; Priest, D.N.; and Switzer, W.G.: Mathematical Modeling of Toxicological Effects of Fire Gases. Fire Safety Science, Proceedings of First International Symposium, Cecile E. Grant, and Patrick J. Pagni, eds., Hemisphere Publishing Corporation, Washington, DC, 1986, pp. 1059–1068.

The investigators, from the Southwest Research Institute, took data for CO, HCN, and HCl lethality and incapacitation for rats to produce plots of concentration C versus $1/t$ (time of exposure). This yielded an exposure dose, Ct, given by $Ct = K\dfrac{C}{C-b}$, where K is slope of plot, and b is zero intercept of $1/t$ (infinite time). This relationship was used to model the buildup of toxicant, and calculations integrated the buildup with time. The effects of these exposure doses on lethality and incapacitation agreed well with additional experiments.

261. Chuan, Raymond L.; and Chen, Houston D.: Aerosol Characterization in an Incipient Fire. Paper presented at the 2nd International Aerosol Conference, Berlin, Sept. 1986.

An experimental study of cellulose, plastic, and elastomer smoldering provided data on particle-size characteristics as smoldering progressed. An abundance ratio of mass concentration of particle sizes near 0.8 μm divided by mass concentration of particles near 0.1 μm is less than 1 (small particles predominate) during initial non-self-sustaining smoldering. The ratio increases to above 1 (~5) for sustained smoldering and decreases with the transition to flaming (still above 1, however). Tests indicate that abundance ratio can be an effective parameter to define incipient fires.

262. Bricker, R.W.: Rationale for Space Station Fire Detection Criteria. Preliminary report, NASA contract NAS 9–15980, 1986.

The report, prepared by a Webb, Murray & Associates author, reviews fire detection criteria for application to Space Station (Space Station Program Definition and Requirements Document, JSC 30000, par. 2.1.11-2.12.1). The quoted Station criteria are obscuration of 0.5 percent/ft (1.5 percent/m) and visible fire particulate of 1.5×10^9 particles/ft^3 (50 000/cm^3). Data quoted show flaming combustion can produce smoke reaching an alarm range in 30 to 70 s, while smoldering requires 225 to 550 s. The Underwriters Laboratories, Inc., standard UL268 cites a spot-type detector obscuration range of 0.2 to 4 percent/ft for gray smoke, 0.5 to 10 percent/ft for black smoke. For smoldering alarms, the alarm point of 7 percent/ft obscuration is reached in 45 to71 min. Factory Mutual Standard 3230–3250 recommends an alarm point of 4 percent/ft. Fenwal CDD 7010/7011 gives the visual effects of obscuration levels; 1.0 to 2.0 percent/ft has minor restrictions; 3 to 4 percent/ft resembles dense clouds. The Celesco Industries test report on the shuttle detector model, conducted by Stanford Research Institute (SRI), used criteria of 2.5 mg/m^3 particles. This report criticizes the SRI tests as having too small a chamber and too high a particle concentration. It cites its own work (Ref. 200), which favors condensation nuclei detectors, as more meaningful. Rockwell criteria for the shuttle specifies a 30-s response time. The author recommends smoke obscuration, particle concentration, and perhaps time for use as spacecraft detection criteria. It urges review of the shuttle system, perhaps including photoelectric detectors for overheating and smoldering.

263. Anon.: The Future Spacesuit. NASA Activities, vol. 17, nos. 10/11, 1986, pp. 7–9.

This is a description of the spacesuit under development, the zero-prebreathe suit, to operate at 8 psi, which eliminates prebreathing and its hazardous high O_2 atmosphere.

263A. Potyankin, V.I.; Melikhov, A.S.; and Ivanov, B.A.: On Conditions for the Existence of a Spherical Flame Under the Effect of Gravitational Acceleration. The Combustion of Heterogeneous and Gaseous Systems, Materials of the Eighth All-Union Symposium on Combustion and Detonation, Tashkent, U.S.S.R., Oct. 1986.

Russian research at the Institute of Fire Safety demonstrated that a spherical poly(methyl methacrylate) (PMMA) sample burns with a spherical flame in a 100 %O_2 atmosphere with pressure reduced to 8 to 11 mmHg after ignition. In a drop tower, the shape of the flame does not change as gravitational acceleration decreases to near zero. At conditions of 16 %O_2 and 760 mmHg, the flame is a typical teardrop, changing to a sphere in 0g (and extinguishing). The authors state that the criterion is Gr <53, and demonstrate a limit of spherical combustion for limits of >40 %O_2 and pressures of 15 mmHg or lower.

264. Alexeeff, George V.; and Packham, Steven C.: A Suggested Role of Combustion Toxicity in Fire Risk Assessment. J. Test. Eval., vol. 14, 1986, pp. 321–325.

This paper includes estimates of animal mortality rates for all causes and a literature survey on combustion-product measurement and toxicity. The formula of H.J. Roux (Ref. 143) is quoted where risk = (expected frequency of event) × (expected degree of exposure) × (potential for harm). The expected frequency may be estimated from statistics, that is, number of fires per year. The expected degree of exposure may be estimated from models of smoke concentration × time (*Ct*). Potential for harm is based on animal tests of lethal concentration of 50 percent (LD_{50}). Static tests have gradually increasing product concentrations; flow tests have nearly uniform concentrations. For risk assessment, the *Ct* may provide the most accurate estimate of dose. For human toxic injury estimates, a relation of *Ct* versus lethal dose may be best, although more statistics are desirable.

265. Edelman, R.B.; and Bahadori, M.Y.: Effects of Buoyancy on Gas-Jet Diffusion Flames: Experiment and Theory. Acta Astronaut., vol. 13, no. 11/12, 1986, pp. 681–688.

The paper is essentially identical to Reference 216.

266. Dosanjh, S.; Peterson, J.; Fernandez-Pello, A.C.; and Pagni, P.J.: Buoyancy Effects of Smoldering Combustion. Acta Astronaut., vol. 13, no. 11/12, 1986, pp. 689–696.

The paper is essentially identical to Reference 217, but the illustrations are clearer.

*267. Chen, C.H.: Diffusion Flame Extinction in Slow Convective Flow Under Microgravity Environment. NASA TM–88799, 1986.

This is a mathematical modeling of flame temperature, flow and pressure contours along a thin solid-fuel plate in microgravity. Superimposed flows are from 1.25 to 20 cm/s, compared with natural convection on the order of 15 cm/s. If there is no radiation from the solid surface, temperature contours are similar for all velocities. However, for heat loss from the surface, $\varepsilon = 1$, the flame envelope “shrinks” with decreasing velocity V (decreasing the Damkohler number, Da, from 7.2×10^8 to 2.8×10^6) to eventual quenching at $V = 1.25$ cm/s. The length of flame and width both decrease. Maximum temperature decreases from ~7 T_∞ to <6 T_∞ at quench. Flame contours always extend slightly upstream of fuel. Thus, microgravity extinction is not blowoff but radiative quenching, approached through flame contractions and pyrolysis length reductions.

267A. Slusher, G.R.; Wright, J.A.; and Speitel, L.C.: Halon Extinguishment of Small Aircraft Instrumented Panel Fires. DOT/FAA/CT–86/26, 1986.

Fuselage fire tests used Halons 1211 and 1301 directed to electrical wire-hydraulic fires through upward discharge and fire ports. Extinguishment was effective if the discharge was close to fire source. For 1- to 3-min tests, at 2 to 3 percent local concentration, extinguishment products HF and HBr were <10 ppm, plus some HCl from insulation material.

268. Ronney, Paul D.: Study of Cellular Flame Propagation at Microgravity. Paper presented at the Eastern Section Fall Technical Meeting, The Combustion Institute, San Juan Bautista, PR, 1986.

The author conducted tests on microgravity premixed flames in the NASA Lewis 2.2-s drop tower. The fuel was lean H_2-air with a trace of Halon 1301 to "color" the flame. Flames were individual cells. Burning velocities were very low, reaching 0.3 cm/s at 5 %H_2 in air. Extrapolation implies that 4 %H_2 flames would have zero velocity (compare methane results with continuous flame fronts in Refs. 219 and 220). Other results show H_2-O_2-N_2 limits. Self-extinguished flames were observed occasionally in lean mixtures, but not to the extent seen for CH_4 (cited) or NH_3 (unpublished). The author suggests that the radiation losses may play a role in self-extinguishment.

*269. Dosanjh, Sudip S.; Pagni, Patrick J.; and Fernandez-Pello, A. Carlos: Forced Cocurrent Smoldering Combustion. Comb. Flame, vol. 68, no. 2, 1987, pp. 131–142.

An analysis of cocurrent smoldering (oxidant flow in same direction as smolder wave) with some simplifications shows that, for a given fuel, the final temperature depends on initial O_2 mass flux. Smolder velocity is also dependent linearly on O_2 mass flux. Momentum calculations show that buoyancy can be neglected for all but very small O_2 flow rates, less than 0.04 cm/s, providing a rationale for space experiments.

*270. Friedman, Robert; and Sacksteder, Kurt R.: Science and Technology Issues in Spacecraft Fire Safety. AIAA Paper 87–0467 (NASA TM–88933), 1987.

For the space station, new issues of fire safety must be addressed. The paper summarizes some key findings of the 1986 Spacecraft Fire Safety Workshop (Ref. 286). Possible applications to the space station are briefly discussed. Two questions of immediate concern are the hazards of the extravehicular activity enriched oxygen atmosphere and the hazards of Halon 1301.

271. Anon.: Halon Provides Extinguishing Gains. Aviat. Week Space Technol., vol. 127, no. 6, 1987, p. 137.

This is a brief news article showing the Total Flood Corp. flame detector (unspecified) and H1301 extinguishers for business aircraft. For a 2- to 5-s flood, the H1301 concentration probably does not exceed 7 percent.

*272. Foutch, David W.: Size and Shape of Solid Fuel Diffusion Flames in Very Low Speed Flows. NASA CR–179576, 1987.

The report describes experiments conducted in the NASA Lewis Research Center 5.2-s drop tower, with $C_{19}H_{40}$ fuel on a fiberfrax wick. Stagnation point extinction was desired at the low-gravity conditions. Extinction was not observed, and steady-state conditions were not observed. The author interpreted the results on basis of visual (camera) observations. Parameters were the O_2 content of atmosphere (volume fraction of 0.15 to 0.19 and velocity of oxidant (1.4 to 6.3 cm/s), induced by moving the supported fuel specimen. Flames appear brighter and sootier at the highest O_2 contents and convective velocities. Stand-off distance increases with O_2 content and decreases with velocity. Flame width also increases with O_2 content and decreases with velocity. Flame brightness is associated with soot formation.

*273. Olson, Sandra L.; and Sotos, Raymond G.: Combustion of Velcro in Low Gravity. NASA TM–88970, 1987.

The authors tested the flammability of Nylon and Nomex Velcro samples (pile and hook) in the NASA Lewis Research Center 5.18-s drop tower. Ignition delay times in normal-gravity of 3 to 10 s caused residual velocities influencing the flames. At 3 s (in microgravity), Nomex showed a hemispheric flame. As expected, the chlorinated Nomex burned more slowly. In some cases, Nylon expelled burning materials at higher velocity. Tests showed that low-gravity flame propagation can be enhanced by residual gas flows and the ejection of burning materials.

274. Mackowski, Maura J.: Safety on the Space Station. Space World, vol. X–3–279, 1987, pp. 22–24.
This is a brief nontechnical article that quotes Cole (Ref. 286) as citing fire and spills as the greatest hazards to the space station. Some discussion of crew emergency rescue vehicles is included.

274A. Babrauskas, Vytenis; Levin, Barbara C.; and Gann, Richard G.: New Approach to Fire Toxicity Data for Hazard Evaluation. Fire J., vol. 81, no. 2, 1987, pp. 22–23, 27–28, and 70–71.
This paper is essentially a condensation of Reference 255, which describes the N-gas model of toxic gas synergy. Of interest is the quotation that 80 percent of fire deaths result from smoke inhalation and nearly 2/3 of deaths occur away from the fire room.

274B. Babrauskas, Vytenis; and Parker, William J.: Ignitability Measurements With the Cone Calorimeter. Fire Mater., vol. 11, no. 1, 1987, pp. 31–43.
This is essentially the same paper as Reference 254, with minor revisions.

*275. Rosenthal, Bruce N.; Glasgow, Thomas K.; Black, Richard E.: and Elleman, Daniel D.: Research Opportunities in Microgravity Science and Applications During Shuttle Hiatus. NASA TM–88964, 1987.
This report is a listing and a very brief description of the NASA Lewis, Marshall, and Jet Propulsion Laboratory(JPL) drop tubes; the 30- and 145-m Lewis and 100-m Marshall drop towers; and the KC-135, F-104, and Learjet aircraft. The Lewis microgravity laboratory and JPL facilities are briefly noted. A summary table lists facilities and managers.

276. Nelson, Harold E.: An Engineering Analysis of the Early Stages of Fire Development—The Fire at the Dupont Plaza Hotel and Casino—December 31, 1986. NBSIR 87–3560, 1987.
Reported data from the fire was used to verify modeling of mass burning rate, heat release, smoke temperature, smoke layer depth, O_2 concentration, fire duration, and potential response of sprinklers and smoke detectors. The report also recommends certain analyses.

*277. Bluth, B.J.; and Helppie, Martha: Soviet Space Stations as Analogs, Second Edition. NASA CR–180920, 1986.
This description of Mir and advanced Salyut space habitats also covers the environments, human factors, and safety. The report quotes without comment the fire extinguisher and detector statement from Reference 155A.

*278. Friedman, Robert: Fire Safety Concerns in Space Operations. NASA TM–89848, 1987.
This paper is partly a condensation of Reference 286, but it also includes a summary of combustion experiments in 0g, unique spacecraft hazards, and current research on these subjects. It also mentions the useful analogies of aircraft and underwater fire-safety approaches to those of spacecraft fire safety.

279. Vannice, W.L.; and Grenich, A.F.: Fighter Aircraft OBIGGS (On-Board Inert Gas Generator System) Study. AFWAL–TR–87–2024–VOL–1, 1987.
Designs of onboard inert gas generating systems for a prototype advanced tactical fighter are evaluated. Results show conceptual designs, five selected missions, and the effect of various parameters (oxygen content, taxi time, fuel temperature variation, etc.). The lowest weight design is a permeable membrane stored-gas system. It is a little heavier than LN_2 and Halon 1301 systems, but it has many logistical advantages. A demand system is much heavier, although state-of-the-art improvement may make this system more comparable to a stored-gas system. Heat transfer and mission analysis studies calculate time histories of temperature, fuel quantity, ullage O_2 concentration, and so forth.

*279A. Galea, E.R.; and Markatos, N.C.: A Review of Mathematical Modelling of Aircraft Cabin Fires. Appl. Math. Modelling, vol. 11, 1987, pp. 162–176.

A review of aircraft model fires and simulations show that prior to flashover, fire hazards are believed to be, in order, acid gases (HCl and HF), then heat, then smoke and CO. Literature values of [time to incapacitation (min.)] × [concentration (ppm)] are cited for CO_2 750 000, CO 24 000, HCl 2400, HF 1140, and HCN 480. Flashover may occur in 2.25 min after ignition. Mathematical modeling of aircraft fires has been useful. The review discusses the Notre Dame UNDSAFE-II, a two-dimensional field model, which lacks combustion modeling and a good interior simulation, and the Dayton DACFIR-3, a three-dimensional zone model.

279B. Levin, Barbara C.: Summary of the NBS Literature Reviews on the Chemical Nature and Toxicity of the Pyrolysis and Combustion Products From Seven Plastics: Acrylonitrile-Butadiene-Styrenes (ABS), Nylons, Polyesters, Polyethylenes, Polystyrenes, Poly(Vinyl Chlorides) and Rigid Polyurethane Foams. Fire Mater., vol. 11, no. 3, 1987, pp. 143–157.

A review of 10 abstract databases is used to establish an extensive table of compounds reported as the thermal degradation products from the seven plastics in the title. A table summarizes lethal dose (LC_{50}) values for combustion or thermal degradation of the plastics in various forms, reported by different investigators. It is noted that certain additives, such as the smoke-suppressant zinc ferrocyanide in polyvinyl chloride (PVC) can add greatly to the toxicity of products (generating HCN in this case).

279C. Green, Terrell J.: Mathematical Modeling of Fire. Ph.D. Thesis, Ohio State University, 1987.

The Ohio State University (OSU) computer fire code is a zone model. The thesis compares the model to the well-known Harvard Model. It then applies the OSU calorimeter (Refs. 62, etc.) along with a radiation model to supply test data and analyses for the zone model. With good combustion input data, the model provides accurate information.

280. Howell, T.J.: Fighter Aircraft OBIGGS Study. AFWAL–TR–87–2024–VOLII, 1987.

This is a companion to Reference 279, which gives results of extensive life cycle cost (LCC) analyses for aircraft inerting systems. For 20 years operating and support and a production of 750 units, LCC was \$533 million for stored gas, \$561 million for on-demand, \$575 million for LN_2, and over \$800 million for Halon and foam. The foam system suffered from a large weight and unusable fuel penalty. LN_2 of course may pose logistic problems.

281. Chen, Chiun-Hsuh; T'ien, James S.; and Foutch, David W.: Size and Shape of Solid Fuel Diffusion Flames in Very Low Speed Flows. AIAA Paper 87–2030, 1987.

This is a condensation of the experimental results of Reference 272 with a comparison to a case from Reference 267 with radiation included ($\varepsilon = 1$) and with some updated properties. Agreement of analysis and experiment appears to be only fair.

282. Tapscott, R.E.; and Morehouse, E.T.: Next-Generation Fire Extinguishing Agent: Phase I Suppression Concepts. New Mexico Engineering Research Institute, Albuquerque, NM, 1988.

This is noted as an interim report from the New Mexico Engineering Research Institute, supported by both the Air Force Engineering and Services Laboratory (Tyndall Air Force Base) and the Naval Air Systems Command. A good literature survey covers combustion and free radicals in flames and extinguishing mechanisms. The extinguishment discussion covers inert gases, water foams, dry chemicals, and Halons. Interesting comments are that CO_2 works not only by dilution but also removes C particles endothermally, reducing flame radiation. Foams and dry chemicals are regarded as "dirty." Halons act through exothermic removal of H for the most part. Experimental work is proposed, using a flat flame burner premixed H-O, with an Ar shield, and Raman diagnostics. The purpose of this test is to investigate new agents such as iodated organics, unsaturated halogens, halogen-hydrocarbon mixtures, halons with polar substitutes, and thermally degraded halons.

283. Davis, Roy G.; and Reuter, James L.: Intermodule Ventilation Studies for the Space Station. SAE Paper 871428, 1987.

The McDonnell Douglas and NASA Marshall programs are used to calculate CO_2 pressure and flow contours for modules of the space station. A proposed module layout is shown. The maximum allowable atmospheric partial pressures for CO_2 are 400 Pa operational, 1013 Pa degraded, and 1600 Pa emergency.

284. Birbara, P.J.; and Leonard, J.T.: A Smoke Removal Unit. SAE Paper 871449, 1987.

The paper describes a Hamilton Standard design for postfire cleanup in submarine compartments or spacecraft cabins. Two parallel filter sets are used: a high-flow smoke unit with particulate filters, and a low-flow toxic unit with smoke filters plus charcoal, sodasorb absorbers, and a catalytic oxidation unit. Test results at the Naval Research Laboratory and the U.S. Coast Guard fire test facility in Mobile, AL, are quoted. For Class A, B, and C fires, the smoke unit restores 100% visibility in 20 to 30 min., and the toxic unit removes 100% gases (including HCN, HCl, etc.) in approximately 20 min. The paper presents a general design for rack mounting and a single fan design for 85% flow through smoke unit. Smoke removal has first priority in emergencies, to enable the protected crew members to enter the post-fire cabin.

285. Foutch, David W.; and T'ien, James S.: Extinction of a Stagnation-Point Diffusion Flame at Reduced Gravity. AIAA J., vol. 25, no. 7, 1986, pp. 972–976.

The paper presents analytical work verified by calculations on poly(methyl methacrylate) (PMMA) flame. A parameter called a stretch rate is related to the velocity gradient at the stagnation point. Results show that for zero radiation, fuel-burning rate and maximum temperature are nearly linear with stretch rate to a blowout limit of 90 s^{-1}. With radiation ($\varepsilon = 1$) , rate and temperature decrease with stretch rate and show a second radiation extinction limit at a low value of about 1.5 s^{-1} . For $\varepsilon = 1$, the flammability boundary shows a minimum oxygen mass fraction of 0.185; there is no minimum for $\varepsilon = 0$.

*286. Margle, Janice M., ed.: Spacecraft Fire Safety. NASA CP–2476, 1987. N88–12520.

This is the summary of the August 1986 NASA Lewis Spacecraft Fire Safety Workshop. Papers are included by R.W. Bukowski: Techniques for Fire Detection, pp. 9–29; V. Babrauskas: Fire-Related Standards and Testing, pp. 31–41; J. DeRis: Fire Extinguishment and Inhibition in Spacecraft Environments, pp. 43–49; H. Carhart: Inerting and Atmospheres, pp. 51–57; D.R. Knight: Fire-Related Medical Science, pp. 59–64; B.P. Botteri: Aircraft Fire Safety Research, pp. 65–72; M.B. Cole: Space Station Internal Environmental and Safety Concerns, pp. 73–87; K.R. Sacksteder: Microgravity Combustion Fundamentals, pp. 89–94; P.W. Ledoux: Spacecraft Material Flammability Testing and Configurations, pp. 95–98; F.J. Benz, and S. Zhu: Ignition and Combustion of Metals in Oxygen, pp. 99–102. The forum section gives findings and specific recommendations in (1) fire detection and ignition, (2) fire extinguishment, (3) human responses to combustion products and inert atmospheres, (4) spacecraft materials and configurations, and (5) selection of spacecraft atmospheres.

287. Rodney, G.A.: Safety Considerations in the Design of Manned Spaceflight Hardware. IAF Paper 87–569, 1987.

The paper comments on prompt-effect and delayed-effect hazards. Fire is the leading prompt-effect hazard, and the discussion of fire is largely taken from Reference 270. Other hazards are explosions, space debris, and so forth. Delayed-effect hazards include toxins, illness, and isolation. Risk management is briefly noted as requiring, first, the reduction of uncertainties and second, the adaptation of uncertainties to risk decisions.

*287A. Arbet, Jim; Duffy, R.; Barickman, K.; and Saiidi, Mo J.: Independent Orbiter Assessment (IOA): Analysis of the Life Support and Airlock Support Subsystems. NASA CR–185539 (McDonnell-Douglas REPT–1.0–WP–VA87001–02), 1987.

As a result of the Challenger disaster, McDonnell Douglas Astronautics Co. performed an independent safety analysis of all shuttle systems. This report describes the smoke detection and fire suppression subsystems within the shuttle Caution and Warning system. Six detectors, two each, are in Avionics Bays 1, 2, and 3 as redundant sensors, and three detectors are in the flight deck (left return air, right return air, and redundant cabin air plenum outlet). The preset levels are 2000±200 $\mu g/m^3$ for 5 s or an increase of 22 $\mu g/m^3$ for 20 s. The siren alarm is broadcast through speakers in the flight deck and middeck. One fixed H1301 bottle is mounted in each of Bays 1, 2, and 3. There are at least two portable extinguishers in the cabin. A pressure switch in the fixed bottles detects discharge. Report figures show cutaways of detectors, fixed and portable extinguishers, the detector schematic, and cabin locations.

288. Yang, J.C.; Avedisian, C.T.; and Wang, C.H.: An Experimental Method for Studying Combustion of an Unsupported Fuel Droplet at Reduced Gravity. Paper presented at the Twentieth Eastern Section Fall Technical Meeting on Chemical and Physical Processes in Combustion, The Combustion Institute, Gaithersburg, MD, Nov. 1987, pp. 43–1 to 43–4.

The paper describes experiments in the Cornell University Drop Tower Facility, a 7.5-m, 1.2-s free-fall time facility, with an aerated foam decelerator. The power to the 45- by 120- by 60-cm experiment package comes from a suspended cable. The droplet generator is an upward-discharging ink jet. Ignition and the package release occur as a droplet is at the apex of its trajectory. Hence, the droplet is in free fall in the package, with residual acceleration measured to be 10^{-3}g. Droplets were 500 μm in diameter. Data for the square of droplet diameter versus time of a n-heptane droplet show a decrease in diameter to near zero in 0.35 s. Hence, the tests represent a full spectrum of steady-state droplet combustion. Backlighted photography measured droplet diameter, but could not determine flame size.

289. Ronney, Paul D.: Thermal Characteristics of Normal and Extinguishing Flames at Microgravity. Paper presented at the Twentieth Eastern Section Fall Technical Meeting on Chemical and Physical Processes in Combustion, The Combustion Institute, Gaithersburg, MD, Nov. 1987, pp. 61–1 to 61–4.

This paper covers NASA Lewis 2.2-s drop tower work on premixed CH_4-air flames near the lean limit of 5.1 percent. The test objectives continued those of References 219 and 220; that is, they are to provide a comparison of temperature and histories of normal and self-extinguished flames.

*290. Olson, Sandra L.: The Effect of Microgravity on Flame Spread Over a Thin Fuel. NASA TM–100195, 1987.

Experimental work was conducted with single and double thicknesses of 76-μm-thick Kimwipe paper ignited by Nichrome V wire in the NASA Lewis 2.2- and 5.2-s drop towers. Flame spread determined from photographs was measured as a function of O_2 concentration in O_2-N_2 atmospheres. Normal and low-gravity results were similar for atmospheres with 50 %O_2 or greater, but the μg flame spread was less than the 1g spread at lower O_2. Extinction occurred at higher O_2 contents for μg. The double thickness results followed a relationship of flame spread rate inversely proportional to increased thickness for 1g, but it deviated for μg. Results suggest that flames are quenched at μg, rather than blown-off as at 1g. Boundaries of O_2 at extinction plotted against characteristic velocity (flame spread plus buoyant velocity) show that an interpolated region between μg and 1g may exhibit greater flame spread and wider flammability limits. The implications for fire safety are that low ventilation rates at μg may increase flammability.

291. Sheridan, Joseph G.: A Systems Analysis of Fire Suppression Alternatives for the U.S. Space Station. M.S. Thesis, Air Force Institute of Technology, 1987.

Two scenarios are chosen—a small localized fire and an explosive concentration of H_2 gas. The study concentrates on determining the best "interim" fire suppressant; that is, using present alternatives from CO_2, N_2, water, foam, dry chemicals, and Halon 1301. For each scenario, system factors are defined for effectiveness against fires, safety to personnel and equipment, and minimum cost and development. On this basis, CO_2 ranks highest for localized fires, and Halon 1301 for total flooding. Although various weighting factors are qualitative and subjective, a sensitivity study shows that over a considerable variation of weighting factors, the highest-ranked (recommended) agent doesn't change.

292. Nowlen, S.P.: Investigation of Smoke Corrosivity in Nuclear Power Plant Equipment. SAND87–2484C, 1987.

Limited data from JP–4 pool fires show that smoke is a dynamic aerosol; that is, its mean diameter increases from initial values of 0.3 to 0.5 μm to peaks of 1.2 to 1.8 μm at 8 to 12 hr and decreases to near initial values after 24 hr. The initial median diameter is smallest for the largest experimental pool, but the spread in the distribution of diameters is greatest for the large pool. Experiments show that, for polyvinyl chloride- (PVC-) insulated cables, only 2 percent of anticipated chlorides are in the atmosphere; the rest are in water-soluble salts carried by the smoke aerosols.

*292A. Carleton, F.B.; and Weinberg, F.J.: Electric Field-Induced Flame Convection in the Absence of Gravity. Nature, vol. 330, 1987, pp. 635–636.

A brief paper from Imperial College describes experiments on a candle in the KC–135, where in μg, an electric field can strengthen the spherical flame by replacing the gravitational body forces. The applications are for improved combustion efficiency rather than for fire safety.

293. Youngblood, W.W.; and Seiser, K.M.: Experiments to Ensure Space Station Fire Safety—A Challenge. AIAA Paper 88–0540, 1988.

Fire safety issues are reviewed and then used to define three experiments for the space station: (1) combustion and flame spread in low velocity convection (2) flow, fire and fire-extinguishant interaction, and (3) smoldering and deep-seated combustion. For each experiment, the technology issues and proposed facilities are described. The first experiment could be accommodated in a generic Combustion Tunnel Facility (note Ref. 253), and the other two in a generic Combustion Research Facility.

294. Edelman, Raymond B.; Bahadori, Yousef; Olson, Sandra L.; and Stocker Dennis P.: Diffusion Flames Under Micro-Gravity Conditions. AIAA Paper 88–0645, 1988.

Previous diffusion flame studies in μg have had 1g ignition. This paper describes work in the NASA Lewis 2.2-s drop tower, with 0.051- and 0.0825-cm nozzle radii, air, 1 atm, CH_4 and C_3H_8 diffusion flames. Ignition was initiated at the start of the drop. The igniter consisted of an electrode connected to the grounded nozzle. Results of flame length versus fuel mass flow (three values for each fuel) are compared to analytical predictions with fair results because of the model's neglect of radiation.

295. Strehlow, Roger A.; Noe, Kurt A.; and Wherley, Brian L.: The Effect of Gravity on Premixed Flame Propagation and Extinction in a Vertical Standard Flammability Tube. Twenty-First Symposium (International) on Combustion, The Combustion Institute, Munich, Germany, 1986, pp. 1899–1908.

Experiments were conducted in a 51-mm-id poly(methyl methacrylate) (PMMA) tube with premixed CH_4-air and C_3H_8-air flames in the NASA Lewis Learjet. Ignition was by capacitive discharge over a Nichrome wire coated with nitrocellulose. Test durations were 15 s. The investigators determined lean limits, providing criteria of no propagation, partial propagation, and full propagation. Values based on 30 to 50 runs are (1) for CH_4: 5.25 percent in 1g upward combustion, 5.85 percent in 1g downward combustion, and 5.25 percent in μg (10^{-2}g) and (2) for C_3H_8: 2.15 percent in 1g upward combustion, 2.20 percent in 1g downward combustion, and 2.06 percent in μg. The CH_4 near-limit flames show cellular sporadic instabilities at μg. Extinction at the lean limit is from the walls inward for μg; center outward for 1g. Flame spread measurements are shown for C_3H_8 at 2.3 percent for variable gravity from ~0 to 1.7, by measurements taken at end of parabola. Flame speed increased from 18 cm/s at 0g nearly linearly to 30 cm/s at 1.7g.

296. Steckler, K.D.; Baum, H.R.; and Quintiere, J.G.: Salt Water Modeling of Fire Induced Flows in Multicompartment Enclosures. Twenty-First Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1986, pp. 143–149.

The technique described uses an inverted 1/20-scale transparent model in a water tank. Dyed salt water, 10 wt% NaCl with a specific gravity of 1.07, was released at 40 to 60 ml/s. Agreement with smoke experiments in height versus time was very good. The analysis notes that the plume should have a Reynolds number of 10^4 or greater, with a minimum initial momentum flux. The method does not simulate heat transfer effects.

297. Quintiere, J.G.: The Application of Flame Spread Theory to Predict Material Performance. J. Res. NBS, vol. 93, no. 1, 1988, pp. 61–70.

The author discusses the underlying theory behind the lateral ignition and flame spread apparatus. From heat-flux and flame-spread measurements, a good determination of kc_p (where k is thermal conductivity and c_p is specific heat), ignition temperature, and minimum temperature for flame spread are obtained. The paper presents some experimental comparisons.

*298. Jason, Nora H.: Spacecraft Fire Detection and Extinguishment: A Bibliography. NASA CR–180880 (NBSIR 88–3712), 1988.

This is an NBS-created (National Bureau of Standards) bibliography, based upon 13 keyword indexes, largely confined to literature from 1974 to 1987.

299. Newhall, J.L.; Fernandez-Pello, A.C.; and Pagni, P.J.: Experimental Observations of the Effect of Buoyancy on Co-Current Smoldering. Paper presented at Spring Meeting, Western States Section, The Combustion Institute, Salt Lake City, UT, March 1988.

The paper describes smoldering experiments. The test fuel was α-cellulose with CH_4 torch ignition at the top and air flow entering from the bottom (cocurrent). The effect of gravity is believed to be small. For air flows of 1 to 5.5 g/m^2-s, smolder velocity is linear with air mass flux, ranging from 1.5×10^{-3} cm/s to 7×10^{-3} cm/s. The effect of air pressure from 0.6 to 1 atm is also slight. Calculated buoyancy from burned to unburned density difference has little effect on smolder velocity, except perhaps at air fluxes of 0.5 g/m^2-s or less (compare Ref. 217).

*300. Priem, Richard J.: Study of Industry Requirements That Can Be Fulfilled by Combustion Experimentation Aboard Space Station. NASA CR–180854, 1988.

The author conducted interviews to assess the industry, university, and research interest in fire-safety experiments for terrestrial and space applications, among other categories of interest. Terrestrial interest promoted microgravity experiments for dust explosions, fundamental suppression studies, fire signatures, ignition requirements, and fire-safety analogies for aircraft submarines, and so forth. Space interest covered low convective flows, fire fighting, ignition, and flame detection. The report describes possible space station combustion facilities and lists the organizations that were interviewed.

*301. Johnson, Alan M.: Optical Fire Detector Testing in the Aircraft Engine Nacelle Fire Test Simulator. AFWAL–TR–87–2089, 1988.

Boeing conducted comparative tests of optical fire detectors, to replace or supplement continuous fire detectors, in a flow rig simulator with a portion of an F–100 engine at the Wright-Patterson Air Force Base. A baseline sensor, installed since 1980 in F–111 test airplanes, was an HTL/Graviner single-sensor ultraviolet (UV) detector. Other detectors were Walter Kidde dual infrared (IR) (N_2-filled sensor plus CO_2-filled sensor), Santa Barbara Research Center dual IR (short wave < 1μm and long wave > 6 μm), Armtec triple sensor (broad IR, narrow IR centered on CO_2 emission, and UV), and Pyrotector single sensor (narrow band). Test conditions were two JP–4 flow rates for fire (3.8 liter/hr, and 118 liter/hr), atmospheric and altitude environments, and varying ventilation rates. Pyrotectors responded to all fires, the baseline HTL to all but the high-air flow rate, and the Armtec to all but two conditions. Kidde and SBRC had bad responses and mechanical problems. All sensors rejected false alarms of strobe lights and hot bleed air.

301A. Ronney, Paul D.: Effect of Chemistry and Transport Properties on Near-Limit Flames at Microgravity. Combust. Sci. Technol., vol. 59, nos. 1–3, 1988, pp. 123–141.

The paper describes experiments with premixed gases in the NASA Lewis 2.2-s facility, continuing the work of References 219 to 220, where mixtures of NH_3-air, H_2-air, and C_3H_8-air gave a range of different reaction mechanisms but similar transport properties. It was found that if the Lewis number Le << 1, cellular flames are observed (H,-O_2-N_2); for Le ≈1, self-extinguished flames are observed; and for Le >> 1, ignition-energy-limited flame propagation was observed.

*302. Youngblood, Wallace W.: Spacecraft Fire-Safety Experiments for Space Station: Technology Development Mission. NASA CR–182114, 1988. N88–20353.

A Wyle Laboratories report describes three concept designs for a combustion facility on an orbiting space station. These are (1) combustion and flame spread of typical spacecraft materials, (2) interaction of extinguishants with fire, and (3) smoldering and/or deeper seated combustion. Also described are three near-term experiments on combustion and flame spread, fire extinguishants, and postfire recovery of sensitive electronic components. For space station experiments, the report gives justifications for conducting them in space. The experiment descriptions include schematic layouts, estimated configurations, and estimated volume, mass, power, and consumables. The report also discusses experiment diagnostics, safety requirements, and preliminary development schedules.

303. Stofan, Andrew J.: A Research Laboratory in Space. 30 Years of Progress in Space, Pergamon Press, Oxford, 1987, pp. 39–43.

The paper gives a general description of the space station, with a more detailed discussion of the management plan, work packages, “levels,” and definition-development schedules.

303A. Ho, V.; Siu, N.; and Apostolakis, G.: COMPBRN III—A Fire Hazard Model for Risk Analysis. Fire Safety J., vol. 13, nos. 2–3, 1988, pp. 137–154.

The paper describes COMPBRN III, a two-zone room model where the fire source is in the lower zone at a constant ambient temperature, and the hot gas and entrained air are in the upper zone. The height of the hot gas layer is variable. The room has a door. The paper presents models and equations for heat release, hot gas layer, mass transfer, door flow, and thermal transfer. The particular value of COMPBRN III for risk analyses is in assessing the frequency of thermal hazards.

304. Anon.: V–22 Osprey: Revolutionary Transportation. Aviat. Week Space Technol., 1988, p. 49.

An advertising-news article notes that the tilt-rotor V–22 will be the first airplane with an onboard inert gas generating system, made by Clifton Precision Investments and the Life Support Division of Litton Systems, for inerting fuel-tank cells. A parallel unit in the V–22 is an onboard oxygen-generating system.

305. Nadis, Steve: Blazing Satellites. Tech. Rev., vol. 91, no. 4, 1988, p. 8.

A news article quotes Friedman, Custer, and Kimzey on tests and needs in spacecraft fire safety, with some history of Kimzey's airplane and Spacelab tests.

306. Johnson, Alan M.: Fire Extinguishing Agent Evaluation in the Aircraft Engine Nacelle Fire Test Simulator (AENFTS). AFWAL–TR–88–2022, 1988.

Tests of JP–4 fires were conducted in the Wright-Patterson Air Force Base nacelle simulator (Ref. 301). Extinguishment tests compared Halons 1301 and 1202, with a schedule of 20 s of preburning before extinguishant discharge and 5 s of fuel flow continued after the discharge. Results showed that a shorter preburn (12 to 15 s) improves extinguishment (i.e., reduces response time) and termination of ventilation flow is beneficial. The more volatile H1301 gave a better agent distribution than 1202. The report has proposed changes to MIL–F–87168, "General Specification for Aircraft Fire and Explosion Hazard Protection Systems," that calls for 6 vol% Halon for at least 0.5 s.

307. Anderson, Charles L.: Advanced Air Separation Module Performance Evaluation. AFWAL–TR–88–2031, 1988.

Ground tests conducted by Boeing evaluated two models of permeable-membrane air separators for onboard inert gas generating systems (OBIGGS). The test objectives included performance, endurance, temperatures, and pressure sensitivity. The test modules were furnished by AIG Technology (Needham, MA) and Permea (St. Louis, MO). Efficiency, weight, size, temperature, and pressure limits were all very much better than those of the only currently operational OBIGGS, which uses a Clifton molecular sieve. The permeable membranes are a bundle of tubes with a very thin membrane (0.06 μm) backed by a supporting thick, porous substrate. Boeing derived general performance correlations of $\%O_2$ as a function of combined parameters of flow, inlet and waste pressure, and temperature.

308. Galea, E.: Smoking Out the Secrets of Fire. New Sci., vol. 119, 1988, pp. 44–48.

This is a news-type article introducing modeling as applied to enclosed fires. A program for field modeling, developed at Thames Polytechnic Institute called "Safeair," was validated in a full-scale 737 fuselage test in 1982 at the NASA Johnson Space Center.

308A. Kramer, Stuart; and Sheridan, Joseph: Preliminary Analysis of Fire Suppression Methods for the Space Station. Engineering, Construction, and Operations in Space, Proceedings of Space 88, ASCE, Albuquerque, NM, 1988, pp. 809–819. (A89–45792).

Generally, this paper is a summary of Reference 291, with added discussion on fire risks in the space station. Recommendations for extinguishing agents are again CO_2 for localized fires and Halon 1301 for major (H_2) fires.

309. Hadlock, Charles R.; and Glaser, Peter E.: Risk Assessment for Safety. Space Safety and Rescue 1986–1987, Gloria W. Heath, ed., Science and Technology Series, vol. 70, IAF 86–59B, 1988, pp. 11–16.

This is an A.D. Little paper on general safety concerns for the space station. The authors cite the design procedures from NASA documents to (1) eliminate hazards, (2) reduce hazards by selection of the least hazardous design or operation, (3) minimize hazards by safety factors, backups, warnings, and so forth, and (4) minimize hazards through maintenance and repair schedules.

310. Kane, Francis X.: Space Station Safety Planning. Space Safety and Rescue 1986–1987, Gloria W. Heath, ed., Science and Technology Series, vol. 70, IAF 86–59E, 1988, pp. 27–39.

This paper is largely a condensation by Rockwell International of the Peercy works (Refs. 203+), with some additional comments on “safe havens,” which are not merely places, but complete capabilities.

311. Rodney, George A.: Safety Considerations in the Design of Manned Spaceflight Hardware. Space Safety and Rescue 1986–1987, Science and Technology Series, vol. 70, IAA 87–569, 1988, pp. 203–216.

This paper is a follow-up to Rodney’s earlier International Academy of Astronautics (IAA) paper (Ref. 287). Prompt-effect and delayed-effect hazards are noted. The discussion on fire presents microgravity concerns, present techniques, space station problems, and so forth—all of which are directly taken from NASA Lewis reports on these subjects.

312. Macidull, John C.: Safety Awareness Continuity in Transportation and Space Systems. Space Safety and Rescue 1986–1987, Science and Technology Series, vol. 70, IAA 87–568, 1988, pp. 191–201.

The author, from the Federal Aviation Administration, was on the Space Shuttle Challenger investigating team. He gives a good, but brief, discussion of zero risks, use of statistics, and general ongoing safety concerns.

313. Okajima, S.; and Hara, H.: Flame Propagation in Liquid-Fuel Droplet Arrays at Elevated Pressure Under Zero Gravity. Dynamics of Reactive Systems. Progress in Astronautics and Aeronautics, vol. 113, 1988, pp. 151–167.

This is another paper based on work in the Tokyo 0.9-s drop tower (Ref. 227). Multiple droplets of n-heptane suspended on quartz filaments are ignited to determine flame spread to adjacent droplets. Results for pressures of 0.1 to 0.5 MPa air and filament spacings of 3 to 6 mm show that at low gravity, propagation decreases with increasing pressure and increasing spacing. At low pressures, propagation is smooth; at high pressures, propagation is intermittent.

314. Andersen, Stephen O.; Ryan, Michael J.; Walker, Joseph L.; Tapscott, Robert E.; and Morehouse, Edward T.: Halons, Stratospheric Ozone and the U.S. Air Force. Mil. Eng., vol. 80, no. 523, 1988, pp. 485–492.

The discussion covers the environmental effects of chlorofluorocarbons (CFCs), used as refrigerants, solvents, and foam agents, as well as those of brominated halons 1211 and 1301, used principally as extinguishants. Domestic usage of H1211 and 1301 is only a few percent of the total of CFC, chloroform, and halogens. However, a weighting factor is derived to account for the strong effect of halons on the ozone layer. On a weighted basis, H1301 (factor 11.43, chloroform = 1) makes up 12 percent of the ozone depleters, and H1211 (factor 2.4) makes up 2 percent. It is noted that only 5 percent of the total halon emissions attributed to the Department of Defense are from extinguishing fires: training releases 32 percent; discharge testing releases, 37 percent; accidental discharge, 18 percent; research, 37 percent; and so forth. The degrees of UV–B radiation from ozone depletion are noted. The Air Force Engineering and Services Center conducts four areas of appropriate research: (1) alternative agents, (2) new technologies to reduce equipment and personnel losses, (3) methods to reduce training and testing discharges, and (4) designs of zoned, localized fire protection systems. Those areas are briefly described. For partial flood systems, H1211, with a lower rating and denser characteristics, may be preferable to H1301. The use of higher concentrations than required by NFPA 12A in small-scale simulations might reduce the need for full-scale testing.

315. Werley, Barry L.: An Oxygen Index Update. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, ASTM Special Technical Publication 986, Dennis W. Schroll, ed., American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 248–261.

This is a discussion of tests by Air Products and Chemicals on the ASTM D 2863 Oxygen Index (OI). Results on premixed gases show that the lower and upper flammability limits converge (principally the upper limit) to a single minimum, the minimum O_2 cone. For diffusion flames, the OI is close, but not equivalent, because of a heat transfer influence. Gases may be ranked according to the OI. Use of other than N_2 diluents for solid fuels affects the OI; OI increases as diluent specific heat *Cp* and thermal conductivity *k* increase. The paper includes a table of OI values for a number of common organic materials. Compatibility with N_2O is also discussed. The N_2O acts as if it were richer in O_2 than its stoichiometric equivalent.

316. Wharton, Ronald K.: An Assessment of the Critical Oxygen Index Test as a Measure of Material Flammability. Flammability and Sensitivity of Materials in Oxygen-Enriched Flammability: Third Volume, ASTM Special Technical Publication 986, Dennis W. Schroll, ed., American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 279–285.

The author, from the UK Explosion and Flame Laboratory, describes tests on the oxygen index (OI) of plastic rods and sheets. For poly(methyl methacrylate) (PMMA), which vaporizes readily to the monomer, the OI is independent of rod diameter or sheet size. For Nylon 66, which tends to drip, the results show that the OI increases as thickness increased. The explanation is in the energy consumed in the phase change. Other results showed that if gas velocities in the OI test fall below the required 30 to 50 mm/s, the measured OI falls (where the OI is less than ambient oxygen concentration). This is shown to be caused by entrainment of room air.

317. Zallen, Dennis M.; and Morehouse, Edward T., Jr.: Fire Extinguishing Agents for Oxygen-Enriched Atmospheres. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres: Third Volume, Dennis W. Schroll, ed., ASTM Special Technical Publication 986, American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 391–412.

The Air Force Engineering and Services Center paper has a brief literature survey on extinguishment tests in aircraft, enriched oxygen, and space. It presents the results of small-scale static chamber, medium-scale, and large-scale fuselage tests on the extinguishment of JP–4 fires by Halons 1301, 1211, and 2402. For 40 %O_2, about a fivefold increase in Halon concentration is required. Typical extinguishment concentrations are in the order 2402 > 1301 > 1211, but sensitivity to O_2 is the same for all Halons. Tests with aqueous film-forming foam showed that foam can initially control directly accessible fires.

318. Tedeman, Lars G.: Safety Approach for ESA Space Programmes. IAF Paper 88–509, 1988. (A89–17843).

This is a general paper on safety for spacecraft modules like Spacelab and Columbus without specific reference to fire. European Space Agency product assurance and safety has set basic safety requirements. Of interest is a definition of risk for ranking as a function of probability of occurrence, security, and quality of information and data.

319. Rodney, G.A.: NASA Post-Challenger Safety Program: Themes and Thrusts. IAF Paper 88–510, 1988. (A88–55435).

The paper briefly reviews NASA organization and reviews changes since the Space Shuttle Challenger disaster. Previous failure modes and effects analyses and critical item analyses were qualitative. Now analyses are going into probabilistic risk assessments. The space station is noted as requiring approaches for fire controls, safe havens, and so forth. The diverse activities in the Space Station are noted. Onboard fires are the single greatest threat. Countermeasures include fire control implemented by average-skill crew and crisis management aids.

320. Blomberg, Richard D.; Bishop, Edward W.; Hamilton, John W.; and Custer, Richard L.P.: Technology Assessment for Aircraft Command in Emergency Situations. FAA Report DOT/FAA/CT–88/20, 1988.

The authors, from Dunlap Associates and Worcester Polytechnic Institute, present an analysis of a computer-based in-flight fire protection system for new commercial aircraft. The computer system, analogous to an expert system, involves sensing, alerting, response, and decision-making. The report discusses at length fire signatures and sensors, alarm systems, and human responses. A proposed system would have two conditions sensed; for example, smoke and heat. Software and logic responses to sensing levels are discussed. Thirteen scenarios based on reported in-flight incidents illustrate the scope of flight problems and emergencies and show how the proposed aircraft command in emergency situations system would respond. The latter analysis determines timelines, procedures, and escape benefits.

321. Anon.: Expert: Ohio State's Fire Man. News in Engineering, vol. 60, no. 5, fall 1988, pp. 26–29.

This is a personalized article on E.E. Smith of Ohio State University (OSU), with an account of the development, use, and description of the OSU test chamber (Refs. 62 and 84). The article briefly notes the present Federal Aviation Administration certification rule for 100–100 (maximum heat release rate of 100 kW-min/m^2, peak heat release of 100 kW/m^2).

*322. Sacksteder, Kurt R.: Facilities for Microgravity Combustion Research. IAF–88–355 (NASA TM–102014), 1988.

The paper presents the usual justifications for low-gravity combustion studies. It includes a brief description of drop towers, reduced-gravity airplanes, the solid surface and droplet combustion experiment packages, and the modular combustion facilities.

323. Anon.: Flammability Configuration Analysis for Spacecraft Applications. NSTS 22648, 1988.

The definitive NASA Handbook for flammability assessment covers procedures to (1) identify flammable materials, (2) limit propagation paths, and (3) evaluate sealed containers for flammable storage. The handbook has an assessment logic diagram. Examples are shown of typical flammable materials, overwrap protection, and proper containment.

324. Quintiere, James: Analytical Methods for Firesafety Design. Fire Tech., vol. 24, 1988, pp. 333–352.

This is an overall literature review, covering the state of the art in fire modeling, research on fire prediction, and applications to fire codes.

325. Sanchez Tarifa, C.; Corchero, G.; and Juste, G.L.: An Experimental Programme on Flame Spreading at Reduced Gravity Conditions. Appl. Microgravity Tech., vol. I, no. 4, 1988, pp. 165–169.

This is a brief summary of KC–135 experiments on poly(methyl methacrylate) (PMMA) cylinders and sheets by European Space Agency researchers. Downward spread was measured at 1g and µg. In both gravities, flame-spread velocity increases as air pressure increases form 20 to 98 kPa. In all cases, µg velocity is of the order of 1/2 the 1g velocity over the range of pressures and O_2 mass fractions of 21 to near 90 percent.

326. Tapphorn, R.M.; Ham, C.; Porter, A.; and Pippen, D.L.: Infrared Fiber-Optic Fire Sensors: Concepts and Designs for Manned-Flight Systems. NASA TR–593–001, 1988.

The report includes a literature survey on radiation- and fiber-optic-based fire-sensor systems. It illustrates concepts for a multiplex system with a common detector and a distributed fiber system (the latter does not sense fire location). The report also reviews fire detection and fiber transmission systems along with the associated optical elements and electronics. Breadboard testing of these systems is also discussed. A recommended system is chopped at the fiber input, with PbS or InAs detectors and Si or ZrF_4 fibers. False alarms from lamps and sunlight may be a problem, but none of these may affect the system used on the Space Station Freedom.

327. Janoff, D.; Beeson, L.; Hadley, L.; and Pippen, D.L.: Development, Manufacture, and Qualification of Igniters to be Used in the NHB 8060.1B Flammability Tests. NASA TR–594–001, 1988.

In-house production of the igniters for the NHB 8060.1B upward flammability tests (Ref. 155) is described. The acceptable igniters are made in 300-g batches, consisting of 10 parts hexamethylene tetramine (igniter), 9 parts Na_2SiO_3 (filler), and 1 part gum arabic (binder). The mixture is then dried (from water paste) and extruded to form cylinders, 0.32 cm in diameter by 2.5 cm long, to meet specifications of 25±5 s burning time at 1093±111 °C. Approximate energy release is 3150 J, and the shelf life is near 2 months.

328. Senecal, Joseph A.: Detection and Suppression of Process Dust Deflagrations: An Overview With Examples. Paper presented at the Winter Annual Meeting of the American Society of Mechanical Engineers, Chicago, IL, Nov. 1998.

Explosions of dust can be controlled by prevention, inerting, containment, venting, and suppression. This paper covers experiments on the latter approach, which involves rapid detection and extinguishment. Dust cloud deflagrations may be characterized from the rate of pressure rise by a parameter K_{st} (ASTM E–1226–88), defined as $K_{st} = R_{max} V^{1/3}$, where R_{max} is the maximum rate of pressure rise in MPa/s and $V^{1/3}$ is the cube root of vessel volume in meters. Dusts are defined in three classes: St-1, where $K_{st} < 20$ MPa·m/s; St-2, where K_{st} is 20.1 to 30 MPa·m/s; and St-3, where $K_{st} > 30$ MPa·m/s. Detection may be by ultraviolet sensors (Geiger-Mueller, best below 280 nm), pressure detectors (common range of 1.5 to 7.0 kPa), or best by rate-of-pressure-rise detectors. Extinguishing agents are rated for toxicity, cleanup, and effectiveness. A rapid discharge delivery is necessary to deliver agent within 20 to 30 ms. H1301 and Hymix (H1301 with dry chemical) appear to be best in experimental tests of pressure versus time.

*329. Friedman, Robert; and Sacksteder, Kurt R.: Fire Behavior and Risk Analysis in Spacecraft. NASA TM–100944, 1988.

Spacecraft fire safety risk analysis is discussed in terms of strategies and risk optimization. A necessary ingredient is knowledge of fire in low gravity, also reviewed. Practical spacecraft applications are covered by examples of space shuttle fire detection and fire extinguishers. The authors also discussed the needs for Space Station Freedom fire safety.

330 to 334 omitted.

335. Leasure, C.S.; Linley, L.J.; and Pippen, D.L.: Evaluation of NHB 8060.1B Test 1: Upward Propagation Test. NASA TR–576–001, 1988.

A series of comparative tests of the NASA Upward Propagation Test with various reference materials gave interesting results. Oxygen concentration strongly affects the burn length, which decreases with time. Even for a 1400-liter chamber, O_2 should be monitored before and after testing. Sample holders (needle rakes, wing nuts, etc.) affect results, but in a random manner. Thin sample results are most reproducible with 1 cm of slack to allow for width shrinkage. Igniter orientation does not affect results for thin samples, but the test gives more conservative results for thick samples when the igniter is positioned perpendicular to the width. K–10 paper mounted 20 cm below the sample serves well as an indicator of ignition by sample dripping. Results for Kydex 100 were very repeatable and suitable for use as a standard reference material.

336. Olson, Sandra L.; Ferkul, Paul V.; and T'ien, James S.: Near-Limit Flame Spread Over a Thin Solid Fuel in Microgravity. Twenty-Second Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1988, pp. 1213–1222.

This experimental work on paper in both the 2.2- and 5.2-s NASA Lewis drop towers largely repeats the results of Reference 290 and the low-velocity results of Ferkul (Ref. 348). More evidence is presented on the low-velocity quenching limit (radiation loss) as contrasted to the high-velocity blow-off limit (reduced residence time). Various comments are attached to the paper. The authors note that including a diffusion velocity to the relative velocity scale will not affect the results.

337. Kawakami, T.; Okajima, S.; and Iinuma, K.: Measurement of Slow Burning Velocity by Zero-Gravity Method. Twenty-Second Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1988, pp. 1609–1613.

The Hosei University (Tokyo) 0.9-s drop facility was used by investigators to measure burning velocities for premixed CH_4-air flames through a streak camera. Burning velocity is calculated from the measured flame speed and the unburnt-to-burnt density ratio. Burning velocity is maximum (40 cm/s) at an equivalence ratio of 1, and it decreases with increasing total pressures (above 1 atm).

338. Ronney, Paul D.: On the Mechanisms of Flame Propagation Limits and Extinguishment Processes at Microgravity. Twenty-Second Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1988, pp. 1615–1623.

The paper describes the premixed combustion of NH_3-air, C_3H_8-air, and H_2-air in the NASA Lewis Research Center 2.2-s facility. The H_2 flames are colored by 0.23 percent CF_2Br. The investigator observed lean limits of combustion. At mixtures just below those of the lean limit, in many cases, self-extinguished flames occur. That is, the flame front continually decreases with temperature. Near-limit extinguishments at *Le* near unity are attributed to radiant losses, where *Le* is the ratio of thermal diffusivity of the entire mixture to the mass diffusivity of the scarce reactant.

339. Gokalp, I.; Chauveau, C.; Richard, J.R.; Kramer, M.; and Leuckel, W.: Observations on the Low Temperature Vaporization and Envelope or Wake Flame Burning of *n*-Heptane Droplets at Reduced Gravity During Parabolic Flights. Twenty-Second Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1988, pp. 2027–2035.

This is a rather preliminary work performed in an European Space Agency flow tunnel carried in the NASA KC–135 airplane. Droplets ~1 mm in diameter were generated from a syringe and transferred to a quartz fiber. For most of the flights, ignition was by a methane diffusion flame. Droplets are ellipsoid because of fiber distortion. Results showed that droplets follow an inverse-square law with much scatter. The vaporization rate constant k increases with the square root of the Reynolds number $Re^{1/2}$. The coefficient is larger in low gravity compared with that in normal gravity. Flame diameter increases to ~10 initial droplet diameters for up to 2/3 of the droplet lifetime (~2.5 s) and then decreases until complete extinction is observed, after the droplet is completely vaporized.

340. Yang, J.C.; and Avedisian, C.T.: The Combustion of Unsupported Heptane/Hexadecane Mixture Droplets at Low Gravity. Twenty-Second Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1988, pp. 2037–2044.

This work continues the Cornell 1.2-s studies of Reference 288 with binary component drops generated by an ink jet. No discernable change in $\frac{\mathrm{d}}{\mathrm{d}t}\left(d^2\right)$ is observed for 0 33, 0.50, and 0.75 mole fraction of n-$C_{16}H_{34}$ in n-C_7H_{16}, compared with that of the pure component drops. This finding suggests that droplet burning is diffusion controlled; that is, fractional vaporization does not occur. The pure component, in 0.5-mm-diameter droplets shows a constant minimum diameter for the last 0.1 s or so of the test, which appeared to be an unexplained flame extinction. Flame diameters were not measured.

341. Galea, Edwin: On the Field Modelling Approach to the Simulation of Enclosure Fires. J. Fire Prot. Engr., vol. 1, no. 1, 1989, pp. 11–22.

The paper briefly notes the existence and use of zone models (Harvard, Dayton, etc.) and notes the advantages of field models using computational fluid dynamics. Among field models under development is the Thomas Polytech SAFEAIR, which uses the PHOENICS code for the fluid dynamics. This code uses body-fitted coordinates to construct various chambers. Examples of the use of this code discussed in the paper include a 1982 validation by NASA Johnson of a B737 fuselage fire and a cabin fire prediction.

342. Jumper, George Y.; and Custer, Richard L.P.: Ignition in Microgravity. AIAA Paper 89–0180, 1989. (A89–25155).

A thermal analysis of a proposed space experiment is discussed. The experiment uses a radiant lamp (20 to 80 kw/m^2) to ignite an α-cellulose sample. The analysis shows that the removal of the natural convection heat-loss mechanism causes an increase in surface temperature (about 50 K for 50 kW/m^2) and a rapid increase in rate of pyrolysis (combustion precursor).

*343. Lekan, Jack: Microgravity Research in NASA Ground-Based Facilities. AIAA Paper 89–0236, (NASA TM–101397), 1989.

This is a description of the size, mass limitations, and turnaround times for the 2.2 Second Drop Tower (27 by 2.75 m) and 5.18-s Zero Gravity Facility (132 by 6.1 m) at NASA Lewis, the 100 m Drop Tower (89.5 m, 4.27 s) and 100 m Drop Tube (105 by 0.25 m, 4.6 s) at NASA Marshall, and the two reduced-gravity aircraft, the Learjet 25 and the KC–135. The Marshall 100 m Drop Tower is unique in that the drag shield is rail supported with gas jets for compensating thrust.

344. Berlad, A.L.; Tangirala, V.; Ross, H.; and Facca, L.: Radiative Structures of Lycopodium-Air Flames in Low Gravity. AIAA Paper 89–0500, 1989. (A 89–25406).

The authors describe experiments on the Learjet airplane with a flame tube in 20 s of low gravity with (1) an acoustic driver on, (2) an acoustic driver off, (3) nitrocellulose ignition at one end, and (4) flame propagation, in sequence. Optical detectors show flame progress. Non-adiabatic conditions cause flame “chattering.”

*345. Vento, D.M.; Zavesky, R.J.; Sacksteder, K.R; and Altenkirch, R.A.: The Solid Surface Combustion Space Shuttle Experiment Hardware Description and Ground-Based Test Results. AIAA Paper 89–0503, 1989. (A89–28419).

The paper is a description of the science requirements, hardware, and procedures for the Solid Surface Combustion Experiment. Planned are five experiments burning ashless filter paper 10 cm long by 3 cm wide by 0.018 cm thick, at combinations of 30 and 50 %O_2, and 1.0-, 1.5-, and 2.0-atm pressure. Tests will include three other tests, as yet undefined, with thermally thick poly(methyl methacrylate) (PMMA). Limited ground experiments in the NASA Lewis 5-s drop tower yield filter-paper spread rates of 0.30 to 0.40 cm/s at 30 %O_2 (1 atm), 0.18 to 0.35 cm/s at 30 %O_2 (1.5 atm), and 0.31 to 0.47 cm/s at 50 %O_2 (1.5 atm).

346. Fakheri, Ahmad; and Olson, Sandra L.: The Effects of Radiative Heat Loss on Microgravity Flame Spread. AIAA Paper 89–0504, 1989. (A 89–28420).

This is an analysis, rather preliminary, of temperature contours around a thermally thin fuel with opposed velocities of 15 to 46 cm/s in microgravity. Radiation, introduced in the model by assuming emissivities of 0.0, 0.5, and 1.0, reduces the flame velocity and may induce extinction at a lower opposed velocity.

*347. Anon.: Microgravity Combustion Science: A Program Overview. NASA TM–101424, 1989. (N89–28665).

“The Microgravity Combustion Group” is an identification of the compilers of this report, members of the Microgravity Research Branch and their associates at the NASA Lewis Research Center. The summary report describes the proposed in-space project, Solid Surface Combustion Experiment, as well as ground tests on droplet combustion, liquid pool fires, and particle cloud combustion. The report includes brief results of microgravity combustion studies on paper (Ref. 336) and a condensed description of the microgravity testing facilities. The report also discusses the needs and justifications for applications to spacecraft fire safety.

347A. Ohlemiller, Thomas J.: Assessing the Flammability of Composite Materials. NISTIR–88/4032, 1989.

Navy-supported studies conducted at the National Institute of Standards and Technology (NIST) include tests to characterize flammability of vertically mounted sheets of composite materials. The principal tests are ignitability (in a lateral ignition and flame spread test (LIFT) facility), rate of heat release (cone calorimeter), and opposed flow-flame spread (in a LIFT facility). The typical results are interpreted with respect to models, with stated assumptions.

*348. Ferkul, Paul V.: An Experimental Study of Opposed Flow Diffusion Flame Extinction Over a Thin Fuel in Microgravity. NASA CR–182185, 1989.

The report covers the thin-paper, microgravity flame studies described in Reference 336. It has more details on the experiments, covering burning characteristics at opposed air velocities from 0.8 to 6.93 cm/s at 14 to 21 %O_2 concentrations. A table gives pertinent data on flame standoff, length, and width. This work strengthens the proposed mechanism of low-flow radiative extinction in microgravity.

349. Hirsch, D.; Linley, L.; and Pippen, D.L.: Comparison of Result of the European Space Agency Oxygen Index Test and the NASA Upward Propagation Test. NASA TR–581–001, 1989.

Tests on 27 materials compared results for NASA's upward flammability test described in NHB 8060.1B with the European Space Agency (ESA) oxygen index test at 85.5 kPa (the ambient atmospheric pressure at NASA White Sands Test Facility). Three conditions for the upward flammability tests were 30 %O_2 at 69 kPA, 25.9 %O_2 at 98.5 kPa, and 20.9 %O_2 at 101.3 kPa. Most, but not all, of the pass-fail results agree. For example, at the 20.9 %O_2 NHB 8060.1B conditions, five materials pass the ESA test but fail the NASA test, and one material fails the ESA test, but passes NASA's test.

350. Brandyberry, Mark D.; and Apostolakis, George E.: Fire Risk Analysis Methodology: Initiating Events. NIST–GCR–89–562, 1989.

An elaborate method of consumer product fire-risk analysis is presented. The general model is based on the expected number of deaths as the product of total fires, probability of fire scenarios, deaths per fire, probability of home occupancy, and so forth. The examples expand on statistics of household heater fires to get frequency of exposure, radiant view calculations to get ignition per exposure, and so on.

*351. Ross, Howard D.; Facca, Lily T.; Berlad, Abraham L.; and Tangirala, Venkat: Feasibility of Reduced Gravity Experiments Involving Quiescent, Uniform Particle Cloud Combustion. NASA TM–101371, 1989. N89–26114.

This report covers NASA Lewis 2.2-s drop tower and Learjet experiments with lycopodium powder in a 5.0-cm-diameter tube for the Particle Cloud Combustion experiment. The ground experiments were replacements for a proposed flight experiment that was determined to be not suitable for spaceflight. For the 2.2-s tests, the fuel-air mixture was subjected to vibrations from a 140-Hz acoustic speaker for 0.55 s of mixing prior to ignition. Learjet tests used 170 to 330 Hz alternating acoustics for mixing. Instrumentation was cameras and light-extinction detectors. The investigators observed chattering flames with discontinuous flame fronts at equivalence ratios $\phi < 1.3$. Flame spreads for rich mixtures are quite uniform. Improvements for the experiments suggested by the authors are additional detectors, better cloud-density measurements, and improved particle positioning.

351A. Griggs, John G. III: Space Station Freedom Safety Program. Proceedings of the 26th Space Congress, Cocoa Beach, FL, 1989, pp. 7–45 to 7–50. (A92–38250).

The Space Station Freedom Program Definition and Requirements Document will incorporate a quantitative risk assessment with rigorous hazard scenarios, likelihood of occurrence, and damage estimate as the product. The international partners are to develop the same analysis through independent data flow. Fire safety is not mentioned specifically in these requirements.

351B. Tapphorn, Ralph M.; Kays, Randy; and Porter, Alan: Infrared-Fiber-Optic Fire Sensor Developments—Role of Measurement Uncertainty in Evaluation of Background Limited Range in Spacecraft Safety. Proceedings of the 35th International Instrumentation Symposium, 1989, pp. 553–565, (A91–19687).

This paper covers the experimental work of Reference 326. Of interest is the estimate for the background limited range of 8 m for a signal chopped at the fiber input. The range is otherwise 2 to 3 m. False alarms are still a major concern.

352. Quintiere, J.G.: State of Fire Research and Safety. Proceedings of the Second International Symposium on Fire Safety Science. T. Wakamatsu, P.J. Pagni, Y. Hasemi, C.E. Grant, A. Sekizawa, P.G. Seeger, eds., Hemisphere Publications, New York, NY, 1989, pp. 15–28.

This paper is a cursory review with some statistics on U.S. fire deaths, costs, and researchers compared with those of the other developed countries. One example is given on poly(methyl methacrylate (PMMA) wall fire spread to illustrate predictions.

353. DeRis, J.: A Scientific Approach to Flame Radiation and Material Flammability. Proceedings of the Second International Symposium on Fire Safety Science. T. Wakamatsu, P.J. Pagni, Y. Hasemi, C.E. Grant, A. Sekizawa, P.G. Seeger, eds., Hemisphere Publications, New York, NY, 1989, pp. 29–46.

The paper is based on a lecture, reviewing the field of flame radiation as part of flame properties. The discrepancies between small-scale flammability measurements and full-scale are usually due to flame radiation heat transfer in the latter. About 80 percent of radiation from luminous flames is from soot, and about 20 percent is from hot gases. In general, past results show good correlation of radiative fraction of energy with smoke-point flame length. The latter is an easily measured quantity for gases and liquids. For solid fuels, the author suggests using a lamp-heating box to pyrolyze fuel and emit flammable gases for smoke-point measurements.

354. Mulholland, G.W.; Henzel, V.; and Babrauskas, V.: The Effect of Scale on Smoke Emission. Proceedings of the Second International Symposium on Fire Safety Science. T. Wakamatsu, P.J. Pagni, Y. Hasemi, C.E. Grant, A. Sekizawa, P.G. Seeger, eds., Hemisphere Publications, New York, NY, 1989, pp. 347–357.

Tests of smoke emissions compared the bench-scale cone calorimeter measurements with full-scale pools and cribs for heptane, crude oil, wood, polyurethane, and poly(methyl methacrylate) (PMMA). Smoke emission rates and specific extinction are comparable for each fuel at either scale, if compared at equivalent specific mass-loss rates.

355. Purser, D.A.: Modeling Toxic and Physical Hazard in Fire. Proceedings of the Second International Symposium on Fire Safety Science. T. Wakamatsu, P.J. Pagni, Y. Hasemi, C.E. Grant, A. Sekizawa, P.G. Seeger, eds., Hemisphere Publications, New York, NY, 1989, pp. 391–400.

The author derived mathematical models for physical hazards of CO, HCN, CO_2, oxygen depletion, smoke optical density, and radiant (plus convective) heat flux. The "narcotic" gases are characterized by fractional effective doses, the ratio of the dose received at a given time to the lethal dose (a fractional effective dose of 1). Several interactions are noted: (1) the effects of CO and HCN are directly additive, (2) CO_2 increases the rate of uptake of CO and HCN by its effect on the respiration volume, (3) low oxygen hypoxia is additive to the effects of CO and/or HCN, but is not influenced by the CO_2 respiration volume increase, and (4) CO_2 has an additional narcotic effect, independent of the effect of the other gases. Heat is characterized by an allowable heat-flux level of 2.5 kW/m^2, above which exposure is limited to a few seconds. Smoke is characterized by a limit of 1.2 percent per meter obscuration. An example of a single armchair burn is used to illustrate these points.

356. Galea, E.R.; and Markatos, N.C.: Modeling of Aircraft Cabin Fires. Proceedings of the Second International Symposium on Fire Safety Science. T. Wakamatsu, P.J. Pagni, Y. Hasemi, C.E. Grant, A. Sekizawa, and P.G. Seeger, eds., Hemisphere Publications, New York, NY, 1989, pp. 801–810.

The Thames Polytechnic (U.K.) field model is tested against the 1982 results of NASA JSC 737 fuselage fire tests of Kuminecz and Brickner (NASA TM–58244, 1982). The tested condition was the fire of a pan of Jet A-1 in an empty fuselage. Good agreement of axial and vertical temperatures with experiment was achieved with a fine mesh, which takes 64 hr. Only qualitative agreement was achieved with a coarse mesh. Calculations tended to exaggerate temperature differences. Calculations also show the effectiveness of using cold air from flow vents with expulsions of hot gases from ceiling (opposite to airplane practice) or air curtains for reducing maximum temperatures. No experimental data are available to verify the venting scenario calculations.

357. Apostolakis, G.E.: Fire Risk Assessment for Manned Spacecraft. PSA '89—International Topical Meeting on Probabilistic Reliability and Safety Assessment, Pittsburgh, PA, 1989, pp. 1–4.

The paper has a brief review of NASA concerns for spacecraft fire safety. Introduced is the University of California at Los Angeles concept of probabilistic risk assessment (PRA). Applied to fires, PRA consists of (1) identification of critical location and frequency of fires, (2) estimation of competing fire growth, detection and suppression times, and (3) response of the process (damage). Fire scenarios require experiments to observe (1) ignition properties of space materials under radiative heating, (2) mechanisms of propagation between two surfaces, and (3) motion of combustion products.

358. Hartzell, G.E.: Prediction of the Toxic Effects of Five Effluents. J. Fire Sci., vol. 7, no. 3, 1989, pp. 179–193.

The paper has tables of LC_{50} values for CO, HCN, HCl, NO_2, and O_2 depletion. Various models of fire product toxic effects are noted: the fractional effective dose model, including gases and smoke; the N-gas model of CO, CO_2, HCN, and O_2 depletion; and the physiological model (Ref. 355), which combines synergistic effects of CO, CO_2, HCN, and O_2 depletion.

*359. Smith, Richard L.; and Kashiwagi, Takashi: Expert Systems Applied to Spacecraft Fire Safety. NASA CR–182266, 1989. N89–23501.

This report has two parts. First is a brief description of expert systems for Space Station Freedom fire safety. Second is a discussion of fire science for the Space Station Freedom. Noted are early fire detection needs, including flow pattern prediction, smoke detectors, CO detectors, and particle detection. Also noted are suppression schemes, promoting N_2-based foams and venting to vacuum.

360. Casserly, Dennis M.; and Russo, Dane M.: A Rationale for Atmospheric Monitoring on Space Station Freedom. SAE Technical Paper Series, no. 891514, SAE International, Warrendale, PA, 1989. A90–27480.

The paper discusses conventional environmental control and life support systems for the Space Station Freedom compared with other human-crew vehicles. Intermodule air exchange is designed for 60 liter/s (130 cfm). Shuttle open loop systems use LiOH to remove CO_2 (CO is catalytically oxidized to CO_2) and activated carbon. The nuclear submarine system is noted, where hydrocarbons, N_2, H_2, O_2, CO_2, and H_2O are measured by mass spectometry, and CO is measured by infrared spectroscopy.

361. Shiraki, K.; Hashimoto, H.; Manabe, K.; Hattori, A.; and Hama, H.: Preliminary Design of JEM Environmental Control and Life Support System. SAE Technical Paper Series, no. 891574, SAE International, Warrendale, PA, 1989. A90–27535.

The Japanese Experiment Module (JEM) consists of three components: the pressurized module, experiment logistic module, and the external facility. The modules have fire detection and suppression subsystems. Generally, the functions parallel those of the U.S. space station modules. The JEM receives intermodule ventilation, but it has its own redundant systems. For fire detection, ionization detectors are to be installed in the racks, avionics air loop, cabin air loop, and special electrical equipment (as required). Thermal detectors are in the same locations. Radiation detectors monitor the open area. Provisions are in place to respond to alarms with air and power shutoff. For suppression, CO_2 bottles are fixed in the racks and consoles, portable CO_2 is available, and venting is possible.

362. Knight, Douglas R.: Medical Guidelines for Protecting Crews With Flame-Suppressant Atmospheres. SAE Technical Paper Series, no. 891596, SAE International, Warrendale, PA, 1989.

This review covers sealed cabins (submarines and aircraft). Flame suppressant atmospheres are possible through N_2 dilution, N_2 pressurization, depressurization, and ternary gas supplementation. Only the first three approaches are discussed. Generally, humans tolerate a sudden reduction in the partial pressure of oxygen (ppO_2) to 17.3 kPa (80 percent reduction) very well, but a sudden reduction to 13.3 kPa (60 percent) induces unpleasant symptoms. N_2 narcosis results from ppN_2 in excess of 400 kPa (5 atm). Decompression sickness results for decompression from a total pressure above 200 kPa to 1 atm, and from 1 atm to <0.5 atm. Significantly lesser reductions can be performed safely. The paper concludes that the closed-cabin atmosphere may be changed to 17 or even to 14.6 $\%O_2$ by increasing total pressure to 120 kPa while keeping the ppO_2 at 17.3 kPa. However, these are not necessarily completely fire-free atmospheres.

363. Cholin, John: Optical Fire Detection. Chem. Engng. Prog., vol. 85, no. 7, 1989, pp. 62–68.

A review article describes passive optical detectors. Conventional flame detectors are ultraviolet (UV) and UV–IR (infrared) types. These detectors suffer from problems of absorption by dust, dirty windows, and so forth, as well as poor reliability of vacuum tube photodiodes. Spark detectors, used in conveyors, ducts, and similar applications, are rapid near-IR detectors. Modern detectors are IR–IR, responding to 3.8- and 4.3-μm wavelength radiation, where the strong 4.3-μm band corresponds only to hydrocarbon flames. The article also describes active optical fiber detection, where heat fuses a fiber interrupting the light transmitted by the fiber (made by FIRETEK of Hawthorne, NJ).

*364. Durox, D.; Prud'homme, R.; and Scouflaire, P.: Premixed Flames in Microgravity. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 1–9. (General N90–16958) (Specific N90–16959+)

Qualitative results are noted for premixed CH_4-air flames in the KC–135 airplane laboratory in the Multi-User Combustion Chamber at 0g, 1g, and 2g for equivalence ratios $\phi = 1.6$ and 1 at 0.65 to 1 atm. Generally, longer flames enlarge at low gravity; small flame lengths are unchanged with gravity.

*365. Carleton, F.B.; and Weinberg, F.J: Electric Field-Induced Flame Convection in the Absence of Gravity. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 21–24. (General N90–16958) (Specific N90–16962).

This paper is on candle flames at low gravity in the KC–135 airplane laboratory, identical to Reference 292A, except illustrations are in color.

*366. Gökalp, I.; Chauveau, C.; Richard, J.R.; Leuckel, W.; and Kramer, M.: Droplet Vaporisation and Combustion in Microgravity. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 25–36. (General N90–16958) (Specific N90–16963).

The paper describes KC–135 experiments with a droplet-generating tunnel. The paper is essentially a description of April 1987 tests, described in Reference 339. Increasing the air flow from stagnant conditions to 50 cm/s greatly increases the rate of evaporation, although further increases are small up to 150 cm/s. Color photographs show drops and flame fronts.

*367. Bryant, D.; and Judd, M.: Polymer Group Microgravity Combustion Experiment. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 37–52. (General N90–16958) (Specific N90–16964)

Photographs are shown from KC–135 experiments on the flammability of Pyrell foam and printed circuit boards. The setup was based on NASA NHB 8060.1 Test 1 (Upward Flammability Test), but the specimens were mounted horizontally, and the specimen size was smaller because of the smaller combustion chamber. Illustrations show the normal-gravity and low-gravity flames, but no spread lengths or rates are reported. Air-gap experiments at normal gravity show that the printed-circuit-board flame propagates over a 2-cm gap but not a 3–cm gap. The Pyrell flame was nearly spherical and nearly invisible. Inhomogeneities in the printed circuit board caused gas “jets” to form. Residual gravity may have influenced the results.

*368. Sanchez Tarifa, C.; Liñan, A.; Salva, J.J.; Corchero, G.; Juste G.L.; and Esteban, F.: Heterogeneous Combustion Processes Under Microgravity Conditions. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 53–64. (General N90–16958) (Specific N90–16965).

This paper is an expansion of the work reported in Reference 325. The investigators conducted experiments in the KC–135 airplane on poly(methyl methacrylate) (PMMA) combustion under varying O_2 and pressure in 1986 to 1987. (This is claimed to be the earliest microgravity solid flame-spread experiment). The cylindrical samples were 7 cm long and had a 4-mm outside diameter with a centered 2-mm annulus filled with asbestos. The flat sample was 6 cm by 12 cm and 2 mm thick embedded in a metal holder with low conductivity plaster resulting in essentially one-sided burning. The cylinders showed greater flame spread velocities in both normal gravity and low gravity (the latter had velocities of the order of 1 to 5 mm/s). Cylinders tend to expel particles radially in low gravity. In general, spreading velocities in low gravity are about 0.2 to 0.5 of those in normal gravity. Velocity increases with pressure from 30 to 100 kPa, and with O_2 concentration from 20 to 90 percent. However, these environmental effects are less marked in low gravity. Interestingly, the ratio of normal-gravity to low-gravity spread velocity continues to increase as O_2 approached 90 percent (in contrast to work of Olson on paper flammability).

*369. Sacksteder, Kurt: A Comparison of European and American Microgravity Combustion Experimental Techniques. Combustion Experiments During KC–135 Parabolic Flight, Brigitte Kaldeich, ed., ESA SP–1113, 1989, pp. 65–69. (General N90–16958) (Specific N90–16966)

The paper is a general survey of the value of microgravity combustion studies and a description of the NASA Lewis facilities and flight and ground-based programs. A brief section notes the varying approaches to droplet and gaseous combustion studies.

370. Omitted.

*371. Friedman, Robert; and Olson, Sandra L.: Fire Safety Applications for Spacecraft. Aircraft Fire Safety. NASA TM–101463, 1989. (N89–24413).

This is a review paper covering the current and past strategies of fire prevention, detection, and extinguishment in space. Fire in space and research results are discussed in terms of material flammability, oxygen concentration, radiation and radiative extinction, and ventilation effects. Aircraft and submarine fire-safety analyses are noted. The authors also discuss future needs for Space Station Freedom and research issues.

372. Fuller, William R.; and Halverson, Mark W.: Space Station Freedom Program Risk Model Control Document. PLG–0702, rev. A, 1989.

This is a report by Pickard, Lowe, and Garrick for Grumman Space Station Program Support Division on a safety risk assessment for the Space Station Freedom manned base (modules). Various questions are raised (some seemingly naïve). Questions for fire detection and suppression include several on automatic response, redundancy of detectors, and venting. An assembly sequence (now obsolete) is included. The risk assessment is based on model generation. For example, models for fire include cases of electrical short and overload, faults in electrolysis units, oxygen leak, chemical reaction, faulty experiment, or improper crew or ground control actions. The authors derive fault tree analyses for the positive results of crew and station safety as well as the negative results (off-nominal) of crew safe and/or station unserviceable as well as crew endangered. The work was not carried out to reach a detailed conclusion.

373. Cintron, N.M.; Pierson, D.L.; and Pool, S.L.: Halon 1301 Human Inhalation Study—Final Report. NASA JSC 23845, 1989.

This report discusses the result of a medical study conducted for NASA Johnson. Volunteers were exposed to 1 percent Halon 1301 for 24-hr periods, during which time the investigators monitored medical signs and work responses. Performance changes were 4 percent or less of the baselines.

*374. Youngblood, Wallace W.; and Vedha-Nayagam, M.: Advanced Spacecraft Fire Safety: Proposed Projects and Program Plan. NASA CR–185147, 1989. (N90–12645).

A formal survey of 36 sources plus several consultants provided a description of fire safety issues and efforts for advanced spacecraft. About 155 recommendations were assembled into 58 specific topics, in turn yielding 30 projects. These were grouped into thematic areas of fire detection, fire extinguishment, risk assessment, toxicology, and human response. The report expands on 14 high-priority projects assembled into a program plan. An appendix by Kimzey reviews the history and experience in spacecraft fire protection, crew attitudes, and housekeeping.

375. Olson, S.L.; Stouffer, S.C.; and Grady, T.: Diluent Effects on Quiescent Microgravity Flame Spread Over a Thin Solid Fuel. Submitted for presentation at the Fall Technical Meeting of the Eastern States Section of The Combustion Institute, Albany, NY, 1989.

A study, conducted in the NASA Lewis 2.2-second drop tower, investigated diluent effects of He, N_2, and CO_2 on flame spread and extinction limits to determine thermal effects in microgravity (i.e., quenching). The experiments were conducted at a constant O_2 partial pressure with varying diluents. Generally, the effect of a diluent is small. CO_2 extinguishes at the highest O_2 concentration; next is He and then N_2. The effects on spread rates are similar.

376. Bahadori, M. Yousef; and Stocker, Dennis P.: Oxygen-Concentration Effects on Microgravity Laminar Methane and Propane Diffusion Flames. Paper 71, Fall Technical Meeting of the Eastern States Section of The Combustion Institute, Albany, NY, 1989, pp. 71–1 to 71–4.

The paper presents preliminary results from the Lewis 2.2-second drop tower. The study investigated diffusion flames at 18 to 30 $\%O_2$, at two volume flow rates, and with two tapered-tip nozzles (0.096- and 0.148-cm diameters). Flame height is greater for all zero-gravity cases. Flame heights decrease as O_2 concentration increases, as flow rate decreases, and as nozzle diameter increases. Propane but not CH_4 low-gravity flames show underventilated tips. The color of the flames is interpreted to show radiation loss for near-limit flames.

377. Baum, Howard R.; Kashiwagi, Takashi; and Di Blasi, Columba: Radiative Pyrolysis of Thin Fuels in a Microgravity Environment. Paper 72; Fall Technical Meeting of the Eastern States Section of The Combustion Institute, Albany, NY, 1989, pp. 72–1 to 72–4.

An analysis of the pyrolysis of thermally thin fuels coupled with gas-phase preheating is simplified by removing buoyancy (no momentum equation). Sample results for temperature and density versus time and length are shown for 40 kW/m^2 heating and assumed reaction rates.

378. Choi, Mun Young; Cho, S.Y.; Dryer, Frederick L.; and Haggard, John B., Jr.: Some Observations on the Burning of Methanol Droplets in Microgravity Using Various Inert Gases. Paper 73, Fall Technical Meeting of the Eastern States Section of The Combustion Institute, Albany, NY, 1989, pp. 73–1 to 73–74.

Limited results are shown for NASA Lewis 2.2-second drop tower tests of methanol droplets in a 50 $\%O_2$ and 50 %He atmosphere. In this atmosphere, the droplet burns faster and extinguishes at a larger diameter compared with air or N_2-O_2. Photographs document the complete droplet history from deployment, ignition, to extinction.

379. Beattie, Robert M., Jr.: Fire Protection for a Martian Colony. The Case for Mars III: Strategies for Exploration—General Interest and Overview, Carol R. Stoker, ed., AAS 87–218, vol. 74, 1989, pp. 595–605. (AAS 87–218). A90–16683.

This is a nontechnical paper, reacting negatively to the suggestion that a Mars transit craft can be designed with a 100 $\%O_2$ atmosphere. The author points out that the human body is a Class A fuel at 100 $\%O_2$. He also cites the Apollo 204 mistake (100 $\%O_2$) and the Space Shuttle Challenger mistake (solid rocket cannot be shut down).

*380. Apostolakis, G.E.; Ho, V.S.; Marcus, E.; Perry, A.T.; and Thompson, S.L.: Risk-Based Fire Safety Experiment Definition for Manned Spacecraft. UCLA–ENG–90–11 (NASA CR–183835), 1989. (N90–14262).

This is the definition-stage University of California, Los Angeles, report for NASA Marshall Space Flight Center. The background of probabilistic risk assessment is introduced by three major tasks: (1) identification of critical locations and frequencies, (2) estimation of fire growth rates as well as fire detection and suppression times, and (3) response of the process. The report presents risk equations based on previous work. It describes the science requirements for flight experiments with six models: heat release, smoke release, heat transfer, damage, detection, and suppression. For each model, background equations, scaling methods, and experiment objectives are described. The report has an excellent literature survey.

381. Gagosian, John: Why Space Station Freedom Won't Get Burned. Princeton Engineer, 1989, pp. 4–5.

This is a popular article by a student of Prof. Ronney, with a general summary of the highlights of shuttle and Space Station Freedom fire protection, quoting the findings of the NASA Lewis Spacecraft Fire Safety Workshop (Ref. 286) and Smith (Ref. 359).

382. Sheinson, R.S.; Penner-Hahn, J.E.; and Indritz, D.: The Physical and Chemical Action of Fire Suppressants. Fire Saf. J., vol. 15, no. 6, 1989, pp. 437–450.

This is a Naval Research Laboratory study on the relative suppression ability of inert gasses over a pool fire. Physical and chemical suppression mechanisms are discussed. The authors analyze experimental work, based on cup burner tests of heptanol and 2-propanol pools (fuel type has a negligible effect on results). Chemical effects were determined from gas sampling of products. The authors also note that suppression of ignition must be a physical effect (no free radicals). Suppressants include noble gases, N_2, CO_2, CF_4, SF_6, Halons, and a few sulfur analogs. Tables show some energy parameters and the minimum concentration of inert in air for suppression. Sample percentages are 32 %He, 30 %N_2 (plus air concentration), 21 %CO_2, 3.2 %CF_3Br, 16 %CF_4, and 11 %SF_6. Only the Halon and sulfur analogs had appreciable chemical effects. For example, the action of Halon 1301 in suppression is 80 percent chemical and 20 percent physical. It is estimated that, for the chemical action, 25 percent was due to CF_3 and 55 percent due to Br.

*383. Chauveau, C; and Monsallier, G.: Observations on the Vaporization and Burning of Fuel Droplets at Reduced Gravity During Parabolic Flights. Acta Astronaut., vol. 20, 1989, pp. 223–228.

The paper describes experiments conducted in the KC–135 airplane with a flow rig capable of forced flow up to 5 m/s (Ref. 366). A syringe and quartz fiber generated 1-mm heptane droplets with ignition by a methane flame. Nonburning evaporation tests showed that the square of the droplet diameter d^2 versus time relation increased with the square root of the Reynolds number $Re^{1/2}$ and that the dependency of $Re^{1/2}$ was greater at zero gravity. Only quiescent burning results are reported. For burning droplets, the d^2 dependency is 0.69 mm^2/s. Flame diameter is nearly constant for the first 0.9 s of combustion, then increases with time to an elapsed time of 1.9 s, and then decreases rapidly with time to approximately 2.5 s of elapsed time (droplet lifetime).

*384. Casserly, Dennis M.: Identifying Atmospheric Monitoring Needs for Space Station Freedom. National Aeronautics and Space Administration (NASA)/American Society for Engineering Education (ASEE) Summer Faculty Fellowship Program—1989, William B. Jones, Jr., and Stanley H. Goldstein, eds., NASA CR–185601, vol. 1, 1989, pp. 5–1 to 5–15.

This is a final report from the University of Houston at Clear Lake on monitoring needs for Space Station Freedom. The report identifies various contaminants. It proposes a model environmental control and life support system that removes contaminants to the extent that no substance will exceed one-half the space maximum acceptable concentration (SMAC) over 90 days. Agents without a published SMAC are estimated at 0.1 mg/m^3. For fire products, the STS–6 incident of an incipient fire is cited. Fire contaminants are CO_2, CO, HCN, HCl, NO_2, H_2S, and SO_2; the major need will be for CO monitoring.

385. Tapphorn, Ralph M.; and Porter, Alan R.: Infrared Fiber-Optic Fire Sensors: Concepts and Designs for Space Station Applications. Proceedings of the Fiber Optic Systems for Mobile Platforms III Meeting, vol. 1173, 1989, pp. 188–200. (A91–19634).

This is essentially a condensed version of Reference 351B.

386. Hartzell, Gordon, E.: Assessment of the Toxicity of Smoke. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 1, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 8–18.

This is a general review of methods and modeling of toxicology. A brief description of several techniques is given. The problems in material-toxicology assessments are that rodent results may not relate to humans, and more importantly, toxic hazards depend more on fire growth than on the toxicities of individual materials and products. Modeling is based on the determination of doses of effluent combustion products. Haber's rule (concentration × time = constant, or Ct = constant) applies to CO. The paper discusses LC_{50}, fractional effective dose, and combination of gases (which lacks experimental validation).

387. Hartzell, Gordon E.: Understanding of Hazards to Humans. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 1, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 19–37.

The difficulties in understanding toxic fire hazards to humans lie in (1) the variability of toxicant accumulation through physical activity, (2) the competition between intake and release of toxicant by the body, and (3) the non-uniformity of human subjects and their health (high fraction of fatalities in normal gravity are in victims with high blood-alcohol levels). The author discusses CO concentration and carboxyhemoglobin (COHb). A rule of thumb is that incapacitation occurs at Ct = 35,000 ppm-min. HCN is 20 times more toxic than CO. Also discussed are O_2 depletion, CO_2 (a lesser factor for toxicity), HCl (its importance is controversial), and multiple toxicants.

388. Alexeeff, George V.; and Packham, Steven C.: Evaluation of Smoke Toxicity Using Concentration—Time Products. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 1, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 202–219.

The paper cites that 80 percent of all fire fatalities (about 6000 annually in the United States) are from smoke inhalation. The paper compiles data using the University of Pittsburgh Test Method for 45 materials and then calculates LC_{50} (lethal concentration for 50 percent of test animals) and $LC_{50} \times$ time for these materials plus effluent gases like CO and HCN.

389. Hartzell, G.E.; Priest, D.N.; and Switzer, W.G.: Modeling of Toxicological Effects of Five Gases: II Mathematical Modeling of Intoxication of Rats by Carbon Monoxide and Hydrogen Cyanide. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 1, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 252–265.

The authors compile data on the incapacitation of rats, described by $Ct = K\dfrac{C}{C-b}$, which approaches Haber’s Rule as $\dfrac{C}{C-b}$ approaches 1. In this equation, C is the concentration, t is time, and K and b are constants. Generally, the data are best fitted by “fractional effective doses” over a short time interval, which can be numerically integrated. This gives a linear plot of concentration versus time up to a time limit for incapacitation (or death).

390. Tsuchiya, Yoshio: On the Unproved Synergism of the Inhalation Toxicity of Fire Gas. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 2, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 86–94.

The author reviews literature on binary gas lethality. Synergistic effects are distinguished from pure additive effects. One method to derive the binary lethality is to add the individual toxicity indexes, $\Sigma(Ce/C_t)$, where Ce is the concentration of a lethal gas and C_t is the lethal concentration of the same gas. If the index is appreciably less than 1 for lethal exposure from combined gases, there is synergism. The author shows that, for most CO-HCN tests, there is little synergism. For CO-CO_2, B.C. Levin (Ref. 405) claims synergism, but the author would like to see Levin's quantitative data before accepting this conclusion.

391. Hirschler, Marcelo M.: Fire Hazard and Toxic Potency of the Smoke From Burning Materials. Advances in Combustion Toxicology, Gordon E. Hartzell, ed., vol. 1, Technomic Publishing Co., Inc., Lancaster, PA, 1989, pp. 229–247.

This paper presents findings from small-scale tests of toxic potency of smoke. Complete flammability measurements are necessary to characterize materials. The paper presents charts of ignition temperatures, limiting oxygen index, surface flammability, total heat release, and maximum heat release rates of common materials. The author notes that 60 to 90 percent of fire deaths are from CO. The toxic potency of most materials do not vary much, since CO is the predominant product. Instead, the author suggests the use of mass loss rate parameter derived by the LC_{50} to determine the toxic fire hazard.

*392. Glover, Daniel: Design Considerations of Space Flight Hardware. NASA TM–102300, 1990.

This is a review of constraints on space flight hardware, including a description of environmental constraints (ground and prelaunch, launch and ascent, and space) and design constraints (weight, power, safety, and reliability). The paper notes the review process and presents a brief literature review of design specifications.

393. Law, C.K.: Combustion in Microgravity—Opportunities, Challenges, and Progress. AIAA Paper 90–0120, 1990. (A90–23703)

This paper is a review of microgravity combustion research, covering, in general, flammability limits, diffusion flames, solid-fuel flame spread, droplet combustion, and particle combustion. For fire safety, studies on the opposed-velocity effects on thin fuels are cited. The paper notes the danger of prefire pyrolyzates as fire hazards and toxicity from smoldering. The paper also cites the problems of fire detection, and it urges a consideration of low-O_2-concentration atmospheres for reducing fire risk.

394. Cantwell, Elizabeth R.; and Fernandez-Pello, A.C.: Smoldering Combustion Under Low Gravity Conditions. AIAA Paper 90–0648, 1990. (A90–22238)

The authors describe tests in the NASA Lewis 2.2-second microgravity facility on a 10- by 10-cm polyurethane block, ignited by a Nichrome wire coil placed against three layers of cotton cloth. Normal-gravity results for downward cocurrent smoldering (air flow up) show that the peak temperature and smolder velocity decrease sharply above 12 cm^3/s. For upward cocurrent smoldering (air flow down), buoyancy and forced flow compete. Peak temperatures decrease, then increase, and finally decrease above 35 cm^3/s. Low-gravity results for downward cocurrent ignition tests (experiment package is dropped shortly after ignition) show that temperatures decrease sharply below 12 cm^3/s. Above 12 cm^3/s, forced convection influence is the same as in normal gravity. Smolder tests (experiment package is dropped 5 to 7 min after ignition) give variable results.

395. Haggard, J.B.; Brace, Michael H.; Dryer, Frederick L.; Choi, Mun Y.; Williams, Forman A.; and Card, John: N-Decane-Air Droplet Combustion Experiments in the NASA-Lewis 5 Second Zero-Gravity Facility. AIAA Paper 90–0649, 1990.

Most of the paper is a description of apparatus improvements in reducing needle vibration and excessive droplet motion. The longer microgravity tests (5.2 s) permitted ignition and complete burning history observations for droplets with diameters as large as 1.6 mm. Compared with previous 2.2-s measurements, the present burning rates are nearly 50 percent higher. The authors suggest that the longer test times and lower droplet motion causes the discrepancy.

396. Bahadori, M. Yousef; Stocker, Dennis P.; and Edelman, Raymond B.: Effects of Pressure on Microgravity Hydrocarbon Diffusion Flames. AIAA Paper 90–0651, 1990. (A90–25039)

This is a study conducted in the NASA Lewis 2.2-second drop tower of propane-air diffusion flames in a 0.15-cm diameter nozzle at pressures of 0.5, 1.0, and 1.5 atm and three mass flow rates. Ignition used an electrode 1.5 cm from the grounded nozzle, activated for 0.4 s. Results indicate that the corresponding normal-gravity flames flicker, but flickering is damped at low pressures. Microgravity flames do not flicker. The microgravity flames are taller than those in normalgravity and have open tips. In general, where low-pressure, low-flow normal-gravity flames do not flicker, the corresponding microgravity flames have closed tips. The microgravity flame heights increase with flow rate, but they show a minimum (near 1.0 atm) with pressure. The minimum may be due to the competition of O_2 availability, pressure, and rate processes. High pressures cause sootier, more radiant flames both in normal gravity and microgravity.

397. Wang, J. Alex; Shih, K.C.; and Holland, R.L.: Numerical Calculations of Mass Diffusion and Convection of Smoke in Spacelab. AIAA Paper 90–0717, 1990.

The authors applied a numerical program to Spacelab to calculate CO_2 distribution, which is assumed to represent fire products and >5-µm smoke particles. Calculations are for short and long modules. Air flows from eight diffusers above to seven outlets below in the long module. Calculations show recirculation patterns at top and corners. The model includes the locations of three smoke detectors in Spacelab and calculates the typical times to reach sensor set points of 2.5 mg/m^3 or a rate of change of 0.03 mg/m^3-s. In the worst cases, where fires are near diffusers, alarm levels are not reached until 30 s after initiation of the model fire event.

398. Youngblood, Wallace W.: Increased Fire and Toxic Contaminant Detection Responsibility by Use of Distributed, Aspirating Sensors. Proceedings of Technology for Space Station Evolution, vol. 2, 1990, pp. 517–541.

A concept is proposed for the use of multiple aspirating tubes for early warning of smoke or combustion products at centralized detectors. The paper presents some outside data on CO and CO_2 buildup and smoke detector responses for reference fires. Recommendations include the review of sensing tube transit times, detector response, gas chromatograph or mass spectrometer evaluation, and the development and testing of such a system for Space Station Freedom.

399. Sarkos, Constantine P.: FAA's Cabin Fire Safety Program: Status and Recent Findings. Paper presented at Seventh Annual International Aircraft Cabin Safety Symposium, Napa, CA, 1990.

This paper is a review of ongoing and proposed Federal Aviation Administration activities. Of interest to spacecraft are projects on arc tracking of Kapton wiring, efforts on compiling an aircraft material fire-test handbook (Boeing and McDonald Douglas), and a new project on low-pressure flammability; that is, control by venting in aircraft to extinguish fires.

400. Babrauskas, Vytenis: The Cone Calorimeter: A New Tool for Fire Safety Engineering. ASTM Standard. News, vol. 18, 1990, pp. 32–35.

This article is a brief description of the cone calorimeter test, now adopted as ASTM E-1354, taken from References 254 and 274B. The features of the cone calorimeter include vertical or horizontal orientation, mass loss (load cell) measurements, heat release peak and rate (O_2 consumption) measurements, radiant ignitability, gas monitoring, and smoke measurements (specific extinction). Nearly 40 instruments, made by five companies, are now in existence.

401. Knight, D.R.; Cymerman, A.; Devine, J.A.; Burse, R.L.; Fulco, C.S.; Rock, P.B.; Tappan, D.V.; Messier, A.A.; and Carhart, H.: Symptomatology During Hypoxic Exposure to Flame-Retardant Chamber Atmospheres. Undersea Biomed. Res., vol. 17, no. 1, 1990, pp. 33–44.

This paper describes chamber tests sponsored by the Navy and Army. Twelve volunteers were exposed for 48 hours to an atmosphere varied from 13 to 21 %O_2 at 101.3 kPa for most of the time. Symptoms of acute mountain sickness were reported in 13 percent O_2 at 101.3 kPa and 17 %O_2 at 77 kPa, but not at 17 %O_2 or greater at 101.3 kPa. Tests of a candle flame showed reduced melting when the total pressure or percent O_2 is reduced, until at 17 %O_2 flames flicker and then self-extinguish. Candles could not be lit at 13 %O_2.

402. Bahadori, M. Yousef; Edelman, Raymond B.; Stocker, Dennis P.; and Olson, Sandra L.: Ignition and Behavior of Laminar Gas-Jet Diffusion Flames in Microgravity. AIAA J., vol. 28, no. 2, 1990, pp. 236–244.

This is a description of methane-air and propane-air diffusion flames in 0.51-mm and 0.825-mm diameter tubes, based largely on Reference 294. Ignition is always in microgravity; that is, after the package is released in the NASA Lewis 2.2-sec drop tower. In contrast to results in normal-gravity ignition tests, flames never self-extinguish. In fact, with the improved photography used in these tests, blue flames were observed that may have been invisible previously. The normal-gravity flame flickers; however, quiescent microgravity flames usually don't flicker except at low flows.

403. Shvartz, E.: Advantages of a Low-Oxygen Environment in Space Cabins. Aviat. Space Environ. Med., vol. 61, no. 3, 1990, pp. 272–276.

A low-oxygen concentration atmosphere in spacecraft offers obvious advantages of reduced flammability. The author proposes a 15 %O_2 atmosphere at 1 atm total pressure, the equivalence in O_2 partial pressure of a 9000-ft altitude. Hypoxia under these conditions may prolong the learning of new tasks, but this is compensated by acclimation. Other advantages of the proposed atmosphere are quicker microgravity acclimation, reduced danger of decompression sickness after extra-vehicular activities, and increased tolerance to hypoxia (in an emergency). A disadvantage is the need for sea-level reference atmospheres in some experiments (which would have to be maintained in a dedicated, isolated environment).

404. NASA Johnson Space Center Operations Integration Office: Space Station Freedom Contingency Operation Scenarios. Unpublished, April 1990.

This is a survey of crew responses to various losses and emergencies at stages of the Freedom buildup. Although it has been superseded by subsequent design changes, some information is still relevant. Fire scenarios in racks and modules or nodes are examined. The report gives recommendations for crew intervention, design, and process considerations. Most of these are already implemented. Of note are the recommendations for 100 %O_2 portable breathing equipment, remotely operated hatches, a common fire suppressant for all modules, and toxic-gas-measuring instruments.

405. Levin, B.C.; and Gann, R.G.: Toxic Potency of Fire Smoke—Measurement and Use. ACS Symp. Ser., no. 425, 1990, pp. 3–11.

An improved approach to fire toxicity measurement is the N-gas method (Ref. 255, etc.). The paper presents an updated technique, linking CO, CO_2, HCN, and O_2 reduction with adjustments for synergistic effects of CO_2 and CO. This permits the comparison of different materials. The use of toxic potency data is discussed. One approach is a full calculation with expert judgments, such as HAZARD I. Another approach is a simplified relative fire hazard index, here defined as Toxic Fire Hazard Index $\propto$ $\frac{\text{mass loss rate}}{t_{ig} \times LC_{50}}$, where t_{ig} is the ignition delay time. The index relates the amount of material burning to time and lethality.

406. Hindersinn, R.R.: Historical Aspects of Polymer Fire Retardation. ACS Symp. Ser., no. 425, 1990, pp. 87–96.

This is a brief review of the subject, covering modern chlorinated polymers, fire-retardant fillers, carbonaceous intumescent systems, and inherently thermally stable polymers with high oxygen indices.

407. Tesoro, G.C.: Fire Resistance in Advanced Engineering Thermoplastics. ACS Symp. Ser., no. 425, 1990, pp. 241–252.

This is a study of aromatic polymers (polycarbonate and polyetheretherketone, PEEK). It discusses their fire resistance as well as additional Br-, P-, and S-derived fire retardants.

408. Hirschler, M.M.: General Principles of Fire Hazard and the Role of Smoke Toxicity. ACS Symp. Ser., no. 425, 1990, pp. 462–478.

This is a review of fire hazards, fire properties, and tests. The maximum rate of heat release, RHR, is the single property that most clearly defines the magnitude of a fire. RHR calorimeters also measure the total heat release, ease of ignition, mass loss rate, and amount of smoke produced (defined as the total of gaseous, liquid, and solid products of combustion). Other fire properties are measured by ignitability tests, limiting oxygen indices, flame spread, and toxic potency. The author stresses that the latter causes over 60 percent of fire deaths, yet the toxic potency of common materials varies by less than an order of magnitude.

409. Hirschler, M.M.: Heat Release Equipment to Measure Smoke. ACS Symp. Ser., no. 425, 1990, pp. 520–541.

The author presents findings of fire tests on 17 plastic materials to compare smoke factors and the product of total smoke release and maximum heat release. Measurements made using the cone calorimeter and the Ohio State University chamber instrument correlate well with each other and presumably correlate with full-scale fire characteristics.

410. Panzarella, Louis; and Lewis, Philip: Crew Lock/Hyperbaric Chamber FDS Fire Suppressant Selection Trade Study. McDonnell Douglas (Houston) Memorandum A96–J753–STN–M–LP–900070, April 19, 1990.

This is a systems study on extinguishing agents, specifically for the Space Station Freedom Hyperbaric Air Lock, up to 6 atm. Original agents considered were water, Halon 1301, H1211, He, N_2, and CO_2. The first three were eliminated on the basis of cleanup and environmental problems. The investigators evaluated, on the basis of scores from 1 to 3, eleven attributes of performance, effectiveness, toxicity, weight, volume, commonality, onboard inspection and test, restorability, technology risk, cost, and growth potential. Nitrogen showed a slight advantage over CO_2, and hence it is recommended. Advantages and disadvantages of venting and agents are discussed. The authors cite a minimum O_2 concentration for extinguishment as 15 percent. They also note the potential for reignition of a deep-seated fire.

411. Stocker, Dennis P.: Size and Shape of Laminar Burke-Schumann Diffusion Flames in Microgravity. Presented at the 1990 Spring Technical Meeting of the Central States Section, The Combustion Institute, Cincinnati, OH, 1990, pp. 281–286.

The paper describes NASA Lewis 2.2-sec drop tower tests of an annular burner, with fuel introduced in the central tube. The microgravity flames are considerably wider than normal-gravity flames, but the heights are similar. Ethane (C_2H_6) and propane (C_3H_8) microgravity flames have open tips, whereas methane (CH_4) microgravity flame tips are closed.

412. Torero, J.; Kitano, M.; and Fernandez-Pello, A.C.: Gravitational Effects on Co-Current Smoldering of Polyurethane Foam. Presented at the 1990 Spring Technical Meeting of the Western States Section, The Combustion Institute, Banff, Canada, 1990.

Normal-gravity tests on square foam samples measured the smolder velocity. Upward and downward burning shows small differences in velocity and maximum temperatures. The implication for space is that trapped air provides oxidant for foam smoldering without convection.

*413. T'ien, James S.: The Possibility of a Reversal of Material Flammability Ranking From Normal Gravity to Microgravity. Comb. Flame, vol. 80, 1990, pp. 355–357.

The author presents a simple example of two flammability curves for O_2 fraction versus velocity for spherical solid-surface fuels, with differing surface impurities and heat of combustion. The curves overlap in such a way that the higher emissivity, heat of combustion material is more flammable (lower O_2 fraction) at normal gravity (high stagnation point velocity), whereas the lower emissivity-heat of combustion material is more flammable at microgravity.

414. Babrauskas, Vytenis: Modern Test Methods for Flammability. NISTIR–4326, 1990.

This is mainly a literature survey, emphasizing bench-scale methods for prediction of full-scale behavior. Evaluations cover ignition, flame spread, heat release, smoke and corrosive products, and toxic products. Quantitative assessments are given, particularly for smoke prediction. Reference 233 is cited for comparison of heat-release methods.

*415. Anon.: Panel Summary and Recommendations. Space Station Freedom Toxic and Reactive Materials Handling, Charles R. Baugher, ed., NASA CP–3085, 1990, pp. 1–1 to 1–13.

This is a summary of a workshop held November 29 to December 1, 1988, in Huntsville, AL, implemented by Teledyne Brown Engineering. Although fire is not specifically addressed, the summary covers potential fire-product contamination. The subsystems concerned are the Environmental Control and Life Support System, Process Materials Management Subsystem, and the Fluid Management System. Findings note the important needs for (1) safety attitude, (2) uniform safety policy, (3) mature safety organization, (4) better communications, and (5) commonality.

*416. Pogue, Bill: Past Experience "Skylab Mission." Space Station Freedom Toxic and Reactive Materials Handling, Charles R. Baugher, ed., NASA CP–3085, 1990, pp. 5–1 to 5–7.

This is a brief discussion of Skylab events, concentrating on Kimzey's zero-gravity flammability tests, such as those discussed in Reference 87. An interesting conclusion is that the inhibiting of convective circulation in microgravity cannot be relied on to prevent space fires because (1) the porosity of materials can trap O_2, (2) the thermomechanical response of combusting materials can cause local air agitation, (3) ventilation induces airflow, and (4) extinguishment induces airflow. Furthermore, false alarms and poor detection-system designs may also be problems.

*417. Humphries, William R.: Space Station Contaminant Control and Monitoring. Space Station Freedom Toxic and Reactive Materials Handling, Charles R. Baugher, ed., NASA CP–3085, 1990, pp. 18–1 to 18–10.

The paper outlines environmental control and life support system subsystems, design premises, and contaminant control, without a specific reference to fire safety.

*418. McGonigal, Les: Space Station Pressurized Laboratory Safety Guidelines. Space Station Freedom Toxic and Reactive Materials Handling, Charles R. Baugher, ed., NASA CP–3085, 1990, pp. 22–1 to 22–8.

The paper outlines the technical safety requirements found in space station requirements document SSP 30000, section 3, and other space station documents. Space station material requirements for flammability are in SPP 30233. A general statement notes the requirement for detecting and extinguishing any fire. Other specific requirements are noted. Customer equipment that may pose a fire hazard shall be instrumented through the caution and warning system of the U.S. lab. Air flows and utilities are to be disconnected in case a fire is detected. Maximum surface temperatures shall not exceed 30 °C, 45 °C with specific requirements; 4 °C is the low limit.

*419. Birmingham, Joseph G.; Moore, Robert R.; and Perry, Tony R.: The Reactive Bed Plasma System for Contamination Control. Space Station Freedom Toxic and Reactive Materials Handling, Charles R. Baugher, ed., NASA CP–3085, 1990, pp. 38–1 to 38–30.

This paper outlines the technique of contaminant removal by low-temperature plasma and catalysis to convert contaminants to simple, removable molecules.

420. Otsuki, F.; Suzuki, T.; Yamaguchi, N.; Hattori, A.; Yoshida, Y.; and Iwasaki, H.: Status of JEM ECLSS Design. SAE Technical Paper Series, no. 901209, SAE International, Warrendale, PA, 1990.

The authors describe the progress on the Japanese module (JEM) as of about January 1990. Major changes include deletion of the crew entrapment requirement and emergency N_2 and O_2 tanks, and commonality of module inner diameter (4.2 m) and rack size. The air reutilization function uses (1) the intermodule ventilation system, (2) its own system, and (3) escape to the Space Station Freedom core for a two-fault failure tolerance. Contamination contingencies are noted as arising from (1) false alarm for CO_2, (2) inadvertent leak of CO_2, (3) fire and fire suppression, and (4) escape of experiment fluids. The JEM monitoring will be confined to atmospheric temperature and pressure. Atmospheric composition and trace contaminant readings from the Space Station Freedom will be available. The fire detection system retains the smoke, thermal, and flame detectors; cabin air loop monitoring; and fixed and portable CO_2 suppression specified for the U.S. Lab.

421. Diamant, Bryce L.; and Humphries, W.R.: Past and Present Environmental Control and Life Support Systems on Manned Spacecraft. SAE Technical Paper Series, no. 901210, SAE International, Warrendale, PA, 1990.

This is an excellent review, with schematic diagrams of the environmental control and life support system for all U.S. and Soviet human-crew spacecraft. A table compares the fire detection and suppression subsystem provisions for the U.S. spacecraft only. Reference is made to the Apollo 204 fire on January 27, 1967. Also noted is that Skylab depressurized to 13.8 kPa between missions, an atmosphere that was allowed to decay to 3.5 kPa.

422. Humphries, W.R.; Reuter, J.L.; and Schunk, R.G.: Space Station Freedom Environmental Control and Life Support System Design—A Status Report. SAE Technical Paper Series, no. 901211, SAE International, Warrendale, PA, 1990.

This paper reviews the status of the U.S. environmental control and life support system for Freedom as of early 1990. This comes after the decision for a four-man crew and a power consumption of 37.5 kW but before restructuring. The fire detection and suppression system is described briefly with a standard drawing. Fire protection for the hyperbaric airlock is still an open question.

423. Thomas, Emory C.: Microgravity Fire Detection Problems—Fact or Fiction. SAE Technical Paper Series, no. 901215, SAE International, Warrendale, PA, 1990.
This paper gives details of space shuttle smoke detectors. The paper discusses the smoke buildup in terms of mass loss and aerosol concentration versus time for slow, moderate, and rapid pyrolysis. The fire detection alarm criteria for the space shuttle and Space Station Freedom are given and compared. A plot shows levels of sensitivity for typical smoke particles. The paper notes normal-gravity tests and the microgravity implications and then proposes a future concept with multiple sensing tubes.

424. Huttenbach, Robin, C.; and Oram, Stephen D.: Life Support—Thoughts on the Design of Safety Systems. SAE Technical Paper Series, no. 901248, SAE International, Warrendale, PA, 1990.
The authors, from Nelson Space Services U.K., discuss fire issues for Space Station Freedom. They list potential hazards of dust ignition, electrical short circuits, spillage, and so on. For smoke detectors, they recommend (1) installation subdivided into defined volumes, (2) at least two sensors for each space, (3) a voting system between sensors for alarm, (4) self-monitoring and -repairing sensor loops, and (5) a detector capable of initiating shutdown. A table presents a matrix of systems (suppression, valves, ventilation) against various hazards (smoke, fire, toxic gas) for suppression. The suppression discussion notes that the authors have reservations about CO_2 because of the dangers of large quantities.

425. Sonnenschein, Rainer; and Hienerwadel, Karl-Otto: Evaluation of the Suitability of CO Measurement for Fire Detection in Space. SAE Technical Paper Series, no. 901285, SAE International, Warrendale, PA, 1990.
The authors review principles of fire detection for spacecraft. They discuss response and sensitivity of ionization and optical detectors, using some information from Reference 423. Shuttle and Space Station Freedom (SSF) smoke detectors are about a factor of 20 more sensitive than commercial units, yet they are not consistent. (SSF criteria are meaningful only near the fire source). The strengths and weaknesses of ionization and optical (light scattering) detectors are noted. The authors propose the use of CO monitoring, and they give data of CO production and suggest detection principles. They recommend future work in CO self-calibrating systems, improvement of light-scattering systems, and comparative testing.

*426. Hill, William C.; and Finkel, Seymour I.: Mission Safety Evaluation Report for STS–32. Post-Flight Edition. NASA TM–107775, 1990. (N92-23243).
Postflight report for shuttle mission STS–32 notes a false alarm from avionics bay 3A, smoke sensor 3A (Flight Day 9). Playback data showed no smoke concentration. When the alarm sounded a second time, ground mission control gave the crew permission to open the circuit breaker. The breaker was closed again during reentry with no alarm. The report also notes the earlier STS–28 incident where a teleprinter cable failed because of long-term fatigue and stress cracking of Kapton insulation at a sharp bend. A 1.5-s short circuit with a 51-amp peak was reported, but the 10-amp circuit breaker did not trip. The short was sustained by arc tracking until the wire pair opened.

427. Mowrer, Frederick W.: Lag Times Associated With Fire Detection and Suppression. Fire Tech., vol. 26, no. 3, 1990, pp. 244–265.
After some discussion on heat release and fire growth correlations, the author presents a description of three components of fire response lag: (1) transport lag, (2) detection lag, and (3) suppression lag. The transport lag, in terms of heat release, is based on an initial sensed heat release of zero up to a certain elapsed time then a growth dependence on time squared thereafter. The detection time lag is a function of environment and the device. The suppression lag, the time to take action, can be of the order of minutes.

428. Gann, R.G.; Barnes, J.D.; Davis, S.; Harris, J.S.; and Harris, R.H.: Preliminary Screening Procedures and Criteria for Replacements for Halons 1211 and 1301. NIST–TN–1278, 1990.

This large report furnishes background for screening tests, and it lists methods and reference results with H1211 and H1301 for fire suppression efficiency, ozone depletion, global warning, toxicity, stability, corrosion, compatibility, and electrical conductivity.

429. Pitts, William M.; Nyden, Marc R.; Gann, Richard G.; Mallard, W. Gary; and Tsang, Wing: Construction of an Exploratory List of Chemicals to Initiate the Search for Halon Alternatives. NIST Technical Note 1279, 1990.

This large report has a basic discussion of fire suppression and then a set of tables with thermal properties of halogen-substituted hydrocarbons, metal inhibitors, and inert gases.

*430. Casserly, Dennis M.; and Russo, Dane M.: Identifying Atmospheric Monitoring Needs for Space Station Freedom. SAE Technical Paper Series, no. 901383, SAE International, Warrendale, PA, 1990. (A90-49411).

A discussion of atmospheric monitoring for Freedom notes that intermodule air exchange will be 140 cfm (66 liter/s). The Crew Health Facility will provide critical care for one patient for 28 days and outpatient care for all crew. The authors describe further mission experience. Halon 1301 was detected in trace quantities on STS–3 and STS–4. For fire monitoring, species are the usual CO_2, CO, HCN, HCl, NO_2, and others. The emphasis is on postfire cleanup monitoring for these products and H1301. The SMAC values (spacecraft maximum allowable concentrations) for various contaminants are given with a good list of references.

431. Sribnik, Frederick; Birbara, Philip J.; Faszcza, Jeffrey J.; and Nalette, Timothy A.: Smoke and Contaminant Removal System for Space Station. SAE Technical Paper Series, no. 901391, SAE International, Warrendale, PA, 1990.

The Smoke and Contaminant Removal System (SCRS) is proposed as an alternative to worst-case venting of the 204 kg of air in a space station module (capacity is that prior to restructuring). The SCRS consists of a catalytic oxidizer for CO and H_2 and replaceable particulate and gas removal filters. Performance is calculated for two fire scenarios. The “small” fire is 0.4 kg material ignited within one rack; the “large” fire is 38 kg of material within one rack. The SCRS unit is sized for 25 percent of the worst-case fire. Calculations show a decrease in contaminant concentration with time for two levels of flow.

432. Jonas, Leonard A.; and Steel, J.S.: Energy Fields for Extinguishment. ESL–TR–90–11, 1990.

Hughes Associates did a Phase 1 small business innovative research (SBIR) study for the Air Force as a literature review on how energy fields affect fire extinguishment. Those having some benefit are negative electrostatic fields, magnetic fields, turbulence, large gravitational levels, and air blasts. A few comments on gravitation notes that upward and downward flammability differences are increased by elevated gravity. The report quotes the work of Strehlow that states that flammability limits in zero gravity are intermediate to the limits for upward and downward flame spread in normal gravity for near limit flames.

433. Armstrong, James A. and Butz, James R.: Incipient Combustion Monitor for Zero Gravity Environments. ADA Report No. 25990F01, 1990.

This is a limited circulation SBIR Phase I report, a project rejected for continuation to Phase II. The proposal is for a condensation nuclei fire detector, based on a Graviner expansion counter. The report has a good, but brief review of spacecraft detection needs. The advantage of the condensation nuclei method is that droplets are uniform in size. Thus a few large dust particles are swamped by equivalent sized nuclei from smaller aerosols. The report also presents computer modeling and preliminary tests of a bread-board model.

434. Tapscott, R.E.; Lee, M.E.; Moore, T.A.; Moore, J.P.; Nimitz, J.S.; Skaggs, S.R.; and Floden, J.R.: Next Generation Fire Extinguishing Agent, Phase V—Initiation of Halon Replacement Development. AFESC/ESL TR–87–03, 1990.

The University of New Mexico Research Institute (UMERI) report is a treatise on Halon-replacement technology. It discusses the Montreal protocol, current agents, ozone depletion, toxicity, and extinguishment, with comparisons and predictions. It notes the roles of flooding (H1301) and streaming (H1211) agents. The report gives tables of properties for a number of halogenated hydrocarbons. It identifies the promising candidates and the needed databases.

435. Buchbinder, Benjamin: The NASA Risk Management Program. AIAA Paper 90–3769, 1990. A91-21798.

This is a general description of the NASA risk management trends. Qualitative assessment, failure modes and effects analyses, and hazards analyses are adequate for most elements. Where decisions require them, quantitative methods can be introduced. Workshops and training for advanced risk management are underway.

436. Kaplan, Stan: Safety Risk Assessment on the Space Station Freedom. AIAA Paper 90-3771, 1990.

The paper raises the subject of probabilistic risk assessment and advances several premises. Among these are (1) that the purpose of risk analysis is to support decision making, (2) that risk analysis is initiated at the start of a project and later refined, and (3) that risk analysis should include an assessment of uncertainty. The three components of risk are the set of scenarios (what can go wrong?), likelihood, and consequences. The paper briefly discusses the applications to Space Station Freedom, quoting Reference 372.

437. Biddle, Wayne: Two Faces of Catastrophe; Apollo Fire and Challenger Explosion. Air and Space, vol. 5, 1990, pp. 46–49.

NASA's response to the disasters of Apollo 204 on January 27, 1967, and Challenger on January 28, 1986, are contrasted. For Apollo, NASA conducted the investigation and blamed the manufacturer, North American Aviation. The report is 3000 pages long and technical, with 11 findings. Only finding 9 of the findings mentions the 100 %O_2, 16.7-psi ground-test atmosphere, and it only suggests the use of a diluent atmosphere. The Challenger investigation was conducted by outsiders. The Challenger report is glossy and genteel. It finds little fault with NASA or the contractors.

438. Saiidi, M.: Crew Lock/Hyperbaric Chamber Fire Suppressant Trade Study. A Presentation to JSC Development Review Board, 1990.

This is a trade study on fire extinguishers (compare with Ref. 410). All candidate fire suppressants are ruled out except, N_2, CO_2, and He. The basis for comparisons is 11 attributes, each given a score of 1, 2, or 3 for a finding of least medium or most favorable, respectively. N_2 scores 22 compared with 21 for CO_2 and 17 for He. Charts show that lethal concentrations of CO_2 are attained at 2.8- and 6-atm environments. Launch costs for N_2 are also more favorable. The conclusions of the study are that CO_2 violates toxicity requirements and that a change is recommended from CO_2 to N_2 for the early work packages.

439. Hillman, Thomas C.; and Kane, William R.: Aircraft Fire Detection and Suppression. SAE Technical Paper Series, no. 901951, SAE International, Warrendale, PA, 1990.

This is a historical review of military aircraft. Continuous wire and ultraviolet/infrared (UV/IR) systems detect incipient fires in engine nacelles. The paper describes features to improve detections such as AND logic for dual elements. It covers extinguishing and suppression systems with Halon and CO_2. In some aircraft, pentane is used for fuel tank inerting by creating a fuel-rich atmosphere. The paper also discusses the state of the art as well as dry bay and cargo bay protection.

440. Rodney, George A.: Critical Safety Assurance Factors for Manned Spacecraft—A Fire Safety Perspective. IAF Paper 90–555, 1990. A91-14075.

The paper cites some of the previous work on microgravity combustion. It notes the safety factors dealing with material testing and selection and the fire-enhancing effect of ventilation. A scenario representing fire initiation by an experiment failure is given as an example. The paper illustrates the NASA approach for Space Station Freedom by discussing fire prevention, suppression, rescue, and restoration. For suppression, it mentions CO_2, N_2, and Halon 1301 without stating which will be the selected agent. Examples of fire protection based on research on aircraft, submarines, and industry are included. Reference 371 is cited extensively.

441. Schürmanns, Horst: Safety and Quality Assurance Experience From Spacelab Payloads. IAF Paper 90–559, 1990. A91-14078.

This paper briefly discusses safety on Spacelab, including toxicity and off-gassing. For fire, the only significant discussion is that of the practical flammability thresholds; that is, maximum material acceptability without further restriction (in terms of maximum quantity and minimum spacing).

442. Cantwell, Elizabeth R.; and Fernandez-Pello, A.C.: Smoldering Combustion Under Low Gravity Conditions. AIAA Paper 90–0648, 1990.

This is a companion paper to Reference 394, describing airplane (KC–135) tests of 10- by 10-cm polyurethane specimens with downward smoldering and upward airflows. The temperature increase as monitored by thermocouples indicates the position of the flame front. Limited data show that the 2g pull up maneuver in the airplane increases the smoldering rate. Microgravity decreases the rate. Gravity effects were diminished as air flows increased from 0.05 to 0.22 cm/s.

443. Babrauskas, V.; and Peacock, R.D.: Heat Release Rate—The Single Most Important Variable in Fire Hazard. FSJOD, vol. 18, no. 3, 1992, pp. 255–272.

The total fire regime is analyzed in terms of the steps (1) ignition, (2) flame spread, (3) heat release, and (4) smoke and toxin release. The paper reviews the literature on fire testing, including UL94 Bunsen burner and limiting oxygen index tests. The authors state that heat release is the most significant predictor of fire hazard, and they give examples of cone calorimeter measurements and scaling.

444. Asuncion C.; and Harkness, B.: Re-Evaluation of Smoke Detector Performance. Rockwell International Internal Letter, no. SE–TSAT–90–070, Oct. 31, 1990.

This report covers the results of a study of the shuttle air duct smoke detectors, two in return ducts and one downstream of cabin fans. Brunswick detectors (on the shuttle) have filters to screen out particles greater than 50 μm. The internal separator channels ~50 percent of particles less than 2 to 3 μm into the ionization chamber. A cabin air model is used to calculate smoke-generation levels (what concentration at the source is required to yield concentration levels of 2000 $\mu g/m^3$ or a rate of 22 $\mu g/m^3 s$ at the detectors). It also calculated time responses for scenarios of no flow, flow at the payload specialists’ station, and flow at the mission specialists' station. The author attempted verification using data from the STS–28 cable ignition incident, where 0.1 gm of Teflon was pyrolyzed for over 1.6 s. Smoke concentration at the detector was calculated as near 2000 $\mu g/m^3$ as compared with the maximum value of 180 $\mu g/m^3$ measured in the flight. Three factors for the discrepancy are suggested: (1) particles adhering to walls, (2) production of gases rather than particles, and (3) production of particles >50 μm.

445. Parsons, Michael L.: Fire Safety for Cargo Bays. Aero. Eng., vol. 10, 1990, pp. 19–22.
A system of multiple IR detectors for aircraft is described. Each detector uses a scanner designed to respond to a 5-in.-diameter fire at 20 ft. Two controllers monitor separate sets of sensors (odd and even). A thermal switch activates the sensor if a body temperature exceeds 85° C, in addition to IR signal response. The paper describes logic with a 15-s timer. If a sensor built-in test (BIT) fails, OR logic prevails. Otherwise, two sensors are required with AND logic for alarm.

446. Bahadori, M.Y.; Edelman, R.B.; Sotos, R.G.; and Stocker, D.P.: Measurement of Temperature in Microgravity Laminar Diffusion Flames. Presented at the 1990 Fall Technical Meeting of the Eastern Section, paper 43, The Combustion Institute, Orlando, FL, 1990.
Measurements of temperature of flame appearance are reported for propane-“air” diffusion flames at 1.0 atm, 21 and 19 %O_2, and 0.5 atm, 21 %O_2 in the NASA Lewis 5.18-second facility. The microgravity flames are always taller and wider and flicker-free, compared with normal-gravity flames. Open-tip flames in microgravity are attributed to sooting, radiation losses, thermophoresis, and so forth. The microgravity flames are redder and dimmer than the normal-gravity flames.

447. Apostolakis, G.: The Concept of Probability in Safety Assessments of Technological Systems. SCI, vol. 250, no. 4986, 1990, pp. 1359–1364.
This is a general discussion on subjective safety assessments and statistical observation. The structure of a probabilistic safety assessment involves four elements of structure: defining the problem, quantifying uncertainties, quantifying preferences, and making the decision. Examples for deterministic (defined by equations) and stochastic (probabilistic) models are given. Aerospace applications are noted briefly.

*448. Reuther, James J.: Definition of Experiments to Investigate Fire Suppressants in Microgravity. NASA CR–185295, 1990. (N91-14378).
This is a Battelle Lab review on the subject. A literature review seeks to answer questions on the nature of fires in space, the effects of low gravity on the suppression process, and the selection of fire suppression agents. A qualitative assessment using 11 attributes rates candidate agents. A ranking gives preference to CO_2 by local application, followed by water by local application, followed by N_2 inerting by atmospheric control. The author states that chemically-active agents are more effective than physical agents, both at low temperatures (smoldering perhaps), and very high temperatures. The report defines a simple space experiment using a carbon fuel.

449. Schmitz, Robert A.; and Newcomb, John F.: Microgravity Science and Application Program. AIAA Paper 91–0137, 1991.
The paper describes the process of developing space flight experiments. It also discusses the ground and flight facilities and gives examples of planned flight experiments, including the Solid Surface Combustion Experiment.

450. Bahadori, M. Yousef; Edelman, Raymond B.; Sotos, Raymond G.; and Stocker, Dennis P.: Radiation From Gas-Jet Diffusion Flames in Microgravity Environments. AIAA Paper 91–0719, 1991. (A91-19432).
This reports work conducted in the NASA Lewis 5.2-second drop tower, with the same apparatus as in Reference 446. Propane-air diffusion flames at 1 atm were observed with a wide-angle thermopile radiometer. For normal-gravity flames, radiation is low and uniform (low radiation loss). The microgravity radiation is 6 to 9 times larger and increases with time, perhaps not yet reaching steady state by 5 s. The authors suggest reasons such as enhanced sooting, larger flame size, and slow transport of hot combustion products. The paper notes the hazard of ignition of nearby materials in microgravity flames.

451. Haggard, John B.; Borowski, Brian A.; Dryer, Frederick L.; Choi, Mun Y.; Williams, Forman A.; and Card, J.M.: N-Decane Droplet Combustion in the NASA-Lewis 5 Second Zero-Gravity Facility—Results in Test Gas Environments Other Than Air. AIAA Paper 91–0720, 1991. (A91-19433).

Tests were conducted at 18, 21, 25, 35, and 50 $\%O_2$ concentrations and 0.5- and 1-atm pressures. Droplet sizes were from 1 to 1.7 mm in diameter. The average burning rate increases as O_2 content increases. The discrepancies between the 2.2 s and 5.2 s results (Refs. 378 and 396) are restated, with the explanation that relative droplet motion in the two facilities is different.

452. Baker, B.B.; and Kaiser, M.A.: Understanding What Happens in a Fire. Anal. Chem., vol. 63, no. 2, 1991, pp. A79–A83.

Normal-gravity experiments on toxicity of products from polytetrafluoroethylene (PTFE) explored the problem of why standard tests generate gaseous toxic products whereas these products are not measured in full-scale tests. The explanation is that lightly toxic particulates of fluorocarbons agglomerate and collect on wood, paper, and product aerosols in full-scale (real) fires.

453. Babrauskas, V.: Effective Measurement Techniques for Heat, Smoke, and Toxic Fire Gases. FSJOD, vol. 17, no. 1, 1991, pp. 13–26.

This is a brief review of the subject of fire measurements. For heat release, bench-scale studies require boundary conditions of incident heat flux and O_2 concentration (usually 21 percent). The rate of heat release, calculated from O_2 consumption, can be multiplied by the covered area to predict full-scale total heat release. Since fires are not uniform, measurements often refer to peak rate of heat release or the average from ignition to a stated time. For smoke, measurements require a specific extinction area to apply the Beer-Lambert law, $\sigma_f = \frac{kV}{m_f}$, where σ_f is the specific extinction area (m^2/kg), k is the measured extinction coefficient, V is the volume flow rate, and m_f is the specimen mass consumption. For toxicity measurements, the paper discusses the N-gas law and variables of species yield (kg/kg) and production (kg).

454. Nimitz, Jonathan S.; Tapscott, Robert E.; Skaggs, Stephanie R.; and Beeson, Harold D.: Alternative Training Agents, Phase I. Survey of Near-Term Candidate Fire Extinguishing Agents and Predicting Properties of Halocarbon Mixtures. AFESC/ESL–TR–90–39–VOL–2, 1991.

This is another University of New Mexico Engineering and Research Institute report on Halon replacements, concentrating on training agents to replace H–1211. The report lists candidate agents and mixtures and their properties, effectiveness, toxicity, availability, and cost.

455. Frank, Michael V.: Data Development and Data Analysis Within NASA: Examples From a Pilot Study. Probabilistic Safety Assessment and Management, George Apostolakis, ed., vol. 2, Elsevier, New York, NY, 1991, pp. 853–858.

The author, a safety specialist, describes the probabilistic risk assessment methods used by McDonnell Douglas for the shuttle. He cites data on the frequency of hardware failures and the evolution of phenomenological events. For the former, he notes the 1983 STS–9 experience of leakage and fires with hydrazine in two of the three of the auxiliary power units upon landing. This is an example of a common-cause failure (stress corrosion cracking of injection tubes). NASA claims that there are no repeat fractures, but the database shows that not to be true. Current challenges are in the creation of models to assess the applicability of test information to flight information, to assess the effectiveness of fixes, to translate expert knowledge, and to develop methods to treat incipient failures.

456. Brown, Alan S.: Fire Rule Changes Aircraft Materials Mix. Aero. Amer., vol. 29, no. 3, 1991, pp. 20–24.

This is a news article on the selection and testing of aircraft materials to meet the 1990 Federal Aviation Administration regulations of maximum heat release of 65 kW-min/m^2 for five minutes and 65 kW/m^2 peak heat release. It notes the promise of phenolic laminates and polyetheretherketone (PEEK), the problems with Kapton insulation, and burn-through-proof panels made of combinations of ceramics, phenolics, and fiberglass.

457. Nimitz, Jonathan S.; Tapscott, Robert E.; Skaggs, Stephanie R.; and Moore, Ted A.: Halocarbons as Halon Replacements. Volume 1: Technology Review and Initiation. AFESC/ESL–TR–90–38–VOL–1, 1991.

This report continues the work of Reference 454 with new data on candidate agents and empirical calculations of physical properties, ozone depletion potential, fire suppression, and so forth.

458. Flammability, Odor, Off-Gassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion. NASA–STD–6001 (previously NASA NHB 8060.1C), 1998.

This is a complete revision of the 1981 requirements (Ref. 155). Particularly important are Test 1-Upward Flame Propagation, Test 2-Heat and Visible Smoke Release, Test 3-Flash Point of Liquids, Test 4-Electrical Wire Insulation Flammability, and Test 18-Arc Tracking.

459. Knight, Douglas R.: The Medical Hazards of Flame-Suppressant Atmospheres. NSMRL–1167, 1991.

A general plot of paper strip flammability as a function of %O_2 and the partial pressure of O_2 (ppO_2) is presented to illustrate the human-support problem. Flame-suppressant life-supporting atmospheres are produced by (1) N_2 pressurization, which decreases the %O_2 at a constant ppO_2, (2) N_2 dilution, which decreases both ppO_2 and %O_2, (3) depressurization, which decreases the ppO_2 at constant %O_2, and (4) supplementation by addition of a foreign diluent (not discussed any further). Medical problems of (1) are barotrauma and N_2 narcosis, that of (2) is hypoxia, and those of (3) are hypoxia, barotrauma, and decompression sickness. Plots show the medical limits for the hazards in degrees of pressurization, depressurization, and hypoxia. For submarines, a procedure of N_2 dilution to 17 %O_2 (ppO_2 of 130 torr) followed by N_2 pressurization to 14.6 %O_2 at total pressure of 760 torr (ppO_2 of 130 torr).

460. Grayson, Gary; Sacksteder, Kurt R.; and T'ien, James S.: An Experimental Study of Low-Speed, Concurrent Flow Flame Spread Over a Thin Fuel. Presented at the Spring Technical Meeting of the Central States Section, Paper 3, The Combustion Institute, Nashville, TN, 1991, pp. 23–28.

This paper reports studies in the NASA Lewis 5.2-second drop tower with Kimwipes as fuels. A translation device moves the fuel sheets to achieve 2.5 and 5 cm/s concurrent velocities. The measured flame spread has a reasonable correlation with O_2 concentration .The flammability limit is near 13 %O_2 Flame spread is ~1 cm/s at 30 %O_2 and 5 cm/s concurrent flow and 0.5 cm/s at 30 %O_2,and 2.5 cm/s flow. The comparative flammability and flame spread at opposed flow are less (Ref. 348). Flame tip spread and flame length appeared to increase with %O_2, but results were quite unsteady.

*461. Friedman, Robert; and Dietrich, Daniel L.: Fire Suppression in Human-Crew Spacecraft. NASA TM–104334, 1991. (N91-21182).

This review paper discusses the history, present methods, and proposed methods for fire extinguishment in spacecraft. Unpublished results show that appreciably less Halon is required in microgravity for small-scale paper extinguishment, compared with that required in normal gravity. The paper illustrates the effect of CO_2 and Halon 1301 on extinction boundaries. It also discusses research needs for the Space Station.

462. Olson, S.L.: Mechanisms of Microgravity Flame Spread Over a Thin Solid Fuel: Oxygen and Opposed Flow Effects. Combust. Sci. Technol., vol. 76, 1991, pp. 233–249.

This paper is a summary of past work on the flammability of thin paper (Kimwipes) in the NASA Lewis 2.2-second drop tower with an opposed flow velocity of 0.35 cm/s and atmospheres of 18, 21, and 30 %O_2 in N_2. The author extends the flame-spread rate correlations to normal-gravity results, using a normal-gravity characteristic velocity of 60 cm/s. A map of controlling mechanisms (%O_2 vs. velocity) indicates that O_2 transport limits flame spread at low velocity (zero gravity), but residence time limits flame spread at high velocity. At the 30 %O_2 condition, flame spread is insensitive to velocity over a wide range of velocities. Excellent color pictures are included.

463. Kaplan, Stan: Risk Assessment and Risk Management—Basic Concepts and Terminology. Risk Management: Expanding Horizons in Nuclear Power and Other Industries, Ronald A. Knief et al., eds., Hemisphere Publishing Corp., New York, NY, 1991, pp. 11–27.

This paper gives the background for the probabilistic risk assessment (PRA) method. It presents 14 points for a PRA, performed to aid in decisionmaking. A quantitative definition of risk and reliability stems from the set of: (1) scenario (description of what can go wrong), (2) likelihood, and (3) damage (consequences). Damage can be multiple and time dependent. The computational process proceeds backward; that is, the evidence starts from the damage experience, calculations, and judgments to establish the probabilities and risk models (set of scenarios). In scenario structuring, the author describes methods using initiating events and branch points plus pinch points. Initiating events may be in the middle (an example is nuclear power) or at the end (in rocket booster failures, since little is gained in recovery and risk assessment is concentrated on "upstream" prevention.) The author notes that risk in isolation is never "acceptable"; instead the risk assessment seeks to optimize the set of cost, benefit, and risk.

464. Garrick, B. John: The Approach to Risk Analysis in Three Industries: Nuclear Power, Space System, and Chemical Process. Risk Management: Expanding Horizons in Nuclear Power and Other Industries, Ronald A. Knief, et al., eds., Hemisphere Publishing Corp., New York, NY, 1991, pp. 173–181. (A92-51438).

This is a discussion on the similarities and differences of safety approaches for the above-mentioned industries. NASA safety is characterized as thorough but lacking an integrative and systems engineering process. Policies supporting quantitative risk management (NASA Management Instruction NMI 8070.4) are cited. The basis of space safety is in failure modes and effects analysis (FMEA), hazard analysis, and use of a critical items list (CIL). FMEA is a hardware failure prediction. Hazard analysis covers software, environment, crew, and procedure anomalies. CIL codifies the enormous amount of information generated by the two other analyses. The lack of a probabilistic risk assessment method in NASA risk analyses is attributed to bad experiences with Apollo, but the author recommends the introduction of these approaches for the improvement of spacecraft safety.

465. Sacksteder, Kurt R.: The Implications of Experimentally Controlled Gravitational Accelerations for Combustion Science. Twenty-Third International Symposium on Combustion. The Combustion Institute, Pittsburgh, PA, 1990, p. 115.

This is a review on the background and general results of microgravity work on premixed gases, gas-jet diffusion flames, droplet combustion, particle clouds, liquid pools, smoldering, and solid fuels. The review notes fire safety applications briefly, citing the prevention by material selection and use of atmospheres that do not support a flame.

466. Beltran, Michael R.; and Simo, Constance: Development of Fuel Neutralizing Agents to Prevent Flashback on Aircraft Fires. AFESC/ESL–TR–90–60, 1991.

The report discusses extinguishment processes with emphasis on aircraft-fuel pool fires. It describes experiments on the use of aqueous film-forming foam to combat aircraft crash fires, with modifications to seal the foam or emulsify the mixture, to prevent reignition.

467. Glassman, Irvin: Combustion Fundamentals of Low Volatility Materials in Oxygen Enriched Atmospheres. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, Joel M. Stoltzfus and Kenneth McIlroy, eds., Fifth vol., ASTM Special Technical Publication 1111, 1991, pp. 7–25.

The paper discusses metal combustion, with vapor phase and heterogeneous burning. It also reviews solid surface ignition, mass burning rate, and flame spreading rate for thin and thick materials.

468. Hirsch, D.B.; Bunker, R.L.; and Janoff, Dwight: The Effects of Oxygen Concentration Diluents and Pressure on Ignition and Flame-Spread Rates of Non-Metals: A Review Paper. Risk Management: Expanding Horizons in Nuclear Power and Other Industries. Ronald A. Knief, et al., eds., Hemisphere Publishing Corp., New York, NY, 1991, pp. 179–190.

The paper is a brief review, presenting equations and tables on ignition and flame spread for common materials, along with the effects of the atmospheres on fires.

469. Steinberg, Theodore A.; and Benz, Frank J.: Iron Combustion in Microgravity. Risk Management: Expanding Horizons in Nuclear Power and Other Industries, Ronald A. Knief, et al., eds., Hemisphere Publishing Corp., New York, NY, 1991, pp. 298–312.

Combustion of 3-mm-diameter and smaller Fe rods in the NASA Lewis Research Center 2.2-sec drop tower in 100 %O_2 at 1.7 to 8.6 MPa showed that metal regression increases as pressure increases and diameter decreases. The same flame behavior occurs in normal gravity, and, in general, Fe burns as well in zero gravity as in normal gravity.

470. Altenkirch, Robert A.; Bhattacharjee, Subrata; and Olson, Sandra L.: Opposed Flow Flame Spread in Normal, Enhanced and Reduced Gravity. Proceedings of the AIAA/IKI Microgravity Symposium, AIAA, Washington, DC, 1991, pp. 305–313.

The review is generally a collection of normal-gravity and microgravity results already presented elsewhere. It covers both experiments and models. Cited in paper, however, are the first results of the Solid Surface Combustion Experiment, where the quiescent flame spread rate at 50 %O_2 and 1.5 atm is 0.44 cm/s, a rate reasonably comparable to the computed value that includes radiation (radiation-controlled spread rate plot).

*471. Ohlemiller, T.J.; and Villa, K.M.: Material Flammability Test Assessment for Space Station Freedom. NISTIR 4591 (NASA CR–187115), 1991. N91-25165.

Selected spacecraft samples of cotton toweling, Kydex, Lexan, and Pyrell foam were tested for flammability in the NASA NHB8060.1 Upward Flammability apparatus and in the National Institute of Standards and Technology (NIST) lateral ignition and flame-spread tester for ignitability (ignition delay) and lateral flame spread. The materials were tested for heat release rate in the cone calorimeter. Only cotton toweling fails the NASA test, but all materials show some level of flammability in the NIST tests. For example, Lexan passed the NASA test and had a high minimum flux for ignition and flame spread, yet it had the highest rate of heat release. The NASA test was then modified to provide up to 15 kW/m^2 heat flux, and the sample material variety was enlarged to include epoxy board and Nomex. The authors characterized the materials by a minimum lateral flux (NIST) and minimum upward flux. Attempts to fit data to models were generally unsuccessful. The authors' recommendation for heated tests requires estimation of self heating. Microgravity predictions require heat flux and airflow parameters. It is also noted that for spacecraft, testing in a minimum O_2 atmosphere (say 19 percent) establishes the worst case for toxicity prediction.

472. Tsuchiya, Y.; and Mathieu, J.F.: Measuring Degrees of Combustibility Using an OSU Apparatus and Oxygen-Depletion Principle. FSJOD, vol. 17, no. 4, 1991, pp. 291–299.

The author continues work reported in Reference 162A. For Canadian aircraft standards, the authors modified the Ohio State University (OSU) apparatus, adding O_2 depletion to measure heat release. The investigators tested four materials that have heat releases ranging from 7.8 to 295 kW/m^2. Control of air flow gives greater reproducibility than that of the cone calorimeter. CO release, which complicates the O_2-depletion method, is small for the selected samples.

*473. Smith, Richard L.; and Kashiwagi, Takaski: Expert Systems Applied to Spacecraft Fire Safety. NASA CR–182266, 1989.

This is an exact reprint of Reference 359.

474. McCarthy, Kristin B.; and Green, James A.: The Effect of Reduced Cabin Pressure on the Crew and the Life Support System. SAE Technical Paper Series, no. 911331, SAE International, Warrendale, PA, 1991.

This paper by Rockwell authors presents a plot of safe cabin environments for human performance, as total pressure versus volume% O_2. The Skylab experience at 35 kPa total pressure revealed problems caused by rapid water evaporation and poor voice projection. To go from 101 kPa to a 30 kPa suit, at least 4 hr of prebreathing is required. The authors suggest a total pressure of 55 kPa, which reduces the mass of stores, the leakage potential, and prebreathing time (actually eliminated). However, flammability is increased if the partial pressure of O_2 remains constant (increasing O_2 concentration). The paper has some misinformation on flammability, and the only previous studies cited are those of Kimzey.

475. Bacskay, Allen S.; and DaLee, Robert C.: Space Station Freedom ECLSS Design Configuration: A Post Restructure Update. SAE Technical Paper Series, no. 911414, SAE International, Warrendale, PA, 1991.

This paper by NASA Marshall Space Flight Center and McDonnell Douglas-Huntsville authors describes Space Station Freedom changes after the 1990 restructuring. Initially, the Space Station will be occupied only when attached to the shuttle. Water will come from the shuttle fuel cells. CO_2 will be vented and O_2 replenished from stores. For the restructuring, a single water system for potable and hygiene loops will be used. The “race-track” configuration of modules is out. A table of requirements shows total pressure limits of 99.9 to 102.7 kPa, O_2 partial pressures of 19.5 to 23.1 kPa operational and 15.8 to 23.7 kPa emergency, CO_2 partial pressures of 400 Pa maximum operational and 1600 maximum emergency, and ventilation flows of 7.6 to 20.3 cm/s operational and 5.1 to 102 cm/s emergency. The fire detection and suppression subsystem is described briefly. CO_2 is the baseline suppressant for the U.S. and international modules. Extinguishant tank capacity is 66 liters for the modules and 14 liters for the nodes and airlock. CO_2 concentration for suppression of fires is to be 50 percent. The report also notes the photoelectric scattering and infrared/ultraviolet (IR/UV) detectors. (Many of these specifications are now obsolete.) The paper recognizes certain unresolved issues: notably, stored energy of high pressure CO_2 and single failure tolerance of the suppression system.

476. Link, D.E., Jr.; and Angeli, J.W.: A Gaseous Trace Contaminant Control System for the Space Station Freedom Environmental Control and Life Support System. SAE Technical Paper Series, no. 911452, SAE International, Warrendale, PA, 1991.

This paper by Boeing-Huntsville and Lockheed-Sunnyvale authors describe the trace contaminant control system for the Space Station Freedom in terms of block diagrams and physical sketches. The paper gives operating conditions and performance of the charcoal bed and catalytic oxidizer. It gives no direct fire applications, but removal of CO has significance for postfire cleanup.

477. Hienerwadel, Karl-Otto: Columbus Cabin Ventilation Concept—First Test Results. SAE Technical Paper Series, no. 911466, SAE International, Warrendale, PA, 1991.

Ground tests of a short mockup of the Columbus module and show that average ventilation velocities of 8 to 20 cm/s are achieved by slit diffusers with recirculation fans. With a slight degradation of uniformity within the 2.2 x 2.2 -m module cross section, the system may operate without the fans.

478. Gedke, Jeff P.; Mohamadinejad, Habib; and Gard, Melissa Y.: Preliminary Analysis of CO_2 Fire Suppressant Distribution System for Space Station Freedom. SAE Technical Paper Series, no. 911473, SAE International, Warrendale, PA, 1991.

Analyses by McConnell Douglas-Huntsville and NASA Marshall modeled the discharge of a CO_2 tank from a 69-liter supply. Isentropic-expansion calculations show that the tank must be initially at 4650 kPa and 21 °C (about a 10 °C superheat) in order to assure gaseous flow in the discharge lines. In this case, 1.81 kg of CO_2 is released in 4.2 s before two-phase condensation occurs. The paper also has flow-line analyses and a discussion of problem areas.

479. Limero, Thomas; James, John T.; Cromer, Raymond; and Beck, Steven: A Combustion Products Analyzer for Contingency Use During Thermodegradation Events on Spacecraft. SAE Technical Paper Series 911479, SAE International, Warrendale, PA, 1991.

The paper has a documented description of the incipient-fire events of STS–6, STS–28, and STS–35. It describes the developmental combustion products analyzer (CPA) made by Exidyne that uses four electrochemical sensors for HF and/or COF_2, HCl, HCN, and CO. The sensing range for CO is 0 to 999 ppm; for the others it is 0 to 99.9 ppm. Tests show some interference for HF by HCl and HCN and a strong interference for CO by atmospheric H_2. A CPA has been flown on all missions since STS–41 (October 1990). Data from selected tests are shown. The model is being adapted for Space Station operation and to address problems of calibration and H_2 interference.

480. LeVesque, Raymond J., II, and Lauger, John B.: Space Station Freedom Resource Nodes Status: First Quarter 1991. SAE Technical Paper 911595, 1991.

This is a review by McDonnell Douglas authors of the resource node construction and outfitting. It includes a brief mention of fire detection and suppression. A small fan constantly circulates air through each smoke detector.

481. Anon.: Space Platforms Focused Program—Program Plan. NASA Integrated Technology Plan, July 1991.

This document describes a portion of an integrated technology plan on space technology. The recommendation for a close-cycle environmental control and life support system includes the development of fire-control technologies through fundamental understanding and validating technologies. Introductory material describes studies of fire safety. The program description includes tasks and schedules for risk assessment, centralized detection, suppression, and atmospheric monitoring.

482. James, John T.: Toxicological Assessment of the Noxious Odors Produced by the Orbiter Refrigerator/Freezer (OR/F) During the STS–40 Mission. Memo to NASA Johnson Space Center (JSC) Division of Space and Life Sciences, August 13, 1991.

This document is a summary of analyses following the STS–40 thermodegradation event. Evidence of potential harm came from odors, on-orbit samples, postflight investigation, and subsequent experiments on Delrin. Recommendations include better thermal protection and modeling of contaminant-removal techniques.

483. Dinenno, Philip J.; and Forssell, Eric: Perflourocarbons as Fire-Suppression Agents. NASA Tech Briefs (KSC–11573), vol. 17, issue 6, 1993.

Hughes Associates researchers investigated C_2F_6, C_3F_8, and C_4F_{10} as Halon 1301 alternatives. Retrofit is no problem. A background section quotes Reference 107 for Halon 1301, CO_2, and N_2 requirements for extinguishment of various fuels. The authors cite cup-burner tests for the selected extinguishants and mechanisms for physical and chemical suppression actions. Calculations of flame temperature change versus oxygen concentration demonstrate the strong chemical action of the perfluorocarbons—quantities are much less than those calculated for pure physical suppression. Agent requirements for C_3F_8 and C_4F_{10} are 1.5 to 2.0 times greater than those of Halon 1301 per volume and 2.2 to 2.4 times per mass. C_2F_6 is not recommended because it can only be stored as a high-pressure gas. The research does not address thermal decomposition and toxicology.

484. Cooke, R.; Frisch, B.; and Saleem, A.: Why Quantify Risk? Proceedings of European Space Agency (ESA) Symposium on Space Product Assurance for Europe in the 1990s, ESA SP–316, 1991. N92-18637.

The authors, from Netherlands and Austria, discuss numbers for probabilistic risk acceptance criteria and probabilistic risk safety goals. They define risk measures in terms of deaths/million, and in loss of life expectancy. Other risk criteria are a yearly probability of death, and an activity-specific hourly mortality rate. The latter is most useful for space activities, and it furnishes a safety goal comparable to that of test pilots.

485. Nagata, Harunori; Ishii, Kazuhiro; Tomioka, Sadatake; Kono, Michikata; and Sato, Jun'ichi: Ignition Delay of Premixed Gases Under Microgravity Conditions. Microgravity Fluid Mechanics, Springer-Verlag, New York, NY, 1991, pp. 355–362.

This is drop tower work in an unstated facility in Japan. Premixed gases are ignited by a hot wire, with ignition temperature determined by the output of a photodiode. Stoichiometric CH_4-O_2 ignition by a hot wire (1250 K) gives the same ignition delay in microgravity as in normal gravity. As the wire temperature decreases (to 1190 K), however, the microgravity ignition delay becomes shorter than in normal gravity. This is thought to be due to convection cooling. However, in CH_4-air mixtures, the ignition delay in microgravity and normal gravity are nearly identical at all wire temperatures.

486. Steinberg, T.; Morelli, J.; Linley, L.; and Benz, F.: Validation of NHB 8060.1C, Test 18 Arc Tracking. TR–651–001, Sept. 30, 1991.

The arc tracking tests compared a known arc tracker, Kapton insulation, a known resistive insulation, polytetrafluoroethylene (PTFE), and an unknown, ethylene tetrafluoroethylene (ETFE). Results are consistent with expectations. The ETFE did arc track but not as readily as Kapton. Test performance was not influenced by varying the depth of insertion of the insulations into graphite or by varying the atmospheric O_2.concentration from 21 to 30 percent.

*487. Friedman, R.: Fire Safety Practices in Human-Crew Spacecraft. J. Appl. Fire Sci., vol. 2, no. 3, 1992, pp. 243–259.

This is essentially the same as Reference 461, with errors corrected and modest updating.

488. Jones, Cherie; Simpson, Kaia; Vickers, Brian; Ledoux, Paul; and Babel, Hank: Material Considerations for Habitable Areas of Manned Spacecraft. Proceedings of the International Conference on Spacecraft Structures and Mechanical Testing, ESA SP–321, 1991, pp. 37–42. N92-23785.

The paper discusses several problem areas for Space Station Freedom material selection. For flammability, test-result statistics show that there is a modest decrease in the number of materials and components acceptable at 30 %O_2. Specifically, at 20.9 %O_2, 766 items passed out of a total tested of 1121, and at 30 %O_2, 654 out of 1142 passed. Of the items acceptable at 30 %O_2, only 123 passed out of 244 at 33 %O_2. The authors note that minor manufacturing changes affect the test results, but batch testing is prohibitive. Other materials topics are outgassing (fluorocarbons are fire resistant but yield toxic problems when overheated), particulates, and fungus. The report comments on the flammability of Velcro patches, found in all space modules. The requirement for Velcro is 25 cm^2 maximum size with 5-cm minimum spacing on all sides.

489. Salva, J.J.; and Juste, G.L.: Gravitational Effects on Flame Spreading Over Thin Cylindrical Fuel Samples. Microgravity Sci. Technol., vol. 4, no. 3, 1991, pp. 191–198.

This paper describes testing by Spanish researchers supported by the European Space Agency. The flammability of several poly(methyl methacrylate) (PMMA) tubes and rods in 35 %O_2 (to accelerate burning) was determined in the NASA KC–135 airplane. Results show a higher flame spread for 10^{-2}g than for normal gravity. Flame-spread rate decreases as diameter or thickness increases.

490. Olson, S.L.: Fuel Thickness Effects on Flame Spread and Extinction Limits in Low Gravity as Compared to Normal Gravity. Paper presented at the 1991 Fall Technical Meeting of the Eastern Section, The Combustion Institute, Orlando, FL, 1991.

This paper is a summary of microgravity combustion tests of thin (paper) and thick (poly(methyl methacrylate), PMMA) fuels. The paper presents plots of extinction limits and transition boundaries (change in flame-spread rates) as functions of O_2 concentration and opposed air-flow velocity). The extinction limits are due to blow off (high velocities) and quench (low, microgravity velocities). The higher-%O_2 region between the extinction and transition boundaries represent residence-time-limited spread at high velocities and O_2-limited spread at low velocities. The inner region—inside the transition boundary—is conduction limited. The author speculates, without experimental verification, that the fuel boundaries (extinction and transition) for thick fuels are wider than for thin fuels in normal gravity (high velocities), but the boundaries for thick fuels are narrower than for thin fuels in microgravity (low velocities).

491. Harris, Leonard A.; Reck, Gregory M.; Ambrus, Judith H.; and Hemmerly, Rodney A.: NASA's In-Space Technology Experiments Program—Status and Plans. IAF Paper 91–001, 1991. A92-12426.

This paper has tabular reviews of all past technology and the then-current experiments in space. Eight technology categories are shown. In the technology category of "In-Space Systems," the Risk-Based Fire Safety experiment is named, to be utilized on the Space Station Freedom in 1998.

492. Friedman, Robert: Fires and Their Atmospheric Products in Spacecraft. Environmental Health Issues in Space. A Conference organized by the Center for Environmental Health at the University of Rochester, Rochester, NY, 1991.

This is a brief abstract on fire effects, fire detection signature, and postfire cleanup.

493. Fendell, Francis: Personal communication to R. Friedman from TRW Space and Technology Group, Nov. 3, 1991.
The letter comments on probabilistic risk analyses (PRAs). The resistance to their application is based on (1) they are not an optimal use of limited resources, and (2) they appear to profess knowledge they do not have. Expertise in both PRA and fire science does not seem to coexist in the same unit or individual. The author stresses the need for good-scaling experiments (large and small) and modeling to support the NASA fire-risk assessments.

494. Rodney, George A.: Rebuilding a Safety Culture. Proceedings of the 44th International Air Safety Seminar, Flight Safety Foundation Proceedings, The Foundation, Arlington, VA, 1992. A92-38159.
This paper from the NASA Headquarters Safety Office briefly reviews the Apollo and Challenger experience and current safety goals. It comments on future directions for reliance on probabilistic risk and failure analyses and human error avoidance. Fire is not specifically cited.

*495. Friedman, Robert; Sacksteder, Kurt R.; and Urban, David: Risks, Designs, and Research for Fire Safety in Spacecraft. NASA TM–105317, 1991. N92-13581.
This review paper starts with risks and strategies, noting the University of California, Los Angeles, risk-analysis approach. Then it surveys the studies in ground-based and flight microgravity combustion. The bulk of the paper covers fire prevention (materials, atmospheres, and problems), fire detection (current, future, and problems), fire extinguishment (current, future, and problems), and fire management (manual vs. automated responses). Concluding remarks point to needs for research.

496. Humphries, W.R.; Mitchell, K.; Reuter, J.; Carrasquillo, R.; and Beverly, B.: Life Support and Internal Thermal Control System Design for the Space Station Freedom. Proceedings of the 4th European Symposium on Space Environmental Control Systems, ESA SP–324, 1991, pp. 23–37.
The paper first reviews the pre-restructure environmental control and life support system (from Ref. 422). After the restructuring to smaller modules, the system closed loops are opened and simplified. The restructuring does not change the basic fire detection and suppression subsystem. The new designs remove the thermal sensors in racks and retain the photoelectric duct detectors and end cone flame detectors as well as the portable and fixed CO_2 systems. The restructuring deletes the European Space Agency Halon 1301 and N_2 (for the hyperbaric chamber) systems. All suppression systems are now based on flooding to 50 %CO_2. Rack overpressurization is avoided by avionics return flapper valves. As a failure mode for extinguishment, intermodule ventilation flow shuts down, hatches close, and the module vents. Unresolved issues are the stored energy of high pressure CO_2 and single failure tolerance for extinguishment.

497. Veneri, Ruggero; Behrens, Burkhand; Leiseifer, Hans Peter; and Petrivelli, Aldo: The Thermal/Environmental System Design of the Columbus Pressurized Modules. Proceedings of the 4th European Symposium on Space Environmental Control Systems, ESA SP–324, 1991, pp. 39–44.
This paper describes the environmental control and life support system and fire detection and suppression functions for the European Space Agency Attached Pressurized Module (APM) for the Space Station final assembly. For the APM, optical smoke sensors are in the module and the rack levels, and the extinguishing agent is CO_2 in 29-kg quantities for 30 to 50 percent flooding (four tanks). For the additional man-tended free flyer, the detectors are the same as in the APM, located in the ceiling and laterals, but the suppressant is N_2 in 41-kg quantities to reduce O_2 to less than 15 percent. Both vehicles can be vented in less than 2 hr.

498. Suzuki, T.; Otsuki, F.; Suzuki, F.; Shibutani, S.; Hattori, A.; Sasayama, H.; Inove, M.; and Sugai, W.: Preliminary Design of JEM ECLSS and TCS. Proceedings of the 4th European Symposium on Space Environmental Control Systems, ESA SP–324, 1991, pp. 45–50.

The description of the Japanese Experiment Module Environmental Control and Life Support System (JEM ECLSS) has a brief section on the Fire Detection and Suppression Subsystem. It is noted that suppression uses CO_2. A dedicated CO_2-removal system for contingency use with a regenerative solid amine system will reduce the partial pressure of a release of 1.2 kg of CO_2 to 1 kPa (1 percent) within 12 hr.

499. Klingele, S.; and Tan, G.: Trace Gas Monitoring for Manned Space Missions. Proceedings of the 4th European Symposium on Space Environmental Control Systems, ESA SP–324, 1991, pp. 323–328.

This is a general assessment of trace gas sources and monitoring strategies for various space missions, compared with corresponding systems in buildings and submarines. The paper notes the problems of CO and CO_2 generation from fires. One of the basic assumptions is that trace gas monitoring is not to be used to detect malfunctions (such as for fire detection).

500. Babrauskas, Vytenis; Levin, Barbara C.; Gann, Richard G.; Paabo, Maya; Harris, Richard H., Jr.; Peacock, Richard D.; and Yusa, Shyuitsu: Toxic Potency Measurement for Fire Hazard Analysis. NIST Special Publication (Fire Tech., vol. 28, no. 2, 1992, pp. 163−167), no. 827, 1991.

This is a literature survey and description of models and experimental (rodent) methods for determining toxic potency (LC_{50}) particularly from pre- and postflashover flaming fires. The N-gas model for mixtures of CO (with CO_2 correction), HCN, O_2 depletion, HCl, and HBr is advocated to get a fractional effective dose (FED). A 50-percent lethality level corresponds about to FED = 1.1. The report has a discussion of CO and the CO/CO_2 ratio and experimental data on mass loss and gas yields for Douglas fir, polyurethane foam, polyvinyl chloride (PVC), vinyl, and other fuels.

501. Babrauskas, Vytenis; Peacock, Richard D.; Braun, Emil; Bukowski, Richard W.; and Jones, Walter W.: Fire Performance of Wire and Cable: Reaction-to-Fire Tests—A Critical Review of the Existing Methods and of New Concepts. NIST Tech Note 1291, 1991.

This is a comprehensive letter review and critique of various U.S. and foreign tests and standards, including bench-scale and full-scale methods, with discussion of ignition, heat release, toxic gas production, modeling, and so forth.

501A. Kimzey, J.H.: Venting a Spacecraft During or After a Fire. McDonnell Douglas Space Station Co. Tech. Note, Preliminary, Dec. 4, 1991.

After a generalized discussion of fire in spacecraft, the document makes several points about venting. The author estimates that extinguishment should occur at a total pressure of 15 to 20 kPa, although if O_2 is released first, pressure may have to drop to <1 kPa. Intermediate venting to around 80 kPa may be sufficient. Repressurizing should go to proof pressure of 150 kPa. The note has recommendations for research.

502. Mulholland, G.; Janssens, M.; Yusa, S.; Twilley, W.; and Babrauskas, V.: The Effect of Oxygen Concentration of CO and Smoke Produced by Flames. Geoffrey Cox and Brian Langford, eds., Fire Safety Science: Proceedings of the Third International Symposium, Elsevier Applied Science, New York, NY, 1991, pp. 585–594.

A cone calorimeter was modified with an enclosure to control the atmosphere. Tests were conducted with CH_4, C_3H_8, and polymer fuels as well as $\%O_2$ reduced to near 14 to determine CO and smoke. The emissions of CO increased by factor of about 2 as $\%O_2$ concentration dropped from 21 to 14. Also, for methane the CO yield increased when CO_2 dilution is substituted for N_2 dilution. The authors derived correlations for CO and smoke yield as a function of ΔO_2.

*503. Weiland, Karen J.: Intensified Array Camera Imaging of Solid Surface Combustion Aboard the NASA Learjet. AIAA Paper 92–0240 (NASA TM–105361), 1992. A92-25702.

The Xybion intensive charge-coupled camera was used for Learjet airplane tests with the Solid Surface Combustion Experiment (SSCE) apparatus, burning filter paper and Kimwipes downward. The camera is superior for flame position measurements, corresponding to an ASA speed of 100 times that of an optical camera. Flame-spread data at 21 and 18 %O_2 are consistent with those of opposed and concurrent flow drop tower tests, implying that airplane environment induces velocities.

504. Beyler, Craig: Unified Model of Fire Suppression. J. Fire Prot. Engr., vol. 4, no. 1, 1992, pp. 5–16.

The article proposes a “fire-point” equation, which is an energy balance at the fuel surface at extinction, with terms of oxygen mass fraction, external heating, and heat losses. The fire-point equation can be interpreted for cases of water extinguishment by evaporation, N_2 or CO_2 extinguishment by oxygen depletion, and Halon 1301 or dry powder extinguishment by modification of flame temperature or energy release. Calculated plots for external radiant flux defining an extinction boundary for poly(methyl methacrylate) (PMMA) versus water application, N_2 mass fraction, CO_2 mass fraction, Halon 1301 mass fraction, and so forth, give good agreement with independent data. The external heat flux is important. For PMMA, for example, the limiting O_2 mass fraction for extinguishment upon dilution decreases as heat flux increases, but for O_2 mass fractions below 0.138, no flame can be sustained at any flux.

505. Meacham, Brian J.; and Motevalli, Vahid: Characterization of Smoke From Smoldering Combustion for the Evaluation of Light Scattering Type Smoke Detection Response. J. Fire Prot. Engr., vol. 4, no. 1, 1992, pp. 17–28.

The article notes that smoke particles are usually well within the Mie range where particle diameter d is between 0.1λ and 4.0λ (see also Ref. 124). The article presents results of experiments conducted in a smoke chamber, with wood, paper, rubber, and cotton fuels heated on a hot plate to smolder. Various light-scattering detectors were evaluated. The highest intensity was at 20°, and at that angle, intensity is nearly insensitive to fuel type. The discussion concludes that the intensity at a 20° angle follows the increase in particle concentration. Detector actuation times are of the order of 130 to 280 s.

506. Rucker, Michelle A.: Specimen Holder for Flammability Tests. NASA Tech Briefs, MSC–21798, vol. 16, no. 2, 1992, p. 73.

This is a patent application from NASA Johnson White Sands Test Facility for a spring-loaded clamp for the NASA upward flammability test to hold the sample securely regardless of shrinkage or expansion during the test.

507. Sircar, Subhasish; and Dees, Jesse: Evaluation of Fire Extinguishants for Space Station Freedom, NASA JSC WSTF TR–650–001, March 5, 1992.

The tests, conducted by Lockheed investigators at NASA White Sands Test Facility, established baseline flammability for a polyester-cotton blend, nylon Velcro, and Pyrell foam in an 8.2-liter NASA NHB 8060.1 upward flammability apparatus. The 8.2-liter assembly was then placed within a 1400-liter chamber holding an atmosphere diluted with Halon 1301, N_2, CO, or He. The inner chamber was moved by air pistons to expose the sample to the quiescent outer-chamber atmosphere to investigate extinguishment. Baseline tests indicated that the worst-condition flame spreads were at 24 %O_2 and a high pressure of 600 kPa (a greater flammabiliity threat than at 30 %O_2 and 70 kPa). Minimum extinguishant concentrations for suppression increased in all cases with combustion atmospheres containing from 16 to 30 %O_2 and also with increasing pressure. Halon 1301 required the least agent concentration for suppression, followed by CO_2, and then He and N_2 were approximately equal. Velcro required more extinguishant than Pyrell and the polyester-cotton blend. The tests are somewhat crude since the rate of agent application was not considered (tests were quiescent); also CO_2, He, and N_2 concentrations varied in bulk increments of 5 percent, and Halon 1301 in 1 percent.

507A. Leiseifer, H.P.; and Sarri, G.: Study of Depressurization as Fire Suppressant. ESTEC/QMO/PG 175, March 3, 1992.

The report describes extinguishment tests by evacuating a 250-liter chamber with burning polyethylene and Delrin (polyoxymethylene) in normal gravity. Evacuation time was of the order of 2.5 min, compared with an estimate of 9 min for the Eueopean Space Agency space module Columbus. Internal air flow decreases from 2.5 to <0.3 cm/s as the pressure decreased. The burning rates also decrease as pressure decreased. Polyethylene extinguishes below 20 percent of the original pressure; Delrin (which has fuel-bound oxygen) extinguishes below 10 percent of the original pressure. Although the work is at normal gravity, it offers the interesting observation that extinguishment requires a lower final pressure for the dynamic than for a static evacuation.

*508. Steinberg, Theodore A.; Wilson, Donald B.; and Benz, Frank: The Burning of Metals and Alloys in Microgravity. Comb. Flame, vol. 88, nos. 3 and 4, 1992, pp. 309–320.

This article continues the work of Reference 469, describing 2.2-second microgravity tests of metals burning in 100 %O_2 at 0.1 to 6.9 MPa. Test metals were Fe, 316 SS, Al, and Ti. Ignition was by a chemical promoter, and combustion proceeded upward. The regression rate of the melting interface increases with increasing pressure and decreasing rod diameter. This is true in both normal gravity and microgravity, but the rate is greater (2 to 3 times for a 1-mm diameter rod) in microgravity. The molten ball remains attached to the rod in microgravity, but it seems to precess.

509. NASA Johnson Space Center Space Station Systems Division: Space Station Freedom Contingency Operation Scenarios. Unpublished, Mar. 1992.

This is an update of the scenario description in Reference 404, to accommodate the restructuring and assembly sequences. Fire is one of seven hazard scenarios. Assumptions are there is an atmosphere of 27 %O_2 at 70 kPa total pressure, all alarms are valid, and all fires produce toxins. Recommendations include the continuation of those from the earlier recommendations (Ref. 404) that (1) crew access is needed to manually disperse CO_2 and to shut off power and airflow, (2) a uniquely identifiable fire alarm is needed, (3) intermodule ventilation is automatically terminated upon alarm, (4) portable breathing apparatuses charged with 100 %O_2 are available, (5) the fire detection and suppression (FDS) subsystem is independent of the data monitoring system, (6) commonality of the FDS subsystem is assured, (7) no materials are present that can burn in a vacuum, (8) a separate emergency power circuit is maintained, and (9) the hatches to untended nodes are to be closed. Further recommendations are made on areas including displays and alarms for toxic gas monitoring.

510. NASA Johnson Space Center Medical Sciences Division: Fire in the Space Station Hyperbaric Airlock Prevention and Response. Unpublished letter, Apr. 16, 1992.

This letter reviews the problems of fire suppression in the Hyperbaric Airlock at 2.8 atm. The use of CO_2 is unacceptable because of toxicity. Instead, the specialists recommend N_2. The letter states that toxic NO_x products are not likely, and N_2 has advantages in logistics and deployment. Water condensation may make the extinguishing stream visible. The letter also urges the use of the compound-specific analyzer for detection and more microgravity research on extinguishment.

511. European Space Research and Technology Centre Materials and Processes Division: Flammability Testing for the Screening of Space Materials. ESA PSS–01–721, issue 2, Apr. 1992. N93-21195.

This document contains the five test methods for acceptance of space materials. Basically, material for normal-pressure operations must pass Test 1—Critical Oxygen Index (based on ASTM D-2863)—at an O_2 concentration 10 percent higher than the worst-case O_2 concentration Wire insulation for normal-pressure operations must pass Test 2—Electrical Wire Insulation Flammability. Materials for other pressures must pass Test 3—Upward Flammability based on NHB 8060.1B (Ref. 155)—rather than NHB 8060.1C (Ref. 458). Wire insulation for other pressures must pass Test 4—Configuration. Materials that fail tests 1 to 3 may be approved by retesting with Test 4 or by passing Test 5—Fire or Flash Point.

*512. Microgravity Combustion Group: Microgravity Combustion Science: Progress, Plans, and Opportunities. NASA TM–105410, 1992. N92-27197.

This is an update of Reference 347. An introduction quotes astronaut experience and notes the Russian spacecraft venting experience. For fire-safety research, three current projects are cited: (1) the NASA flammability test assessment (conducted by the National Institute of Standards and Technology, NIST), (2) the probabilistic risk assessment application (conducted by the University of California, Los Angeles), and (3) metal ignition and combustion (conducted by the University of Colorado). The report gives the justifications for continued microgravity research, along with the opportunities and needs in spacecraft fire safety.

513. Stocker, Dennis; Greenberg, Paul; and Ross, Howard: Small-Scale Combustion Experiments on the USML–1 Shuttle Mission.

The paper gives descriptions of three in-progress combustion projects: (1) Smoldering Combustion in Microgravity (SCM) investigates axial ignition and plate ignition with and without low-velocity flow, (2) Wire Insulation Flammability (WIF) investigates overheated polyethylene wires instrumented with thermocouples for two concurrent flow cases and two countercurrent cases, and (3) Candle Flames in Microgravity (CFM) investigates the combustion of a single candle, a single candle with thermocouple, double candles, and an unspecified repeat. All these projects are designed to be mounted in four sealed containers each.

514. Kushida, G.; Baum, H.R.; Kashiwagi, T.; and di Blasi, C.: Heat and Mass Transport From Thermally Degrading Thin Cellulosic Materials in a Microgravity Environment. J. Heat Transfer Trans. ASME, vol. 114, no. 2, 1992, pp. 494–502.

The article presents a numerical analysis for thin paper heated with a radiative circular Gaussian air flux, based on steps of endothermic pyrolysis, exothermic oxidative degradation, and exothermic char oxidation. Results illustrated in plots of temperature, velocity, and O_2 contours show that for the quiescent microgravity environment, heat addition creates a flow that rapidly dies out, mass addition of products from the surface to the gas phase creates a dominant flow, and degradation gases are generated mainly by pyrolysis since oxidation is severely limited by dilution of O_2 by degradation gases.

515. Babrauskas, Vytenis; Levin, Barbara C.; Gann, Richard G.; Paabo, Maya; Harris, Richard H., Jr.; Peacock, Richard D.; Yusa, Shyuitsu: Toxic Potency Measurement for Fire Hazard Analysis. Fire Tech., vol. 28, no. 2, 1992, pp. 163–167.

This is a condensation of the scope and conclusions of Reference 500.

516. Patton, J.S.; and Wolf, K.: Fire and Smoke Corrosivity of Metals. Mater. Perf., vol. 31, no. 5, 1992, pp. 46–49.

Tests were conducted in a cone calorimeter with burning polyvinyl chloride (PVC) samples and targets of carbon steel, Cu-Ni, 304 SS, and 400 Monel coupons and corrosion probes. Plots indicate 1 hour corrosion depth of ~ 0.25 μm for Monel, 0.28 μm for carbon steel, 0.36 μm for 304 SS, and 0.81 μm for Cu-Ni. The coupons were also subjected to 4 days posttest exposure to humid air, which increased the corrosion depth of carbon steel, 304 SS, and Cu-Ni to ~ 2 μm and that of Monel to 0.8 μm.

517. Tewarson, A.: Nonthermal Fire Damage. J. Fire Sci., vol. 10, no. 3, 1992, pp. 188–242.

This is a comprehensive literature review. First it discusses corrosion, and it shows threshold concentration of product gases for electronic component damage and specific corrosion constants for several plastics and cable insulations. Then it discusses smoke yield, smoke particle size (nuclei = 0.0025 to 0.020 μm, accumulation of 0.075 to 0.25 μm, and coarse mode >0.25 μm) for various materials and combustion times. The paper quotes experimental data and also has tables for chemical heat release, thermal response, product gases, and corrosion rates for various materials.

518. West, Jeff; Bhattacharjee, Subrata; and Altenkirch, Robert A.: A Comparison of the Roles Played by Natural and Forced Convection in Opposed-Flow Flame Spreading. Combust. Sci. Technol., vol. 83, nos. 4–6, 1992, pp. 233–244.

Computational analysis prior to the Solid Surface Combustion Experiment results indicates that adding surface radiation (ε = 0.5 or 1.0) decreases flame spread for gravity levels less than g = 0.1 for thin paper, but has little influence above g = 0.1. For ε = 1, flame spread is less at microgravity than at normal gravity. For ε = 0, flame spread is greater in microgravity.

519. Debanne, Sara M.; Hirschler, Marcelo M.; and Nelson, Gordon L.: Importance of Carbon Monoxide in the Toxicity of Fire Atmospheres. ASTM Special Technical Publication 1150, 1992, pp. 9–23.

A literature review and statistical analysis cover the toxicity of CO and the effect of carboxyhemoglobin (COHb) concentration on humans. The analysis shows that CO is almost always the exclusive toxicant in fires and COHb levels >20 percent can produce lethality with no other cause. CO concentrations in postflashover fires are influenced by atmospheric O_2 but not by the chemical composition of the fuel. Small-scale tests tend to give low CO yields for ventilation-controlled postflashover fires, although corrections can make these tests useful.

520. Judd, M.D.: Practical Problems Related to Flammability and Combustion in Space. Fluids in Space, Brigitte Kaldeich, ed., ESA–SP–353, 1992, pp. 145–161. N93-22839.

This is a general survey of materials for use in Spacelab. About 800 flammability tests and 400 off-gassing tests were performed. About 20 to 25 percent of the materials do not pass the NHB 8060.1 upward flammability test, but they are accepted based on configuration testing or with hazard and usage analysis. It is noted that there is no experience on flammability in microgravity. The paper notes the improved combustion testing with the cone calorimeter and the problems with arc tracking. The paper also mentions limited airplane tests on a KC–135 where polyurethane foam and printed circuit board were tested in a 250-liter chamber. An International Organization for Standardization (ISO) standard defines six classes of fire growth: smoldering, nonflaming oxidation, nonflaming pyrolysis, developing flaming, low ventilation fully developed, and high ventilation fully developed. The first four are pertinent to space and emissions.

*521. Apostolakis, G.E.; Catton, I.; Paulos, T.; Paxton, K.; and Jones, S.: Findings of a Review of Spacecraft Fire Safety Needs. NASA CR–189181 (UCLA ENG 92–19), 1992. N93-13715.

This report summarizes a November 1991 workshop held at the University of California, Los Angeles. The conclusion section proposes a probabilistic risk assessment, with smoldering as the most probable scenario and with smoke damage assessed in addition to heat damage. The report has summaries of the presentations at the workshop. Among these are sections by George Apostolakis on the establishment of models for probabilistic risk assessments; by Robert Friedman on the state of the art and design requirements for spacecraft fire safety and relevant risk projects; by William R. Fuller, B. John Garrick, and James C. Lin, on the partial results of a qualitative safety assessment for fire on the space station; by P.D. Ronney, Y. Zhang, and E.V. Roegner on the effects of dilution on flame spread rates and the promotion of He as a potential extinguishant; by Dimitrios Karydas, and Michael Delichatsios on smoke damage models and probabilities; and by John Pauperas, J. Howard Kimzey, and Andrea Gardner on space station design requirements and hazards, material selection, and fire detection, response, and suppression.

522. Shah, Burt H.; Schmid, Robert J.; and Franks, Gerald D.: Gas Detector Tube Applications on Space Station Freedom. SAE Technical Paper 921150, 1992.

This paper is a general discussion of the history and applications of reagent gas sampling tubes and how they may be used in the Space Station for pre-entry monitoring of trace contaminants.

523. Fuhs, Susan; Buchmann, Oscar; Hu, Raymond; McLin, John; and Armstrong, Mark: Development of the Fire Detection System for Space Station Freedom. SAE Technical Paper 921152, 1992.

This paper describes the smoke and flame detector proposed for the space station, with reference to a previous review in the International Conference on Life Support and Biospheres. The major performance requirements of the photoelectric smoke detector are a sensitivity of 1.6%/m (0.5%/ft), range of 0 to 6.5%/m (0 to 2%/ft) for 0.5 Vdc, response time of 5 s for a mean particle size >0.3 μm, and a maximum input power of 1.48 W at 120 Vdc. The paper also states limits on pressure drop, duct diameter range, light interference, and repairable life (30 years minimum). The paper specifies two models of the smoke detector, area and duct. An area detector differs from the duct unit in its enclosure in a perforated canister to minimize ambient light interference. The flame detector monitors ultraviolet (UV), visible, and infrared (IR) radiation as well as IR flicker (5 to 40 Hz). Its requirements are a response to a 0.09-m^2 kerosene pool fire at 15 m (1 ft^2 at 50 ft), 120° viewing angle, and a 2.5-W input power. The current system comprises 152 duct-type smoke, 54 area-type smoke, and 24 flame detectors. Ground testing of the spacecraft models was performed in a smoke chamber with cotton, Teflon insulation, resistor, punk, and kerosene fuels. Tests show that the obscuration responses of the smoke detectors compared with a reference photocell are nearly identical, but scattering responses vary with fuel material. A change in air flow from 2.4 to 80 liters/s (5 to 165 ft^3/min) has no effect on the obscuration response, but it reduces the scatter response by 25 percent.

524. Lauger, John B.: Space Station Freedom Resource Nodes 1992 Update. SAE Technical Paper 921252, 1992.

This paper by a McDonnell Douglas author is a detailed discussion of the components and design of the Space Station Freedom Resource Nodes. Sketches show the location of smoke detectors, flame detectors, fan, portable fire extinguishers, and CO_2 tanks.

525. Huchler, Markus; and Honnen, Karl: Analysis of CO_2-Distribution in the COLUMBUS Subfloor Area for Fire Suppression Purposes. SAE Technical Paper 921289, 1992.

A computer program examined the CO_2 distribution for the subfloor racks and stand-offs in the European Space Agency module. The initial atmosphere had 24 vol% O_2. For a criterion of reduction to 15 %O_2, the CO_2 dilution required about 30 min. Three attempts to redesign the CO_2 nozzle configuration and mass flow rate did not yield any shorter time in the calculations. The slow mixing is due to the lack of forced ventilation.

526. Winkler, H. Eugene: Shuttle Orbiter Environmental Control and Life Support System—Flight Experience. SAE Technical Paper 921348, 1992.

The components of the shuttle Environmental Control and Life Support System (ECLSS) are described. The ECLSS subsystems are Atmosphere Pressure Control, Atmosphere Revitalization, Active Thermal Control, Water and Waste Management, Smoke Detection and Fire Suppression (SDFS), and Airlock and Tunnel Adapter. The SDFS has nine smoke sensors, three portable bottles, and a fixed suppression system. Flight experience and changes are described, none of which are in the SDFS.

527. Oberdörster, Günter; Ferin, Juraj; Finkelstein, Jacob; Baggs, Raymond; Stavert, D.M.; and Lehnert, Bruce E.: Potential Health Hazards From Thermal Degradation Events: Particulate vs. Gas Phase Effects. SAE Technical Paper 921388, 1992.

The University of Rochester and Los Alamos National Laboratory researchers hypothesize that ultrafine (nanometer-diameter) particles from fire events are more responsible for lung damage than gases. Preliminary tests with TiO_2 in vitro and clinically with rats indicate ultrafine particles penetrate and damage the lower respiratory tract.

528. Limero, Tom; Wilson, Steve; Perlot, Susan; and James, John: The Role of Environmental Health System Air Quality Monitors in Space Station Contingency Operations. SAE Technical Paper 921414, 1992.

The paper first reviews several thermal breakdown events on Apollo, Skylab, and the shuttle. It states that for the space station, thermodegradation events and chemical leaks are the most likely unintended contingencies. Overheated wiring or electronic components is the greatest concern. Continuous monitors selected and under development are (1) compound-specific analyzers for combustion products of CO, HCN, HCl, and HF (including COF_2), using electrochemical cells, (2) the same for hydrazine and N_2O_4, using ion mobility, (3) a total hydrocarbon analyzer, and (4) a volatile organic analyzer. The authors note that the CPA can supplement the smoke detector for early warning.

529. Zhang, Y.; Ronney, P.D.; Roegner, E.V.; and Greenberg, J.B.: Lewis Number Effects on Flame Spreading Over Thin Solid Fuels. Comb. Flame, vol. 90, 1992, pp. 71–83.

The article gives a very good explanation of flame spread using the de Ris prediction with infinite chemical rates. Experimental work on thin, ashless filter paper indicates that flame spread is independent of pressure. Results for He, Ne, Ar, N_2, CO_2, and SF_6 atmospheric dilution are in good agreement with the de Ris prediction if the flame-temperature calculation is corrected for equivalence ratio and Lewis number. Dilution results suggest that He is the best extinguishant on a mass basis.

530. Heskestad, G.; and Newman, J.S.: Fire Detection Using Cross-Correlations of Sensor Signals. FSJOD, vol. 18, no. 4, 1992, pp. 355–374.

Tests investigated detector response for various fuel and detector combinations. The purpose of the tests was to examine mathematical cross correlations to strengthen sensitivity and reject false alarms. Results are preliminary and varied. The best sensor combinations are (CO detection + ionization) and (CO_2 detection + temperature rise).

531. Sorathia, Usman; Rollhauser, Charles M.; and Hughes, W. Allen: Improved Fire Safety of Composites for Naval Applications. Fire Mater., vol. 16, no. 3, 1992, pp. 119–125.

The paper covers the results of fire tests of four composites with nine fire-barrier methods (ceramic fabric, ceramic coating, intumescent coating, etc.) for submarine applications. Tests include smoke generation, residual strength, heat release rate, and ignitability. The tests seek to derive options and flexibility rather than give “pass-fail” assessments.

*532. Stavnes, Mark W.; and Hammoud, Ahmad N.: NASA Requirements and Applications Environments for Electrical Power Wiring. NASA CR–191064, 1992.

A table lists electric wiring failures in NASA missions and describes the mechanisms of failures, such as arc tracking. The paper gives the requirements for wiring on various missions and defines a testing program. It cites fire as a problem, particularly in 30-%O_2 atmospheres and notes the toxicity of combustion and extinguishment products.

*533. Ohlemiller, Thomas J.: An Assessment of the NASA Flammability Screening Test and Related Aspects of Material Flammability. NISTIR 4882 (NASA CR–189226), 1992. N92-33707.

The report continues an assessment of the NASA material flammability tests (Ref. 471), pursuing the issue of one-sided versus two-sided burning. Simple models are presented to show that the peak rate of heat release is different for one- or two-sided burning of thermally thin materials. The author conducted experiments with a vertical sample ignited downward in the cone calorimeter (modified), with two-sided or one-sided (foil-insulator) ignition and heat flux. Experiments with thermoset (Haysite) resins and circuit board material give a rate of heat release for two-sided burning almost three times greater than for one-sided burning. The NASA test uses two-sided burning. Thus, the author suggests more experiments, with a 20-kW/m^2 superimposed heat flux over the burning sample.

534. Shipp, M.P.; Andrews, S.; Burry, P.E.; and Fardell, P.J.: A Preliminary Experimental Investigation of Fire Behavior in Microgravity. Report Columbus Parabolic Fire Experiment Phase One. K. Rygh and J. Flidh, eds., COL–TN–ESA–003, issue 01, 1992.

The paper discusses the European Space Agency (ESA) attached pressurized module designs and notes the nominal values of 7.6- to 20.3-cm/s air flow. It describes free-floating experiments in the ESA Caravelle airplane, with gas jets alone and with gas jets igniting filter paper, cotton cloth, and balsa wood. The air flow across the flame is about 30 cm/s. About 46 tests were performed, but none of the solid fuels was tested with air flow. Observations are mainly qualitative. Microgravity flames are difficult to see, and little smoke is produced. The researchers observed reignition of charred paper and cloth. One test caused a mild explosion in the test chamber. An appendix to the report is a literature review on fires in space, microgravity combustion research, material flammability tests, and spacecraft fire detection and suppression, with 45 references.

*535. Branch, M.C.; Abbud-Madrid, A.; Feiereisen, T.J.; and Daily, J.W.: A Study of Ignition Phenomena of Bulk Metals by Radiant Heating. The Second International Microgravity Combustion Workshop, 1993, pp. 265–271.

The paper describes the University of Colorado project on the burning of metal pellets in O_2 initiated by a radiant lamp. Temperature-time plots for Ti, Cu, Fe, and carbon steel at 1 atm are presented to establish ignition temperatures. Unexpected results are the ignition of copper and, in contrast, the non-ignition of aluminum. Results are mostly qualitative.

536. Weil, Edward D.; Hirschler, Marcelo M.; Patel, Navin G.; Said, M.M.; and Shakir, Saleem: Oxygen Index: Correlations to Other Fire Tests. Fire Mater., vol. 16, no. 4, 1992, pp. 159–167.

The limiting-oxygen index (LOI) test is simple and shows good precision—sufficient, for example, for quality control in flame retardants. The authors, however, tested the relationships of LOI measurements to material properties, rate of heat release, and other tests, showing poor correlations. The LOI, with downward burning and enriched O_2, is an unrealistic measurement. The article includes a good literature survey of test methods.

537. Grosshandler, William L.: Assessment of Technologies for Advanced Fire Detection. Heat and Mass Transfer in Fire and Combustion Systems—1992, ASME HTD, P. Cho and J. Quintiere, eds., vol. 223, 1992, pp. 1–10.

This article is a review, stressing novel approaches and developments in smoke detectors, chemical sensors, optical sensors, and acoustic sensors. The article notes intelligent detection systems, multipoint and integrated, and identifies applications to various uses, including critical system such as spacecraft.

*538. Steinberg, Theodore A.; Wilson, D. Bruce; and Benz, Frank: The Combustion Phase of Burning Metals. Comb. Flame, vol. 91, 1992, pp. 200–208.

This is a paper on the theory of metal combustion, discussing the burn ratio, which is the ratio of enthalpy of combustion at inlet conditions to total enthalpy at either the melting point or the boiling point of the metal fuel. The value of the paper is in its tables of thermodynamic and bum ratio values for common metals.

539. Inergen Fire Extinguishing Agent: The Environment-Friendly Replacements for Halon 1301. White Paper 1002, Ansul Fire Protection, Marinette, WI, Nov. 1992.

This is the probably the first announcement of Inergen, an inert blend of 52 %N_2, 40 %Ar, and 8 %CO_2. A chart shows the inerting capability of Inergen, but there are no other data.

540. Bhattacharjee, Subrata; and Altenkirch, Robert A.: A Comparison of Theoretical and Experimental Results in Flame Spread Over Thin Condensed Fuels in a Quiescent Microgravity Environment. Twenty-fourth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, PA, 1992, pp. 1669−1676.

The paper describes the temperature and appearance of the Solid Surface Combustion Experiment flame at 50 $\%O_2$ and 1.5 atm, from STS–41. The flame forms two lobes above and below the paper-sheet fuel. The spread rate of the flame leading edge, 0.44 cm/s, is steady, but the spread of the tail decreases with time, causing the flames to increase in length. Sporadic surface smoldering is observed behind the gas-phase flames. The flame has a blue leading edge but the remainder is yellow. Computations give good agreement of surface temperatures along the preheat and flame zones. The 1200 K contour matches the yellow flame zone.

*541. Motevalli, Vahid; Elliott, William; Garrant, Keith; and Marcotte, Ryan: Microgravity Ignition Experiment. NASA–CR–195118, 1992, pp. 358–364. N94-25707.

This describes the design and ground checkout heat-transfer measurements of a GASCAN (shuttle "getaway special canister") apparatus. The project is to determine the ignition time (by ionization gage) of α-cellulose ignited by a radiant lamp. A model predicts a 5.5-s ignition time for the particular test conditions. This experiment is part of the continuing Worcester Polytechnic Institute microgravity program (Ref. 342).

542. Boyer, E.O.; Rieke, W.J.; and Grodsinsky, C.M.: Microgravity Research on the NASA Lewis Learjet Test Facility. AIAA Paper 93–0573, 1993.

After a historical summary, the paper deals with the trajectory optimization of the Learjet airplane, as affected by velocity, pitch entry, pitch exit, pull-up acceleration, and so forth. The paper shows typical measured acceleration levels (75 percent within ±0.02 g for 20 to 22 s low-gravity exposure). A Learjet flight campaign is limited to six parabolas because of engine oil loss.

543. Ferkul, P.V.; and T'ien, J.S.: Numerical Computation of Low-Speed Concurrent Flow Flame Spread in Mixed Buoyant and Forced Flow. AIAA Paper 93–0827, 1993.

Interesting calculations and results are shown for combustion of a thin solid fuel with concurrent forced air flow in low gravity. The flame spread rate increases monotonically with increases in forced velocity and gravitational force (0g to 0.03g). A quench limit for paper fuel at 15 $\%O_2$ is attained at 0g, where the flame will not spread if forced flow is less than around 3 cm/s This limit decreases until for $\geq 10^{-3}$g, there is no quench limit even at a forced velocity of 0 cm/s (but the calculated buoyant velocity at this condition is around 3 cm/s). A high-velocity blow-off limit at around 16 cm/s does not change as the gravitational force increases to near 0.03g, because the forced flow overwhelms the low, buoyant flow.

544. Sacksteder, Kurt R.; T'ien, James S.: Downward Diffusion Flame Spread and Extinction in Variable Gravitation Fields: Lunar and Martian Simulations. AIAA Paper 93–0828, 1993.

Tests were conducted on 25.4- by 5-cm cellulose (Kimwipes) with a chemical igniter and color Schlieren diagnostics. The KC–135 airplane provided test times of around 8 s at 0.05g, 17 s at 0.1g, 23 s at 0.16g, 23 s at 0.38g, and ~50 s at 0.6g. A flammability map indicates that flammability increases as gravity decreases for downward burning. The flammability limit drops from 15.6 to 13 $\%O_2$ at 1g to 0.05g. Spread rates at 18 and 21 $\%O_2$ increase with gravity to a maximum at 0.6g then decrease. Spread rates at 14 to 16 $\%O_2$ decrease with gravity. (Note the agreement with Ref. 489). Extrapolation to previous work at 4g was uniform, but extrapolation to drop tower values (gravity $\rightarrow$ 0) is not possible.

545. Torero, J.L.; Fernandez-Pello, A.C.; and Urban, D.: Experimental Observations of the Effect of Gravity Changes on Smoldering Combustion. AIAA Paper 93–0829, 1993.

White polyurethane foam was ignited in KC–135 and Learjet airplane tests, which have cyclic low-gravity and microgravity periods. In the central reaction zone, the temperature decreases at low gravity because of a lack of O_2. In the end zones, affected by the igniter and the external environment, temperature increases in low gravity because of the lack of convective cooling.

546. Hshieh, Fu-Yu; Motto, Sammy E.; Hirsch, David B.; and Beeson, Harold D.: Flammability Testing in a Controlled-Atmosphere Cone Calorimeter. Paper presented at the 18th International Conference on Fire Safety, San Francisco, CA, Jan. 1993.

This paper reports on the results of White Sands Test Facility combustion tests on poly(methyl methacrylate) (PMMA), Kydex, Neoprene, rubber, and Pyrell at normal gravity and 15 to 50 %O_2. The report notes that NASA is considering testing at 30 to 40 %O_2 for the Mars Program. Ignition delay strongly decreases with heat flux, but it is little influenced by O_2 concentration except near the limit of low O_2 and low flux. Mass-loss rates and average heat-release rates increase linearly with O_2 concentration and heat flux. Total heat release is independent of O_2 for materials that burn completely, but it increases with O_2 for incomplete burn-out materials. The CO/CO_2 yield decreases as O_2 concentration increases.

*547. Sato, Jun'ichi: Japan's Microgravity Combustion Science Program. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 27–32. N93-20178.

This is a plenary paper with a sketch and brief description of the Japan Microgravity Center 10-second drop tower and a note on fire spread over a paper honeycomb, where spread is independent of the honeycomb cell size in microgravity.

*548. Lekan, Jack; Neumann, Eric S.; and Sotos, Raymond G.: Capabilities and Constraints of NASA's Ground-Based Reduced Gravity Facilities. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 45–60. N93-20178.

This paper describes the features, user guides, and capabilities of the NASA Lewis 2.2- and 5.18-second drop towers and zero-gravity airplane along with relevant safety requirements. The Spacecraft Fire Safety Facility is mentioned briefly.

*549. Friedman, Robert: Fire Safety Practices in the Shuttle and the Space Station Freedom. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 213–225. N93-20178.

This is a then-current summary, covering fire scenarios, history of spacecraft fire safety, protection for the shuttle and the Space Station, problems, and directions for combustion research on fire safety.

*550. Altenkirch, Robert A.; Bhattacharjee, Subrata; Olson, Sandra L.; and Sacksteder, Kurt: Opposed-Flow Flame Spreading in Reduced Gravity. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 237–243. N93-20178.

This paper cites results for four flights in the Solid Surface Combustion Experiment (SSCE), covering thin-paper burning at conditions of 50 %O_2 at 100, 150, and 200 kPa pressures and 35 %O_2 at 150 kPa. The flames are bright for the 50 %O_2, at 150 and 200 kPa pressure conditions, but the flames dim as they spread with time. For the 50%, 100 kPa and the 35% conditions, the flame is always blue. The leading-edge spread rate is uniform, but the trailing edge slows, elongating the flame. Typical leading-edge spread rates are 0.358, 0.454, 0.547, and 0.092 cm/s for 50 %O_2 at 100, 150, 200 kPa, and 35 %O_2 conditions, respectively. For flame-fixed coordinates, the flame-spread rate is an opposed-flow velocity.

551. T'ien, James S.; Sacksteder, Kurt R.; Ferkul, Paul V.; and Grayson, Gary D.: Combustion of Solid Fuel in Very Low Speed Oxygen Streams. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 245–250. N93-20178.

The authors conducted experiments in the NASA Lewis 5.2-second drop tower to verify predictions of O_2 concentration extinction boundary, maximum flame temperature, flame-spread rate, and flame shape for Kimwipe sheet fuels. Combustion time was too short for tests with concurrent air flow to establish steady state. Calculations yield a map with a quenching branch (due to radiative extinction) and a blow-off branch. Airplane results from Reference 544 are also included. These data show that , for downward burning, the observable flame spreading limit in low-g is 14 %O_2 (the normal gravity limit is 16.5 percent), and for upward burning, the flame spreading limit is 12 %O_2 (the normal gravity comparison is turbulent and not reproducible).

*552. Branch, Melvin C.; Abbud-Madrid, A.; Feiereisen, T.J.; and Daily, J.W.: A Study of Ignition Phenomena of Bulk Metals by Radiant Heating. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 265–271. N93-20178.

This is the same as Reference 535, except for a shortening of the background and a comment on Al ignition.

*553. Steinberg, Theodore, A.; Wilson, D. Bruce; and Benz, Frank J.: Metals Combustion in Normal Gravity and Microgravity. Second International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10113, 1993, pp. 273–279. N93-20178.

This paper continues and expands on the data found in Reference 508. For promoted ignition and upward burning in the 2.2-s NASA Lewis drop tower facility, the regression rate of the mean interface of steel and Fe in microgravity is 2 to 3 times that in normal gravity. The rate increases with increasing O_2 pressure and decreasing rod diameter. Results for Al and stainless steel are similar. An analysis of the molten ball with Fe combustion shows an excess of O_2 beyond stoichiometric FeO.

554. Friedman, Robert: Fire Safety Practices and Needs in Human-Crew Spacecraft. JAFS, vol. 2, no. 3, 1992–1993, pp. 243–259.

This is an expanded version of Reference 549, with discussion of the STS–28 incident from Asuncion (Ref. 444), diagrams of the space station stand-offs, suppression system layout, discussion of failure tolerance and zoning, and possible postfire clean up schemes.

*555. Friedman, Robert; and Urban, David L.: Contributions of Microgravity Test Results to the Design of Spacecraft Fire-Safety Systems. AIAA Paper 93–1152 (NASA TM–106093), 1993. A93-31028.

Generally, this is a review of the usual fire safety information. New material includes data on the Solid Surface Combustion Experiment results, plots of flame spread influenced by O_2 concentration and flow rates, diluent effects on suppression, and venting. The applications emphasize those for the space station, and they expand on those of Reference 554. The critical issues for Freedom are emphasized.

556. Paulos, T.; Paxton, K.; Jones, S.; Issacci, F.; Catton, I.; and Apostolakis, G.: Risk-Based Spacecraft Fire Safety Experiments. AIAA Paper 93–1153, 1993.

This presents the background of the NASA-funded project. The paper briefly states the general approach of a probabilistic risk assessment. It identifies the four threats of heat, smoke, toxins, and corrosion. The qualitative risk is defined as the combination of growth and hazard times. The proposed experiments will measure smoke production and obscuration in zero gravity.

*557. Wilson, Steve; Limero, Thomas F.; Beck, Steve W.; and James, John T.: A Combustion Products Analyzer for Contingency Use During Thermodegradation Events on Spacecraft. Sixth Annual Workshop on Space Operations, Applications, and Research, vol. 2, pp. 590–596. N94-11555.

The paper briefly describes the four shuttle thermodegradation events (STS–6, 28, 35, and 40). It describes the experience with the new Compound Specific Analyzer (CPA) made by Exidyne, using electrochemical sensors for CO, HF, HCN, and HCl for 13 shuttle missions. The CPA responds to the four common effluents from thermodegradation. The spacecraft maximum allowable concentration (SMAC) and threshold limiting values (toxicity measures) are shown for the four contaminants. The CPA operation in missions since STS–37 has been promising, but more ground testing is needed for space station applications and for reduction of CO cross-sensitivity to H_2.

558. Bahadori; M.Y.; Stocker, D.P.; and Sotos, R.G.: Effects of Oxygen Concentration on Radiation from Microgravity Laminar Propane Diffusion Flames. Paper 1, Paper presented at the Combustion Fundamentals and Applications: Joint Technical Meeting, Central and Eastern States Sections, The Combustion Institute, New Orleans, LA, 1993, pp. 41–45.

This continues the work reported in References 402, 446, and 450 on propane-air burning from a 0.825 mm diameter tube in 101 kPa air in the 5.2-s drop tower. Quantitative measurements of radiation show that radiant energy increases with time and with O_2 concentration (15 to 30 %O_2). Corresponding normal gravity flames have uniform radiation, constant with time and O_2 concentration at levels 0.2 (15 %O_2) to 0.1 (30 %O_2) those of zero gravity. The zero-gravity flames are blue at 15 %O_2 and become reddish-orange at higher O_2.concentrations. The normal gravity flames are yellow.

559. Zhou, L.; Hegde, U.; and Bahadori, M.Y.: Experimental Observations of Turbulent Gas Jet Diffusion Flames in Microgravity, Paper 67, Paper presented at the Combustion Fundamentals and Applications: Joint Technical Meeting 1993, Central and Eastern States Section, The Combustion Institute, New Orleans, LA, 1993, pp. 362–366.

Tests in the NASA Lewis 2.2-second drop tower of turbulent propylene diffusion flames from a 0.78-mm nozzle showed that flame height increases in the laminar regime and continues to increase with Re in the turbulent regime. Normal-gravity flame height increases in the laminar regime but decreases with Re in the turbulent regime. These results are a surprise, since zero-gravity flames are thought to approach normal-gravity flames in size at high flows (high Re). The zero-gravity flames are taller, wider, and brighter than the normal-gravity flames in turbulent conditions.

560. Abbud-Madrid, A.; Branch, M.C.; Feiereisen, T.J.; and Daily, J.W.: Experimental Results on the Ignition and Combustion Behavior of Pure Bulk Metals. Paper WSS/CJ93-007, Paper presented at the 1993 Spring Meeting of the Western States Section, The Combustion Institute, Salt Lake City, UT, 1993.

Basically, this is the same paper as Reference 535, except that temperature-time plots and data tables are included for the combustion of Zn, Sn, Mg, and Zr.

561. Paté-Cornell, Elisabeth; and Fischbeck, Paul S.: Probabilistic Risk Analysis and Risk-Based Priority Scale for the Tiles of the Space Shuttle. Reliab. Eng. System Safety, vol. 40, 1993, pp. 221–238.

This is a brilliant analysis, not addressing fire, but illustrating probabilistic risk assessment. The paper describes the black thermal tiles (20 000) of the shuttle, with details of their mounting. It analyzes the probability of failure due to debris impact and debonding and the consequences of additional tiles debonding, burn through, and loss of critical systems. The tiles are grouped into 33 “mini-zones” with common risk criticalities. Thus, it is shown that the probability of orbiter loss due to tile failure is 10^{-3} per flight, and about 15 percent of the tiles account for 80 percent of the risk.

562. Paté-Cornell, Elisabeth; and Fischbeck, Paul S.: PRA as a Management Tool: Organizational Factors and Risk-Based Priorities for the Maintenance of the Tiles of the Space Shuttle Orbiter. Reliab. Eng. System Safety, vol. 40, 1993, pp. 239–257.

This is a follow-on to the last paper, Reference 561, discussing the history of the black tiles, management and organizational factors influencing the failures of tiles, and recommendations.

*563. Ferkul, Paul V.: A Model of Concurrent Flow Flame Spread Over a Thin Solid Fuel. NASA CR–191111, 1993.

This is modeling report, based on a thesis at Case Western Reserve University. While only a few experimental comparisons are given, a computer plot shows the quenching and blow-off extinction boundaries for a map of O_2 concentration versus concurrent free-stream velocity.

564. Bhattacharjee, Subrata; Altenkirch, Robert A.; and Sacksteder, Kurt: Implications of Spread Rate and Temperature Measurements in Flame Spread Over a Thin Fuel in a Quiescent, Microgravity, Space-Based Environment. Combust. Sci. Technol., vol. 91, 1993, pp. 225–242.

This article expands on the results of the 50 %O_2, 152 kPa Solid Surface Combustion Experiment in STS–41, based on those reported in Reference 540. Noted are the persistence of the flame at the end of the sample as fresh O_2 diffuses and the importance of radiative heat transfer between the surface and gas.

*565. Weiland, Karen J.: Intensified Array Camera Imaging of Solid Surface Combustion Aboard the NASA Learjet. AIAA J., vol. 31, no. 4, 1993, pp. 786–788.

This journal note is essentially a shortened version of Reference 503.

566. Friedman, Robert, Chair: Independent Assessment of the Proposed Fire Detection and Suppression Subsystem for the Space Station Freedom. Unpublished report to NASA Space Station Program and Operation Deputy Chief, April 15, 1993.

Two questions on fire safety were raised by the Deputy Chief: (1) Are the design requirements overly conservative? and (2) Is the Marshall Space Flight Center (MSFC) approach for implementation appropriate? A panel of specialists concluded that the design requirements are not overly conservative and that the NASA MSFC approach for implementation is appropriate. The report of the panel points out several issues and concerns in spacecraft fire safety, namely, the effects of the 30 %O_2 atmosphere, the lack of quantitative risk assessments and the lack of data on detection characteristics, extinguishment processes, and clean up procedures in microgravity. Appropriate research needs are stated.

*567. Tewarson, A.: Flammability Parameters of Materials: Ignition, Combustion, and Flame Spread. Richard G. Hill, Thor Eklund, and Constantine P. Sarkos, eds., Proceedings of the International Conference for the Promotion of Advanced Fire Resistant Aircraft Interior Materials, DOT/FAA/93/3, 1993, pp. 263–281. N94-10766.

This is a background review of the test parameters of critical heat flux, thermal response, heat release, and flame spread, with reference to test results in the Ohio State University apparatus, the cone calorimeter, and the Factory Mutual Research Corporation Flammability Apparatus. Tables give useful information on thermal response, mass consumption, heat release, and flame propagation for plastic and aircraft-panel materials.

568. Abbud-Madrid, Angel; Branch, Melvyn C.; Feiereisen, Thomas J.; and Daily, John W.: Ignition of Bulk Metals by a Continuous Radiation Source in a Pure Oxygen Atmosphere. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, D.D. Janoff and J.M. Stoltzfus, eds., ASTM Special Technical Publication 1197, 1993, pp. 211–222.

This work expands the metal combustion results reported in Reference 535 by including results with Ti, Zn, Zr, Mg, and Sn. The study characterizes the ignition behavior of the various metals in two categories: those igniting above their melting points and those igniting below their melting points.

569. Feiereisen, Thomas J.; Branch, Melvyn C.; Abbud-Madrid, Angel; and Daily, John W.: Gravity and Pressure Effects on the Steady-State Temperature of Heated Metal Specimens in a Pure Oxygen Atmosphere. ASTM Special Technical Publication 1197, 1993, pp. 196–210.

This is the companion to Reference 568 with modeling results. The paper presents reference calculations for the heating of Fe. Plots indicate that average steady-state temperature of the burning metal decreases as gravity levels change from 0g to 10g. It decreases with pressure from ~0 to 0.6 MPa and then remains nearly constant to 1.0 MPa. Convective and radiative heat transfer results are also shown. Indications are that bulk metals may be easier to ignite in low gravity because of reduced convective heat transfer.

570. Hshieh, Fu-Yu; Motto, Sammy E.; Hirsch, David B.; and Beeson, Harold D.: “Flammability Testing of Materials in Oxygen-Depleted and Oxygen-Enriched Environments Using a Controlled Atmosphere Cone Calorimeter,” in Hasemi, Y., ed., Proc. First Japan Symposium on Heat Release and Fire Hazard, Volume 1, Tsukubu, Japan, May 1993, pp. III-15 to III-24.

This is a shortened version of Reference 546 with the same data curves, but also with extensive tables of data removed.

571. Ohlemiller, T.; and Shields, J.: One- and Two-Sided Burning of Thermally Thin Materials. Fire Mater., vol. 17, no. 3, 1993, pp. 103–110.

Numerical models indicate that the rate of heat release for burning thermally thin fuels on two surfaces is greater than twice that for one-sided burning (for thermally thick fuels, it is exactly twice). Experimental results with composite materials in a modified cone calorimeter confirm these results, with an even greater difference for two-sided burning. Analysis shows that two-sided burning is more prone to concurrent flame spread. The implication for the NASA upward flammability test is that materials should be ignited on both sides for the more hazardous conditions.

572. Judd, M.D.; and Bryant, D.: Toxicity of Thermal Degradation in a Manned Space Environment. Centre National d'Etudes Spatiales Fifth International Symposium on Materials in the Space Environment, Capadues Editions, Toulouse, France, June 1993, pp. 457–471.

This paper is an overview of the subject. It is first noted that in microgravity, flammability is influenced by ventilation and fuel jet release. Then, the paper reviews arc tracking, heat release testing, and toxic emissions. It notes the monitoring of fire gases by a 20-element polymer array. The particular safety problems for spacecraft are those of the difficulty of advance material assessments, the release of ultrafine particles by polytetrafluoroethylene (PTFE) over-heating, and the fire sensitivity of the proposed 30 %O_2 environment.

573. Bullard, D.B.; Tang, L.; Altenkirch, R.A.; and Bhattacharjee, S.: Finite-Rate Chemistry in Unsteady Flame Spread Over Solid Fuels in Microgravity. Journal of Advances in Space Research, vol. 13, no. 7, July 1993, pp. 171–184.

The paper presents a typical set of flame photographs and flame-spread results for the Solid Surface Combustion Experiment (SSCE). Three data sets at 50 %O_2 concentration and 1, 1.5, and 2.0 atm pressures give information on the flame spread rate over filter paper. The modeling, surprisingly, is for thick poly(methyl methacrylate) (PMMA) fuel. The unsteady equations yield no sustained flame for quiescent environments (<1 cm/s velocity at 50 %O_2).

573A. Sarri, G.; Leiseifer, H.P.; Laux, U.; Veneri, R.; and Hienerwadel, K.-O.: Status of the Columbus Attached Pressurized Module ECS Design. SAE Technical Paper 932050, 1993.

The paper describes the then-current status of the fire detection and suppression subsystem for the European Space Agency (ESA) module. The principal concern is the lack of commonality with NASA, as shown in a table of comparative features. For example, an earlier ESA design allowed 30 min for CO_2 suppression time, compared with 1 min for NASA. The latest ESA proposal uses a zone system, where a zone is a specified volume such as a group of racks. Each powered zone has a Rack Essentials Package with two smoke sensors and either an Avionics Air Assembly (for cooling) or a Circulation Fan Assembly (detection flow only). Photoelectric sensors are used. The CO_2 is stored in two redundant tanks with a centralized system plus provisions for portable fire extinguishers. Backup control is through depressurization to reduce the O_2 partial pressure from 25 to 7 kPa in less than 10 min. Positive pressure relief for the module is set at 106 kPa. The paper includes some observations on repressurization after venting.

574. Balocco, Paolo; Potenza, Francesco; and Cafaro, Emilio: MPLM Fire Detection and Suppression: Architecture and Analysis. SAE Technical Paper 932104, 1993.

The Mini Pressurized Logistic Module (MPLM, now the Multi-Purpose Logistics Module) has subsystems and a payload rack (refrigerator), designed for supply to and return from the space station. Fire detection is through area detectors in pairs at three stand-off locations and the forward cone. Two duct detectors are in the air ducts downstream of a subsystem rack. Two flame detectors monitor the core. For suppression, two CO_2 tanks have 2.7 kg each stored at 20.5 °C. Calculations for a nozzle effective diameter of 4 mm show that the O_2 is reduced to 10.5 percent within 60 s, while keeping the module below the maximum overpressure of 104.8 kPa (15.2 psia, or 3.4 percent overpressure).

575. Milburn, Vanessa: Space Station Freedom Node 2 Fire Detection and Suppression System Design and Performance. SAE Technical Paper 932105, 1993.

The fire detection and suppression system for the Node 2 by McDonnell Douglas is illustrated, and its specifications are itemized in tables. Analyses define the free-air volumes in components. The detection volumes are zoned, and there are two critical racks and four critical exo-racks (standoffs). The paper includes information on the design of components and their layouts. It describes the detection, verification, and suppression sequence.

576. Fuhs, Susan; Hu, Raymond; and McClure, George: Development of the Flame Detector for Space Station Freedom. SAE Technical Paper 932106, 1993.

The paper, by Allied Signal authors, describes the requirements for the Space Station smoke detector, but concentrates on the radiant flame detector performance, specification, false alarms, and testing. (The flame detector is now dropped from the designs.)

577. Todd, Paul; Sklar, Michael; Ramirez, W. Fred; Smith, Gerald J.; Morgenthaler, George W.; and Oberdörster, Günter: Physics, Chemistry, and Pulmonary Sequelea of Thermodegradation Events in Long-Mission Space Flight. SAE Technical Paper 932144, 1993.

This paper from the University of Colorado defines three stages in the production of toxic spacecraft hazards: (1) production of thermodegradation products, (2) transport of these products, and (3) respiratory effects of these products. For the first phase, the zero-gravity affects on flammability limits and extinction are quoted from the premixed fuel work of Ronney (Refs. 219, 220, 229, and 301A). The paper also discusses the degradation of polytetrafluoroethylene (PTFE) and includes an assessment of the environmental control and life support system requirements of the space station. The second phase of transport is discussed only in general terms, with stirred-tank models.

578. Smith, Gerald J.; Todd, Paul W.; Barkley, Robert M.; and McKinnon, J. Thomas: Fluorocarbon and PTFE Thermodegradation and Contamination Modeling in a Space Habitat. SAE Technical Paper 932146, 1993. (A95-90385).

The researcher investigated thermodegradation experimentally by heating perfluorohexane (representing polytetrafluoroethylene, PTFE) in He and He-30 %O_2. Mass spectrometer analyses at 700 °C give some information on product species, but the work is preliminary.

579. Martin, Charles E.; and DaLee, Robert C.: Spacecraft Fire Detection and Suppression (FDS) Systems: An Overview and Recommendations for Future Flights. SAE Technical Paper 932166, 1993.

This is an independent McDonnell Douglas review. It has a good historical summary of the FDS on early spacecraft, through the shuttle, its laboratories, and the space station. There are sketches and tables of requirements. The paper notes that Apollo (after the fire) used 60 %O_2 in N_2 at 5.0 psia pressure on the ground, changing to 100 %O_2 in orbit. A general discussion of the FDS covers fire prevention, detectors and their types, and suppressants. The paper cites the results of the White Sands Test Facility extinguishment tests (Ref. 507) and compares the designs for CO_2 and N_2 extinguishers. Mass and flow rates for suppression in both 30 and 21 %O_2 atmospheres are estimated.

580. Steisslinger, H.R.; Hoy, D.M.; McLin, J.A.; and Thomas, E.C.: Comparison Testing of the Space Shuttle Orbiter and Space Station Freedom Smoke Detectors. SAE Technical Paper 932291, 1993.

These tests were conducted in an Underwriters Laboratories, Inc. smoke chamber, where smoke obscuration was monitored by a photocell. The two detectors were mounted in series in a downstream duct. The four tests in the project were (1) tests at four flows with burning punk, (2) tests at one flow (50 cm/s) with burning paper squares, (3) tests at the same flow with burning Kapton wire, and (4) particle tests with 0.3 μm polystyrene spheres. Results are difficult to interpret. In general, the shuttle detector is more sensitive to low levels of smoke (paper, wire), while the Space Station detector is more sensitive to rapid combustion (punk).

581. Paxton, Kevin R.; Jones, Stan T.; Paulos, Todd; Issacci, Farrokh; Apostolakis, George E.; and Catton, Ivan: Smoke and Flammability of Wires in Microgravity. Heat Transfer in Microgravity Systems—1993, ASME HTD, S.S. Sadhal and A. Hashemi, eds., vol. 235, 1993, pp. 43–48. (1998 0149963 A)

This is the first paper on results in the Risk-Based Fire Safety Experiment. The paper gives only qualitative results, with photographs, of pyrolyzed and burning wires having insulations of fluorinated ethylene propylene, Kapton, and Tefzel in the NASA Lewis 2.2-second drop tower. This is the initial study for data applicable to probabilistic risk assessments.

582. Paul, Mark R.; Issacci, Farrokh; Apostolakis, George E.; and Catton, Ivan: Morphological Description of Particles Generated from Overheated Wire Insulations in Microgravity and Terrestrial Environments. Heat Transfer in Microgravity Systems—1993, ASME HTD, vol. 235, 1993, pp. 59–66. (1998 0149963 A)

A literature survey covers microscopy and sampling techniques for particles. The paper then continues with sample photographs, histograms, and curve fits for zero-gravity and normal-gravity particle distributions from ignited Tefzel wires.

583. Abbud-Madrid, A.; Fiechtner, G.J.; Branch, M.C.; and Daily, J.W.: A Study of Bulk Metal Ignition in Oxygen Atmospheres. Paper presented at the Western States Section of the Combustion Institute 1993 Fall Meeting, Paper WSS/CI 93–079 (University of Colorado CCR Report Number 93–06), Menlo Park, CA, 1993.

This continues the reporting on the bulk-metal ignition combustion studies, reported in References. 535 and 568. Aluminum is omitted. The studies include emission spectra of Mg, surface morphology and photographs of Cu, and results of high-gravity (to 20g) measurements of ignition delay.

584. Ross, Howard D.: Neither Up nor Down: A Perspective on Combustion Science in Microgravity. Paper presented at the 1993 Fall Technical Meeting of the Eastern States Section of the Combustion Institute, Princeton, NJ, 1993.

The paper includes a broad review and literature survey on microgravity combustion. It cites shuttle and Russian “pre-fire” incidents as motivations for fire safety. It notes the lack of correspondence to normal-gravity fire testing and differences in fire signatures for zero gravity. Several pertinent microgravity fire examples are given: for example, extinction burning wires when air flow ceases, and the inability to light one candle near another.

585. Bahadori, M. Yousef; Stocker, Dennis P.; Vaughan, David F.; Zhou, Liming; and Edelman, Raymond B.: Effects of Buoyancy on Laminar, Transitional, and Turbulent Gas Jet Diffusion Flames. Modern Development in Energy, Combustion and Spectroscopy, F.A. Williams, A.K. Oppenheim, D.B. Olfe, and M. Lapp, eds., ch. 4, Pergamon Press, New York, 1993.

This is a summary of findings from 2.2-second and 5.2-second tests, taken from References 558, 559, and earlier. The paper gives a good description of diffusion (non-premixed) flames. In zero gravity, the flame flicker disappears, and the flame becomes larger and shows a range of colors. These effects are attributed generally to the accumulation of combustion products at the zero-gravity flame front. Laminar flames need more time in zero gravity to reach near-steady-state. The paper also reviews radiation effects. It shows that flame height increases in the transition to turbulent flow, in contrast with normal-gravity flames whose height reach a maximum, then decreases.

586. Jones, S.T.; Issacci, F.; Catton, I.; and Apostolakis, G.: Temperature and Mass Loss of Overheated Wires in Microgravity. Proceedings of the 1993 ASME Winter Annual Meeting, ASME HTD, C.T. Avedisian and V.A. Arpaci, eds., vol. 269, 1993, pp. 67–77.

This paper summarizes the tests results for the burning of Teflon and Tefzel insulated wires in the NASA Lewis 2.2-second facility. The paper gives heating rates, temperature histories, mass losses, and predicted values of these parameters. An initial presentation of modeling attempts to predict insulation mass loss and temperature-time correlations.

587. Paxton, K.R.; Issacci, F.; Apostolakis, G.; and Catton, I.: Smoke Production From Overheated Wires in Normal and Microgravity. Proceedings of the 1993 ASME Winter Annual Meeting, ASME HTD, C.T. Avedisian and V.A. Arpaci, eds., vol. 269, 1993, pp. 87–97.

This paper starts with some discussion of overheated wire experience and risks on human-crew spacecraft. The theory covers smoke obscuration. The paper gives results in terms of smoke fractions for Teflon and Tefzel. The smoke fraction from Teflon is much less than for Tefzel. Any effects of the microgravity environment are unclear.

*588. Stocker, Dennis P.; Olson, Sandra L.; Torero, José L.; and Fernandez-Pello, A. Carlos: Microgravity Smoldering Combustion on the USML−1 Space Shuttle Mission. Proceedings of the 1993 ASME Winter Annual Meeting, ASME HTD, C.T. Avedisian and V.A. Arpaci, eds., vol. 269, 1993, pp. 99−110.

This paper reports on the smoldering experiment carried on the United States Microgravity Laboratory Glovebox on the shuttle mission STS–50, June and July 1992. The samples were 50-mm-diameter by 80-mm-long cylinders of polyurethane foam in air. Four tests were conducted: (1) an axial igniter in the center of the cylinder, with a quiescent environment; (2) the same kind of sample, but with fan-induced air flow; (3) a plate igniter 20 mm from the end of the cylinder, with a quiescent environment; and (4) the same with flow. Results for 10 to 24 min of ignition indicate that for the axial igniter, the smoldering eventually extinguishes. Char patterns are similar to those of reference normal-gravity tests, except that the char has voids in normal gravity (gravity-induced perhaps). The most significant results are a larger evolution of gases in zero gravity: for example, 90 to 3900 ppm for CO compared with trace amounts for normal gravity. Plate igniter temperature results were not available.

589. Rygh, Knut: Fire Safety Research in Microgravity: How to Detect Smoke and Flames You Cannot See. Preparing for the Future, ESA, vol. 3, no. 4, Dec. 1993.

This is a condensation and update of the Caravelle tests described in Reference 534. The free-floating rig investigated gas flames and burning filter paper, cloth, balsa wood, and hexamethylene tetramine. In quiescent conditions, the flame is blue and barely visible. No smoke or IR emissions are observed. Since the thermocouple readings are high (800 °C), the investigators assume that combustion efficiency is high. Air flow (~1 cm/s) prevents self-extinguishment (noted in some cases) and causes a normal yellow flame.

*590. Wieland, Paul: Designing for Human Presence in Space: An Introduction to Environmental Control and Life Support Systems. NASA RP−1324, 1994.

This is a comprehensive handbook by a NASA Marshall author. Noteworthy information includes a brief summary of fire detection, suppression, and clean-up; atmospheric oxygen limits on spacecraft; centralized versus distributed systems; and designing for safety (citing the Apollo 13 incident). The report describes the environmental control and life support systems for aircraft, submarines, and past and present spacecraft. An explanation of documentation for program control is included. Charts give specifications for spacecraft atmospheres, flows, venting, volumes, and so on. The report also includes some historic requirements and an extensive literature survey.

*591. Second NASA Workshop on Wiring for Space Applications. NASA CP−3244, 1994.

This is a summary of the charts presented at the October 6–7, 1993, conference. Stavnes (p.31) cites the wiring failures on STS–28 and Apollo 13 and the statistics of shuttle failures. Friedman (pp. 147 to 164), describes the shuttle experience illustrated by photographs and temperatures from the Wire Insulation Experiment and particle-diameter measurements from the Risk-Based Fire-Safety Experiment.

592. Graham, Sandra J.; and Rhome, Robert C.: Achievements in Microgravity: Ten Years of Microgravity Research. AIAA Paper 94-0344, 1994.

This is a survey of the field, with the most emphasis on biotechnology and materials. In combustion research, the paper notes some of the fundamental discoveries. It defines the practical implications for energy, the environment, and fire safety. Flow effects, radiative quenching, and smoldering results are cited qualitatively.

593. Paul, M.; Issacci, F.; Catton, I.; and Apostolakis, G.: Elemental Description of Smoke Particles. AIAA Paper 94–0433, 1994.

This is based on Reference 582, presenting the same plots of particle-size distribution, but the paper includes chemical analyses of C, O, and F content in the particles for pyrolysis of the wire insulations in normal gravity and microgravity. In particular, fluorine release appears to be greater in microgravity than in normal gravity for Teflon, but it is unchanged with gravity for Tefzel.

*594. Abbud-Madrid, A.; Fiechtner, G.J.; Branch, M.C.; and Daily, J.W.: Ignition and Combustion Characteristics of Pure Bulk Metals: Normal-Gravity Test Results.

This paper is identical to that of Reference 583.

595. Law, C.K.; and Faeth, G.M.: Opportunities and Challenges of Combustion in Microgravity. Prog. Energy Combust. Sci., vol. 20, no. 1, 1994, pp. 65−113.

This comprehensive review of zero-gravity combustion research and findings has some observations on fire safety. Dominant factors in microgravity flame spread are continuum radiation from soot (p. 88), smoldering, which accumulates flammable and toxic products (p. 93), and low-velocity forced flows (p. 97). The relationship of zero-gravity to normal gravity fires has not been established to a quantitative extent (p. 104). The authors make a plea for reduced O_2 or substitute atmospheres for fire safety, and they include a table from Huggett (Ref. 26) on pages 104 to 105. Finally, they note that the concerns for fire detection are slow response and limited technology base, and the concerns for fire extinguishment are low effectiveness and harmful emission s (p. 106).

*596. Friedman, Robert: Risks and Issues in Fire Safety on the Space Station. NASA TM−106430, 1994. N94-27436, [19980166261A Paper].

This is another review with a discussion of space station fire hazards and experience with a summary of the key issues in material flammability, atmospheres, detection, suppression, and clean up.

597. Frank, Michael V.; and Epstein, Steven A.: A Risk and Decision Analysis for Choosing Wind Tunnel Turbine Blade Strategies. G.E. Apostolakis and J.S. Wu, eds., Proceedings of the International Conference on Probabilistic Safety Assessment and Management Conference (PSAM−II), paper session 058, San Diego, CA, 1994, pp. 13−18. N94-27436, [19980166216A Paper].

This is a trade study for the turbine blades of NASA Ames Unitary Plan Wind Tunnel. Four options were (1) to maintain the present aluminum blades, (2) to replace blades with high-aspect-ratio aluminum blades, (3) to replace blades with high-aspect-ratio composite blades, and (4) same as option 3 with other modifications. The two criteria were life-cycle costs and the possibility for catastrophic failure. Results show the rankings for cost emphasis, safety emphasis, and equality (neither emphasized). Option 3 was recommended.

598. Buchbinder, Benjamin: Risk Management at NASA—A New Environment and a Challenge. G.E. Apostolakis and J.S. Wu, eds., Proceedings of the International Conference on Probabilistic Safety Assessment and Management Conference (PSAM–II), paper session 098. N94-27436, [19980166216A Paper].

The paper gives several examples of risk assessments. For the shuttle auxiliary power units, a probabilistic risk assessment shows only 20 failure nodes out of a possible 313 contributed 99 percent of the risk. A previous qualitative assessment identified 106 critical risks, when only 18 are significant, and it missed two others. The shuttle program management felt the probability risk assessment adds little value to the system safety, however. More successful risk assessments were those for Galileo and Ulysses, the Ames Wind Tunnel (Ref. 597), and a limited study for the space station.

599. Paulos, T.; Issacci, F.; Catton, I.; and Apostolakis, G.E.: Estimating the Frequency of Electrical Overload Events in Space Station. G.E. Apostolakis and J.S. Wu, eds., Proceedings of the International Conference on Probabilistic Safety Assessment and Management Conference (PSAM–II), paper session 099, 1994, pp. 15–20. N94-27436, [19980166216A Paper].

The paper cites breakdown events in the shuttle. Then it uses the space station for an exercise in the prediction of the frequency of failures, based on Boeing component failure-rate data, rack components, burning reliability, and so on. Calculations give probabilities of electrical shorts per year and electrical overloads per year, consistent with the shuttle experience.

600. Paxton, K.R.; Issacci, F.; Apostolakis, G.; and Catton, I.: A Methodology for Quantifying Fire Risk On-Board Spacecraft. G.E. Apostolakis and J.S. Wu, eds., Proceedings of the International Conference on Probabilistic Safety Assessment and Management Conference (PSAM–II), paper session 102, 1994, pp. 9–14. N94-27436, [19980166216A Paper].

The probabilistic approach to spacecraft fire safety involves four modes of damage: heat, smoke, toxins, and corrosives. The paper presents the same probability relations as in Reference 556, with some change in the nomenclature. It introduces the concepts of source, transport, and deposition processes. Damage or detection time is shown as a calculated minimum time.

601. Jackson, M.A.; and Robins, I.: Gas Sensing for Fire Detection: Measurements of CO, CO_2, H_2, O_2, and Smoke Density in European Standard Fire Tests. FSJOD, vol. 22, no. 2, 1994, pp. 181–205.

The paper presents data from sample fires established in a British Standard test. Fuels were wood, smoldering wood, smoldering cotton, polyurethane, n-heptane, and methanol. The tests measured temperature, mass loss, optical smoke density, ionization smoke density, CO, humidity increase, H_2, and O_2 decrease. Results show a strong CO response for smoldering, adequate for the other fires, while the O_2 decrease is adequate for smoldering, strong for the others. The H_2 increase is appreciable only for the smoldering cotton. Humidity increase is appreciable only for the liquid fuels. The authors note that a combination of CO detection at around 20 ppm and detection of a rate of change of O_2 concentration would make an effective chemical detector.

602. Meacham, Brian J.: International Developments in Fire Sensor Technology. J. Fire Protection Engineering, vol. 6, no. 2, 1994, pp. 89–98.

The author, originally at Worcester Polytechnic Institute, now at FireTech of Switzerland, reviews the latest in fire sensors, covering heat sensors (fiber optics with a wax tube and metal cladding), temperature fluctuation sensors, gas sensors (HCl and CO), fire sensors (radiation and machine vision), and smoke sensors (electrostatic and optical-bridge light scattering).

603. Leonard, J.T.; Budnick, E.K.; Rosenbaum, E.R.; Perrault, D.J.; and Hayes, E.D.: Flightline Aircraft Fire Incidents and Suppression Agent Effects: Field Inquiries and Incident Analysis. WL–TR–93–3519, 1994.

Researchers at the Naval Research Laboratory and at Hughes Associates prepared this report. It notes that 95 percent of the fire database deals with small fires. An estimate of Halon 1211 usage by the U.S. Air Force shows about 40 percent is used for training, and no more than 25 percent for fires (The remainder are leaks and other losses). Tables compare H1211, CO_2, dry chemical, aqueous film-forming foam, and water properties, criteria, and damage potential. The report also discusses candidate agent for replacement of Halons.

*604. Altenkirch, Robert A.; Sacksteder, Kurt; Bhattacharjee, Subrata; Ramachandra, Prashant A.; Tang, Lin; and Wolverton, M. Katherine: The Solid Surface Combustion Experiment Aboard the USML–1 Mission. Joint Launch + One Year Science Review of USML–1 and USMP–1 With the Microgravity Measurement Group, N. Ramachandran, D.O. Frazier, S.L. Lehoczky, and C.R. Baugher, eds., NASA CP–3272, vol. I, 1994, pp. 83–101. N95-14212.

This paper presents the results of the fifth Solid Surface Combustion Experiment on the shuttle. In this test, the fuel was filter paper at 35 $\%O_2$, 1 atm. The flame is dim and nearly parallel to the fuel surface, curving slightly toward the surface at the leading and trailing edges (both equally bright). Leading edge flame-spread rate is 0.092 cm/s. For reference, previous flights found flame spread rates of 0.150 cm/s at 35 $\%O_2$ and 1.5 atm, 0.358 cm/s at 50 $\%O_2$ and 1.0 atm, 0.454 cm/s at 50% and 1.5 atm, and also 0.547 cm/s at 50% and 2.0 atm. There is evidence that the fuel is not entirely consumed as the flame passes. Modeling shows that conduction and radiation fluxes are comparable.

*605. Stocker, Dennis P.; Olson, Sandra L.; Torero, José L.; and Fernandez-Pello, A. Carlos: Microgravity Smoldering Combustion on the USML–1 Space Shuttle Mission. Joint Launch + One Year Science Review of USML–1 and USMP–1 With the Microgravity Measurement Group, N. Ramachandran, D.O. Frazier, S.L. Lehoczky, and C.R. Baugher, eds., NASA CP–3272, vol. II, 1994, pp. 609–621. N95-14212.

The paper discusses microgravity smoldering tests conducted on cylindrical polyurethane foams, 50 mm diameter by 80 mm long, with and without air flow. Ignition was either by a heated wire positioned axially along the centerline or by a heated plate at a circumferential station 20 mm from one end of the fuel cylinder. Smoldering temperatures are 400 °C or below. For quiescent tests, the temperatures are about 30 °C higher than those of reference normal gravity. For flow tests, temperatures are the same. Char patterns resemble those in normal gravity, except for more uniformity and lack of voids in zero gravity. Light gas production is greatly increased in zero gravity, possibly because of longer residence times. For example, CO emission is 3 to 6 ppm in normal gravity but is 90 to 150 ppm in zero-gravity quiescent conditions and 600 to 3900 ppm in zero gravity with flow. The CH_4 emission is 0 in normal gravity and 17 to 570 ppm in zero gravity; and CO_2 emission is 2 to 3 times that in normal gravity.

*606. Greenberg, Paul S.; Sacksteder, Kurt R.; and Kashiwagi, Takashi: Wire Insulation Flammability Experiment: USML–1—1 Year Post Mission Summary. Joint Launch + One Year Science Review of USML–1 and USMP–1 With the Microgravity Measurement Group, N. Ramachandran, D.O. Frazier, S.L. Lehoczky, and C.R. Baugher, eds., NASA CP–3272, vol. II, 1994, pp. 631–655. N95-14212.

The paper reports the results for combustion of polyethylene-insulated Nichrome wire (0.75-mm-diameter wire with 0.37 mm insulation), 110 mm long. Air flows were 10 cm/s, both concurrent and opposed. For both flow directions, the flame tips are open. Spread rate measured in concurrent flow is about twice that in opposed flow. In turn, opposed flow rate is 1/3 that in downward normal gravity. Flames stabilized around a bead of molten insulation, within which bubble nucleation is observed. Ignition at 0 flow ignites a cloud of fuel, but flame spread is not sustained. The flames are bright and sooty.

607. Ostroumov, B.; and Rumin, V.: Mir-NASA Programs: Main Program Provision on the Assessment of Fire Detection and Extinguishment Capability. Requirements for NAS15–10110, RSA Document Number 0006A8, May 13, 1994.

The document notes the fire detection and detection system for the Functional Cargo Modules on the International Space Station. In brief, the key items are provisions for operation at O_2 concentrations up to 40 percent, and the installation of smoke detectors described as ESD–2 electrotransfer, sensing particles in range of 0.01 to 2 μg, at a sensitivity of 10 μg/m^3. The detector has three levels of warning: (1) 2 to 4 times background level, (2) 4 to 10 times, and (3) adjustable to maximum. Two extinguishers are specified: OKR–4 is a manual unit filled with 3 percent foaming agent in water and 11.5 kg charge for 60-s operation. OKR–1 is a manual unit filled with 6 percent foaming agent in water and 4.2 kg charge for 30-s operation. Both apparently use N_2 as the carrier.

608. Gann, Richard G.; Babraukas, Vytenis; Peacock, Richard D.; and Hall, John R., Jr.: Fire Conditions for Smoke Toxicity Measurement. Fire Mater., vol. 18, no. 3, 1994, pp. 193–199.

A review of models and statistics indicates that overall 67 to 75 percent of fire deaths occur from “smoke” inhalation, predominantly after fires have progressed beyond flashover. The victims are most often in a room other than that of the fire origin. In the room of fire origin, thermal victims are more common.

609. Grayson, G.; Sacksteder, K.R.; Ferkul, P.V.; and T'ien, J.S.: Flame Spreading Over a Thin Solid in Low-Speed Concurrent Flow—Drop Tower Experimental Results and Comparison With Theory. Microgravity Science and Technology, vol. VII, issue 2, 1994, pp. 187–195.

The paper presents results for the microgravity combustion of thin paper (Kimwipes) fuels, conducted in the NASA Lewis 5.18-second facility. Concurrent air flow was induced by a translation mechanism to move the fuel holder slowly across the monitored combustion zone. The series of tests covered combustion with 0.3 to 5.0 cm/s concurrent flow in modified air at O_2 mole fractions of 0.12 to 0.30. At O_2 mole fractions above 0.18, the flame is sooty and bright. Otherwise it is pale blue. The char front is flat, rather than rounded as for normal-gravity upward spread. At the higher O_2 concentrations, the concurrent-flow flame width is the same as for opposed flow found in previous testing; at lower O_2, the widths are greater. Spread rates are 30 percent greater at low O_2, and two times greater at high O_2 than for opposed-flow combustion. The spread rate at the flame tip and base are not the same. In some cases, 5.2 s is too short of a time to reach a steady flame size.

610. Hill, R.G.: A Review of Recent Civil Air Transport Accidents/Incidents and Their Fire Safety Implications. Fire Safety Science, 1994, pp. 85–94.

The paper lists recent Federal Aviation Administration fire-safety rules, along with a brief discussion of 14 recent accidents and incidents. Future trends in material selection, system improvement, and Halon replacement are also noted.

611. Tsuchiya, Y.: CO/CO_2 Ratios in Fire. Fire Safety Science, 1994, pp. 515–526.

This paper is mostly a review. It notes the importance of the CO/CO_2 ratio as a fire parameter, since CO_2 can be estimated from mass loss. Illustrations are given of CO/CO_2 ratios for various fuels. In wood fires, for example, CO/CO_2 is nearly 1 mole/mole in preflaming, near 0 at flaming, and 0.25 for glowing.

612. Shipp, Martin; and Spearpoint, Michael: The Detection of Fires in Microgravity. Fire Safety Science. Proceedings of the Fourth International Symposium, International Association for Fire Safety Science, Takashi Kashiwagi, ed., Boston, MA, 1994, pp. 739–750.

The paper expands on results already presented in References 534 and 589. It describes tests conducted on the European Space Agency Caravelle airplane, using an apparatus to burn propane, filter paper, cloth, balsa wood, and hexamethylene triamine. Air flow up to 13 cm/s was superimposed. Instrumentation included optical sensing as well as sensing with ultraviolet detectors and thermocouples, but the paper contains mainly qualitative results and observations. Paper, cloth, and wood fires die back in quiescent air. Enhanced $\%O_2$ up to 27 to 29 eliminates the self-extinguishment. Flames are nearly invisible with little smoke in quiescent air but turn yellow with 1 cm/s flow or greater.

613. Apostolakis, G.E.; Catton, I.; Issacci, F.; and Jones, S.: Experimental Needs for Spacecraft Risk Assessment. Fire Safety Science, Takashi Kashiwagi, ed., Proceedings of the Fourth International Symposium, International Association for Fire Safety Science, Takashi Kashiwagi, ed., Boston, MA, 1994, pp. 949–960.

This is largely a repeat description of the University of California, Los Angeles, project that applied probabilistic risk assessment to spacecraft fire safety. The paper emphasizes the NASA Lewis 2.2-second drop tower results in thermal response (Ref. 586), particle size distribution (Ref. 582), smoke and gas production (Ref. 587).

*614. Stavnes, Mark W.; Hammoud, Ahmad N.; and Bercaw, Robert W.: Operational Environments for Electrical Power Wiring on NASA Space Systems. NASA TM–106655, 1994.

This paper repeats much of the material found in Reference 532, but it concentrates on the operating environment for pressurized modules, satellites in low and geosynchronous Earth orbit, trans-atmosphere vehicles, and lunar and Martian surface habitats. It notes previous missions with wiring system failures and fires caused by wiring failure. Work to be performed includes measurement of zero-gravity flame spread.

615. Boutros, Ramzy; Cory, Jay; and Beasley, Mark: Modular Rack Design for Multiple Users. SAE Technical Paper 941587, 1994.

The paper describes and illustrates the racks for the space station. Standard racks are used for stowage, subsystems, payloads, and crew functions. They are made from graphite/epoxy composite “bathtubs” with aluminum rails and attachment points. A diagram shows the fire suppressant tanks in the stand-offs, but otherwise the fire detection and suppression subsystem is not described.

616. Gustavino, Stephen R.; Garner, Ed; and Olson, Keith R.: Design and Test of a Fire Detection System for a Microgravity Environment. SAE Technical Paper 941591, 1994. Also, SAE 1994 Trans. Jour. Aerospace. Section 1, vol. 103, 1995, pp. 1647–1657.

The prototype space station detector was tested in normal gravity with smoke generated by dioctylphthalate aerosols (neutrally buoyant, with 90 percent of the aerosol particles between 1 and 3 μm). McDonnell Douglas used a node mock-up with detection “piccolo” tubes. The paper presents the investigation results for the sensing of fires using optical techniques (both obscuration and scattering), ultraviolet radiation, and thermocouples. For an alarm threshold equivalent to 0.5%/ft, average detection time is ~140 s, and 60 percent of cases result in alarm. Detection time is not sensitive to limited changes in the alarm threshold, with a small dependence on air flow.

617. Ross, Rogard; Williams, Teresa A.J.; and Sargent, Donald: Post-Fire Cleanup on the Space Station. SAE Technical Paper 941606, 1994.

The paper first notes that fire is still a most feared hazard in space. It then summarizes a three-part NASA Marshall Space Flight Center-Johnson Space Center study. Task 1 examines the fire detection and suppression system. The authors note that CO_2 is selected as the extinguishant because of compatibility and its ground database. The investigators conducted experimental and analytical tests to demonstrate the displacement of air by CO_2 and the representative contamination levels from a fire. Task 2 summarizes the recovery operations of access, ingestion, and damage control. Task 3 surveys system and equipment needs, noting that portable breathing apparatuses have an inadequate supply time of 10 min and that more cleanup and contamination equipment is needed. The alternative approach for removing high contamination is venting.

618. Veneri, Ruggero; Parodi, Paola; Glynn, David; and Taylor, Kate: CFD Modelling on Fire Detection and Suppression in a Columbus Rack. SAE Technical Paper 941607, 1994.

The paper, based on a study by Alenia Spazio, describes the Columbus Space Station module smoke detector and circulating fan assembly and then presents analyses for CO_2 storage and spread in a subsystem rack. Smoke analyses show typical times of as much as 100 to 120 s for response. The CO_2 addition is adequate, provided there is at least one nozzle per half rack.

619. Lyon, R.E.: Advanced Fire-Safe Aircraft Materials Research Program. DOT/FAA/AR–95/98, 1994.

While this report is an initial introduction to the Federal Aviation Administration program, it has some useful background information. About 3300 to 8400 kg of combustibles are found on aircraft. Aircraft fires can occur on the ramp, in flight, and after a crash. Some examples are given for the time to ignition, and flame spread rate of thermally thin and thick materials (with data given for poly(methyl methacrylate), PMMA), and plots of heat release versus time to flash over for sandwich materials. Testing must include incident heat flux that is not used in NASA tests.

620. Fernandez-Pello, A.C.: The Challenge of Fire Prediction. Combust. Sci. Technol., vol. 98, 1994, pp. 281–290.

Basically this is a review of fire ignition and spread information in buildings and transportation. For space, two NASA fire-safety papers are cited on the recognition that ventilated microgravity conditions can enhance fire spread.

*621. Tewarson, A.: Flammability Parameters of Materials: Ignition, Combustion, and Fire Propagation. J. Fire Sci., vol. 12, 1994, p. 329.

This paper reviews and illustrates cone calorimeters, the National Institute of Standards and Technology (NIST) lateral ignition apparatus, and other flammability testing apparatuses at Factory Mutual Research Corporation and Ohio State University. The paper presents flammability parameters of thermal response $[(T_{ig} - T_o)(kC_p\rho)^{1/2}]$, mass loss rates, heat release, and so forth. It gives tables of values for plastic and wood heating thermal response, mass-loss rate, chemical heat release, and fire-propagation rate. It also shows relative values of radiative and convective heat flux.

621A. Zallen, Dennis M.: Halon Replacements Study. WL–TR–94–5032, 1994.

This report is a review of properties and test results on 12 Halon replacements (all halocarbons), in a study conducted for the Wright Patterson Air Force Base (Wright Labs).

622. Chow, W.K.; and Wong, William C.W.: Experimental Studies on the Sensitivity of Fire Detectors. Fire Mater., vol. 18, no. 4, 1994, pp. 221–230.

The Hong Kong authors tested ionization, photo-optical, infrared (IR), and rate-of-heat-rise detectors on a normal-gravity smoke box with thermocouples and a laser-beam photodetector. Groups of reference fires included liquid pools, cotton and plastic smoldering, open polyurethane, open wood, and natural gas. Results include time-response plots and correlations. In general, the IR detector is the faster responding for flaming and nonsmoky fires, photo-optical for slow smoldering, ionization for smoky fires, and rate of heat rise only for high-temperature fires.

623. Shipp, Martin; and Spearpoint, Michael: Fires in Micro-Gravity. Fire Safety Engineering, vol. 1, no. 4, Aug. 1994, pp. 41–45.

This is largely a condensation of Reference 612, with a good sketch of the apparatus, the Caravelle airplane flight path, and typical flames. Qualitative results are that gas flames are very pale, and paper and cloth self-extinguish in most cases in quiescent microgravity. Thermocouples show flame temperatures of around 880 °C (normal gravity would be 1000 °C) even when the flames are “invisible.” Flames turned yellow at air velocities of >1 cm/s; and they yield only small quantities of smoke. The study implications are that invisible flames may pose a risk, and smoke detection may have limited effectiveness.

624. Avedisian, C. Thomas: Microgravity Work Yields Clues About Thermal Processes. Aero. Amer., vol. 32, no. 8, 1994, pp. 40–42.

This is an introduction to microgravity combustion science for a general engineering audience. It states several justifications for microgravity investigations, including (1) fire safety and applications, (2) obscured phenomena such as soot shells around droplets, and (3) better analytical models of combustion.

*625. Friedman, Robert: Combustion and Fires in Low Gravity. First NASA Workshop on Wiring for Space Applications, NASA CP–10145, 1994, pp. 81–90.

This is a viewgraph summary of a talk at the Workshop (actually held July 23-24, 1991), covering the topics of wire flammability testing, fire detection, and extinguishment on the shuttle and space station.

*626. Sawyer, C.R.: Space Station Freedom Secondary Power Wiring Requirements. First NASA Workshop on Wiring for Space Applications, NASA CP–10145, 1994, pp. 99–113.

These are charts giving wiring specifications, including derating for fire prevention, hazard ranking, and historic wiring types.

*627. Nakabe, K.; McGrattan, K.B.; Kashiwagi, T.; Baum, H.R.; Yamashita, H.; and Kushida, G.: Ignition and Transition to Flame Spread Over a Thermally Thin Cellulosic Sheet in a Microgravity Environment. Combust. Flame, vol. 98, no. 4, 1994, pp. 361–374.

This is a continuation of analyses (reported earlier in Ref. 514) on the radiative ignition of black paper under 5 W/cm^2 heat flux. The authors note that the complete reaction model covers steps of endothermic pyrolysis, exothermic char, and char oxidation. The ultimate transition to flame spread has fire-safety implications. Transition is achieved only at 50 $\%O_2$; at 30 $\%O_2$ there is autoignition but no spread.

627A. Rodak, E.M.; Taylor, Ronald J.; Hirsch, David B.; and Linley, Larry J.: Effects of Sample and Test Variables on Electrical Wire Insulation Flammability. J. Test. Eval., vol. 22, no. 5, 1994, pp. 447–450.

The article is a description of the NASA NHB 8060.1B Test 4 on electrical wire flammability, with data on repeatability and the effects of wire size and orientation.

*628. Ferkul, P.V.; and T'ien, J.S.: A Model of Low-Speed Concurrent Flow Flame Spread Over a Thin Fuel. Combust. Sci. Technol., vol. 99, nos. 4–6, 1994, pp. 345–370.

Analytical models show flame shape, stand off, and isotherms, for zero-gravity flames with concurrent imposed velocities from 0.8 to 20 cm/s. The paper presents a two-branched extinction curve (similar to that of Ref. 181A). Flame shapes agree with those observed in tests conducted in the NASA Lewis 5.18-second drop tower (Ref. 609).

629. Ito, H.; Fujita, O.; and Ito, K.: Agglomeration of Soot Particles in Diffusion Flames Under Microgravity. Comb. Flame, vol. 99, no. 2, 1994, pp. 363–370.

Experiments are described that were conducted in the Japan 10-second (490 m) drop shaft. The tests consisted of butane burning in a tube. Ignition was prior to the drop on a screen above the burner to damp the residual convection. The investigators observed soot particles as luminous spots in atmospheres of 50 %O_2 and even 21 %O_2 (although few particles disappeared before 10 s). An array of 13 thermophoretic grids collects particles. In zero gravity, particles cluster into large arrays (~100 μg in size), which is 200 to 500 times the agglomeration noted in corresponding normal gravity. Primary particle sizes (10 to 70 nm) are about the same in either environment. Local flow velocity and O_2 concentration affect agglomeration.

630. Frank, Michael V.; and Kazarians, Mardy: Fire Risk Modeling and Management for Industrial Sites: Going Beyond the Codes. Proceedings of the 1994 International Mechanical Engineering Congress and Exposition, Safety Engineering and Risk Analysis (SERA), vol. 2, ASME, New York, NY, 1994, pp. 51–58.

The authors note the reasons to address risks quantitatively (go beyond codes) are (1) to predict the financial losses, (2) to know the likelihood of catastrophic accidents, and (3) to protect against litigation. The scenario approach for risk management is recommended. The paper defines risk, risk assessment, and risk management. It gives an example of the use of influence diagrams to assess the risks of a shuttle auxiliary power unit hydrazine leak.

631. Paxton, Kevin; Apostolakis, George; and Ho, Vincent: On the Four Modes of Spacecraft Fire Damage and Control Processes. Proceedings of the 1994 International Mechanical Engineering Congress and Exposition, Safety Engineering and Risk Analysis (SERA), vol. 2, ASME, New York, NY, 1994, pp. 123–129.

This is based largely on the risk models of heat, smoke, toxins, and corrosives, reported earlier (Refs. 556 and 600). The damage time and control time models are expanded with hypothetical quantitative illustrations.

632. Grosshandler, W.L.; and Gann, R.G.: Low Environmental Impact Fire Suppression Concepts. Paper presented at the Chemical and Physical Processes in Combustion, Eastern States Section, The Combustion Institute, Clearwater Beach, FL, 1994, pp. 37–46.

This is a review of fire-extinguishing agents. It compares cup-burner and detonation-tube data for Halon alternatives. Most of these agents have drawbacks in low efficiency, lack of flexibility (to meet varying fire threats), possible collateral damage, or potential for environmental damage. The promise and flaws of CF_3I are noted. The paper also considers other chemical agents, inert gases, fine water sprays, pyrotechnic gases and aerosols, and combinations of agents.

*633. Goldmeer, Jeffrey S.; Yang, Chin-Tien; Urban, David L.; and T'ien, James S.: Combustion of a Solid Cylinder in Low Speed Flows. NASA CR–202692, 1994.

Analyses of a burning poly(methyl methacrylate) (PMMA) cylinder with forced air flowing axially predict that flame length grows from a minimum at 0.8 cm/s air velocity to a maximum at 40 cm/s, then blows off first at the forward stagnation point and finally completely at an air velocity of 150 cm/s. Experiments on the KC–135 airplane with 1.9-cm-diameter PMMA cylinders at 1 atm show that a normal-gravity flame at 10 cm/s air velocity envelopes the fuel, but it shrinks and extinguished within 10 s at low gravity. This is assumed to be because of increased heat conduction to the PMMA.

*634. Branch, Melvyn C.; Daily, J.W.; and Abbud-Madrid, Angel: Ignition and Combustion of Bulk Metals in a Microgravity Environment. NASA CR–197519 (Colorado University CCR–94–08), 1994.

This is largely similar to Reference 583, but it has more details on the instrumentation, a discussion of results for Cu, and lists of industrial affiliations, references, and publications.

634A. Hirano, T.; and Saito, K.: Fire Spread Phenomena: The Role of Observation in Experiment. Prog. Energy Combust. Sci., vol. 20, no. 6, 1994, pp. 461–485.

The review of fire-spread experiments covers scale modeling, horizontal, downward and upward flame spread, and other phenomena. It mentions gravity effects briefly, noting the predominance of radiation heat exchange in low gravity.

635. Sacksteder, Kurt R.; and T'ien, James S.: Buoyant Downward Diffusion Flame Spread and Extinction in Partial-Gravity Accelerations. Twenty-Fifth Symposium (International) on Combustion. The Combustion Institute, Pittsburgh, PA, 1994, pp. 1685–1692.

Basically, this paper repeats the data of Reference 544 on the KC–135 airplane test with paper (Kimwipes) fuel. More analyses are added, along with a plot of flammability in terms of O_2 concentration versus buoyant velocity V_{ref}, which shows a concentration minimum at low V_{ref} (near zero gravity).

636. Kobayashi, Hideaki; Ono, Naomichi; Okuyama, Yozo; and Niioka, Takashi: Flame Propagation Experiment of PMMA Particle Cloud in a Microgravity Environment. Twenty-Fifth Symposium (International) on Combustion. The Combustion Institute, Pittsburgh, PA, 1994, pp. 1693–1699.

The investigators conducted experiments with spherical poly(methyl methacrylate) (PMMA) particles aerated in vertical tubes and ignited at the top. Normal-gravity reference experiments show a flame-spread rate maximum at slightly above stoichiometric. Flame spread rate V_f decreases as mean particle size increases from 4.8 to 18 μm. In the Japanese 10-second drop tower, tests with 7.2-μm particles give V_f values with a similar relationship to particle mass as in normal gravity, but with spread rates about 2/3 as great.

637. Sacksteder, K.R.; and T'ien, J.S.: A New Formulation of Damkohler Number for Studying Opposed Flow Flame Spread and Extinction. AIAA Paper 95–0150, 1995.

The Damkohler number has a term relating to flame temperature; hence it serves to correlate blowoff and quenching limits, giving the U-shaped flammability boundary of oxygen versus gravity level g. The data of Reference 635, taken in the KC–135 airplane laboratory from g ≅ 0.05g to 4g, are fitted to the upper half of the correlation.

638. Sarkos, C.P.: Status of Halon Replacement Evaluation in Commercial Aircraft and Airport Application. Proceedings of the 20th International Conference on Fire Safety, Millbrae, CA, 1995, pp. 72–81.

This paper gives a brief summary of the current aircraft fire-extinguisher practices, with agents Halon 1301 for cargo, nacelle, and lavatory protection, and Halon 1211 hand-held extinguishers in the cabin.

639. Friedman, R.: Review of Fire Safety in Spacecraft. Proceedings of the 20th International Conference on Fire Safety, Millbrae, CA, 1995, pp. 170–174.

This is generally a description of the state of the art, with a list of International Space Station design features and research.

640. Ramachandra, Prashant A.; Altenkirch, Robert A.; Bhattacharjee, Subrata; Tang, Lin; Sacksteder, Kurt; and Wolverton, M. Katherine: The Behavior of Flames Spreading Over Thin Solids in Microgravity. Comb. Flame, vol. 100, nos. 1/2, 1995, pp. 71–84.

This paper covers the 35 %O_2 cases for the Solid Surface Combustion Experiment, expanding the findings of Reference 604, but also serving to summarize the 50 %O_2 cases. The fuel is ashless filter paper, with a specific density of 7×10^{-2} kg/m^2, a half thickness of 0.00825 cm, and an area of 3.0 by 11 cm exposed. For 50 %O_2, the flame is blue at 1.0 atm, has a yellow spot just behind the leading edge at 1.5 atm, and is almost all yellow with a blue leading edge at 2.0 atm. For 35 %O_2, flame is nearly undetectable at 1.0 atm, but is slightly brighter at the leading edge (still blue) at 1.5 atm. Some evidence suggests that fuel is not completely consumed as the flame passes. Measured and predicted flame-spread rates are as follows:

	50 %O_2			35 %O_2	
	1.0 atm	1.5 atm	2.0 atm	1.0 atm	1.5 atm
Measured, cm/s	0.36	0.45	0.55	0.092	0.15
Predicted, cm/s	0.387	0.554	0.630	0.290	0.476

*641. Yaniec, John S.: Users Guide for NASA Lewis Research Center DC–9 Reduced-Gravity Aircraft Program. NASA TM–106755, 1996.

This is a brief description of the DC–9 and its facilities, with emphasis on documentation for tests.

642. Grosshandler, William Lytle: A Review of Measurements and Candidate Signatures for Early Fire Detection. NISTIR–5555, 1995.

This is a literature review of fire products and emission, with a discussion of signatures and smoke detection, heat detection, gas sensing, and radiation standards. It presents new methods in principle for fire detection. It cites some of the results of Reference 601 on fire tests and notes future directions and needs.

643. Sacksteder, Kurt R.: Parabolic Airplane Experiments in Microgravity Combustion. Experiment Results of ESA and CNES Parabolic Flight Campaigns—Tenth Anniversary of First ESA Parabolic Flight Campaign Workshop Proceedings, ESA WPP–90, CNES ED/MV–95–039, February 1995, pp. 69–76.

This brief review lists the 47 current microgravity projects, notes the ground-based facilities, and then illustrates airplane experiments with plots of flammability and flame spread taken from Reference 635.

644. Bryant, D.; and Judd, M.D.: The Effects of Gravity Level on Rate of Heat Release and Time to Ignition. Experiment Results of ESA and CNES Parabolic Flight Campaigns—Tenth Anniversary of First ESA Parabolic Flight Campaign Workshop Proceedings, ESA WPP–90, CNES ED/MV–95–039, February 1995, pp. 99–101.

This is a brief summary of Caravelle airplane experiments to determine the rate of heat release of ventilated candles and the ignitability of solid plastics under radiant heat flux. For candles, heat release in microgravity is about 60 percent that of normal gravity. Increased air flow rate increases heat release in microgravity.

645. Tapscott, Robert, ed.: Chemical Options to Halons for Aircraft Use. DOT/FAA/CT–95/9, 1995. (N95-31569).

This is the final report of Task Group 6 of the International Halon Replacement Working Group. It is a comprehensive report discussing extinguishants, their properties, toxicology, and environmental impact. Halon replacements are discussed with tables of properties and assessments of effectiveness and toxicity. The report discusses alternatives including foams, water sprinklers, dry chemicals, and CO_2. Longer term alternatives mentioned are water mists, particulate aerosols, inert gases, and gas generators.

646. Edwards, John C.; and Morrow, Gerald S.: Development of Coal Combustion Sensitivity Tests for Smoke Detectors. U.S. Department of the Interior, Bureau of Mines, Report of Investigations, vol. 9551, 1995.

The authors conducted smoke-chamber tests with coal samples heated on a disk heater for smoldering. The vapors were ignited for flaming tests. The authors measured optical transmission and ionization chamber responses as functions of response time. They report a linear correlation of ln(transmission) and ionization current, with a different shape for smoldering or flaming.

647. Moore, P.: Houston, We Have a Fire On Board. New Sci., vol. 145, no. 1963, 1995, pp. 36–39.

This is an article in a popular British magazine. It overemphasizes the shuttle incidents as problems. The author notes the characteristics of zero gravity, and he mentions the Solid Surface Combustion Experiment, the European Space Agency experiments, fire ventilation modeling, and anticipated problems in suppression.

648. Sharma, S.K.: Measurement of Smoke From Fires: The Present Trends. J. Sci. Ind. Res. (India), vol. 54, no. 2, 1995, p. 98.

This is a review illustrating various smoke chamber and instrument methods, with typical values of smoke, soot, and optical obscuration. It introduces the concept of mean optical density or smoke density per unit mass loss.

649. Daviss, Bennett: Heavens on Earth. Air and Space, vol. 9, no. 6, February/March 1995, pp. 34–41.

This is a popular article on the NASA Lewis 2.2-second and 5.2-second drop towers and the Learjet airplane. As an example, the article explains and illustrates the experiment on the interaction of flames over parallel solid surfaces.

650. Aerospace Safety Advisory Panel: Topical Annual Report. NASA TM–110554, 1995, pp. 7 and 19–20.

In the report, Finding 3 notes the inadequacy of the use of laptop computers to localize faults on the space station, and Finding 4 notes the absence of experimental zero-gravity data on CO_2 fire extinguishers.

*650A. Ostroumov, B.; and Legostaev, V.: ISS ALPHA: Main Provisions on Fire Detections and Extinguishing. NASA Contract NAS15–10110, Document Number 0006A8a, March 13, 1995.

The document is essentially the same as Reference 607, with a better English translation. Principal changes over the previous requirements are the increase in habitable O_2 concentration from 23 to 24.8 percent, and changes in fire alarms to cover all modules. The document notes that the fire detection and suppression system on the FGB (the Russian tug) differs from that of Kvant and Kristal. It changes the description of the Russian ESO–2 detector to an "electric induction fire detector."

*651. Benson, Johan: Conversations With Harry Holloway. Aero. Amer., vol. 33, no. 4, 1995, pp. 15–17.

This article is an interview with the NASA Associate Administrator for Life and Microgravity Sciences and Applications. The administrator expresses his opinion that combustion is important and is different in zero gravity. He also states perhaps controversially that spacecraft designs are changed because fires produce no smoke and smoke detectors are worthless.

*652. Ross, Howard D.; Gokoglu, Suleyman A.; and Friedman, Robert, eds.: Microgravity Combustion Science: 1995 Program Update. NASA TM–106858, 1995.

This is the third in the series of microgravity-combustion reviews, updating those of References 347 and 512. Fire safety is discussed in a brief review of shuttle and International Space Station practices, the needs and opportunities for research, and current projects. The latter include the conclusions of the National Institute of Standards and Technology (NIST) material flammability assessment and the University of California, Los Angeles, risk-based fire safety experiment. The wire insulation findings are also mentioned. The science section of the review covers soot morphology in zero gravity and concurrent- and opposed-flow solid surface combustion, as well as a description of the NASA Lewis 2.2-second and 5.2-second drop towers and DC–9 airplane facilities.

*653. Abbud-Madrid, A.; Branch, M.C.; and Daily, J.W.: Ignition and Burning Behavior of Pure Bulk Metals Under Normal and High-Gravity Conditions. Presented at the Combustion Fundamentals and Applications Joint Technical Meeting, Central and Western States and Mexican National Sections, International Combustion Institute, San Antonio, TX, 1995.

While this is basically the same material as presented in Reference 634, it concentrates on Ti combustion and illustrates transition, critical, and ignition temperature and contains pictures of Ti particles with oxygen penetration after combustion.

654. Milke, James A.; and McAvoy, Thomas J.: Analysis of Signature Patterns for Discriminating Fire Detection with Multiple Sensors. Fire Tech., vol. 31, no. 2, 1995, pp. 120–136.

The authors conducted tests on multisensor fire detectors, incorporating light obscuration, CO, CO_2, and O_2 concentration sampling as well as Taguchi metal oxide gas sensors for oxidizing gases. Results classify the sources as flaming fires if CO_2 exceeds 11 500 ppm and as pyrolyzing solids if CO exceeds 28 ppm and metal oxide response is less than 6 V. Outside this range, the sources are nuisance odors (spray, polish, etc.). The paper shows a more complex network involving the photoelectric source.

655. Rygh, Knut: Fire Safety Research in Microgravity: How to Detect Smoke and Flames You Cannot See. Fire Tech., vol. 31, no. 2, 1995, pp. 175–185.

The paper has the same title as Reference 589. It is a summary of the project documented in References 534, 589, 612, and 623. The paper notes the lack of information on fire characteristics in zero gravity that is useful for detection and suppression. It describes the full program of 191 flights on the Caravelle airplane with a free-floated test apparatus. Gas flames are initially blue and then invisible in quiescent conditions. In air flow, they turn yellow. Flames over paper, cloth, and wood are invisible but show infrared responses. Some materials self-extinguish in quiescent conditions but burn under air flow. The 30 %O_2, 10.2 psi condition intensified burning. New results are reported for the dispersion of aviation fire-fighting foam (AFFF with no fire) in 50 parabolic tests with a target 60 cm from a nozzle. Only a slight increase in pressure is needed to achieve the same spray in zero gravity as in normal gravity. The foam does not “curl” over the deflector plate to cover the back side of the target (as it does in normal gravity). The AFFF did form a good steady film in zero gravity, while other liquids (water) bounce off surfaces.

656. Ross, Howard D.: Combustion and Fire Safety in Microgravity.: Proceedings of the Microgravity Science and Applications Session, International Aerospace Conference (held August 16–17, 1994), R.K. Crouch and V.I. Polezhaev, eds., NASA/Inst. Problems in Mechanics, RAS, May 1995, pp. 225–236.

This is a review covering much of the same material as in Reference 652. Three motivations for zero-gravity combustion studies are given. They are scientific knowledge, on-orbit fire safety, and practical benefits or relevance. For fire safety, the author notes that the shuttle incidents show that current practices are adequate. Nevertheless, scientific and engineering studies are necessary, because (1) the zero-gravity environment may enhance flammability, (2) safety studies are evolutionary, (3) the International Space Station and advanced missions will have complex configurations and long-duration exposure to low-gravity environments, and (4) the current designs need further tradeoffs and optimization.

657. Belyaev, Andrey Yu.; Egorov, Sergey D.; Ivanov, Anatoly V.; Klimin, Lev P.; Balashov, Yevgeni V.; Grigorov, Edward I.; Zaitsev, Yevgeni N.; and Semyonov (Semenov), Alexey V.: Main Trends of Investigations of Material Combustion in Reduced Gravity for Orbital Station Fire Assurance. Proceedings of the Microgravity Science and Applications Session, International Aerospace Conference (held August 16–17, 1994), R.K. Crouch and V.I. Polezhaev, eds., NASA/Inst. Problems in Mechanics, RAS, May 1995, pp. 237–240.

This paper describes research conducted at the Keldysh Scientific-Research Institute of Thermal Processes, Moscow, with contributions (first four authors) from NPO Energia. The paper quotes prior studies on the limiting flow (minimum to sustain combustion) versus O_2 results for poly(methyl methacrylate) (PMMA) combustion at zero gravity in the 0.72-second facility (Refs. 145A and 181A). The paper has a sketch of the combustion tunnel, Skorost, under development for tests on the Mir space station. The work also notes the simulation of zero gravity on the ground by low-pressure combustion, where convection is slight and flames are spherical (Refs. 162A and 226B).

658. Sánchez-Tarifa, Carlos: Flame Spread Experiments Carried Out in the Minitexus 3. Unpublished Report, Escuela Técnica Superior de Ingeneios Aeronáuticos, University Politéc Madrid, June 13, 1995.

This summarizes microgravity tests of 6-mm-diameter poly(methyl methacrylate) (PMMA) rods in a sounding rocket. The tests in 37 vol% O_2/N_2 covered a range of conditions including axial and inclined (45°) rods in quiescent atmospheres and in concurrent and opposed flows of 5, 10, and 20 cm/s. The enriched atmosphere is near the extinction limit. The quiescent flames are invisible, but after initiation of air flow, the flame becomes visible. For the axial rods, flame-spread rates are approximately 0.12 to 0.18 mm/s quiescent, 0.63 mm/s at 5 cm/s, 0.81 mm/s at 10 cm/s, and not determined at 20 mm/s. Corresponding normal-gravity flame spreads are 1, 1.04, and 1.08 mm/s, respectively (vertical orientation, opposed flow). For inclined rods in zero gravity, flame spread rates are about the same for opposed flow, but they are 0.75 mm/s at 5 cm/s flow (3.0 mm/s for normal gravity), 1.2 mm/s at 10 cm/s flow (3.2 mm/s for normal gravity), and 2.1 mm/s at 20 cm/s (3.6 mm/s for normal gravity).

659. Ku, Jerry C.; Griffin, Devon W.; Greenberg, Paul S.; and Roma, John: Buoyancy-Induced Differences in Soot Morphology. Comb. Flame, vol. 102, nos. 1/2, 1995, pp. 216–218.

A brief communication gives results of soot sampling in the NASA Lewis 2.2-second drop tower. Particle samples were taken above ethylene and propane flames from 1.65-mm-diameter tubes. The primary-particle diameters in microgravity are approximately 2 times as large as those in normal gravity. The normal-gravity data show soot particle growth and burnout, whereas the microgravity data show near-uniform soot well above the burner exit. For ethylene, there is little difference between 1.0 and 1.5 cm^3/s flows. For propane, a 1.5 cm^3/s flow gives perhaps 25 percent greater precursor particles. Because of a factor of 20 longer residence time, mean aggregate lengths in microgravity over normal gravity are 20 times greater for ethylene and 6 times greater for propane. These results are also shown in Reference 652, fig. 12.

*660. Committee on Microgravity Research, Space Studies Board: Microgravity Research Opportunities for the 1990s. National Research Council, Washington, DC, 1995.

The executive summary has ranked priorities for microgravity research. Number 1 establishes the need for variable-gravity studies of fire; number 2 notes fire research subfields of ignition, flammability limits, smoldering, flame spread, and extinguishment. The report also notes the present knowledge and future needs in fire-safety research.

661. Janssens, Marc L.: Methods and Equations of Fire Calorimetry. Fire Calorimetry, Marcelo M. Hirschler and Richard E. Lyon, eds., DOT/FAA/CT–95/46, 1995, pp. 11–22.

The paper was one of those presented at a July 27–28, 1995, conference sponsored by the Federal Aviation Administration and the Interagency Working Group on Fire and Materials. It discusses and illustrates fire calorimetry by sensible enthalpy rise, substitution, compensation, and oxygen consumption methods. It concludes that the oxygen consumption technique is the most accurate and convenient method to measure heat release from fires.

661A. Antonacci, Massimo; Bruno, Giosuè; Ladisa, Pietro; and Parodi, Paola: MPLM ECLS S/S Cabin Air Ventilation and Fire Suppression Test. SAE Technical Paper 951529, 1995.

Ground-test experiments and models examined the CO_2 distribution system on the Multi-Purpose Logistics Module (MPLM). A single storage bottle supplies CO_2 with a nozzle selected for performance. Results confirm that CO_2 reaches 50 percent concentration with 60 s of discharge.

662. Smith, Edwin E.: Heat Release Rate "Calorimetry." Fire Calorimetry, Marcelo M. Hirschler and Richard E. Lyon, eds., DOT/FAA/CT–95/46, 1995, pp. 23–32.

The inventor of the Ohio State University apparatus describes a modification to compensate for convection and radiant heat losses, noting that the Federal Aviation Administration procedure lacks these compensations.

663. Babrauskas, Vytenis: Oxygen Consumption Calorimetry: ASTM and ISO Apparatuses. Fire Calorimetry, Marcelo M. Hirschler and Richard E. Lyon, eds., DOT/FAA/CT–95/46, 1995, pp. 33–44.

The paper covers the history and application of the cone calorimeter, along with some large-scale test methods.

664. Hirschler, Marcelo M.: Use of Heat Release Calorimetry in Standards. Fire Calorimetry, Marcelo M. Hirschler and Richard E. Lyon, eds., DOT/FAA/CT–95/46, 1995, pp. 69–80.

This is a comparison of small-scale fire-test apparatuses and techniques, namely, the Ohio State University method, ASTM E906, cone calorimetry, ASTM E1354, and the technique using the Factory Mutual Research Corporation apparatus. The paper also describes room-sized test procedures.

665. Lyon, Richard E.: Material Properties and Heat Release Rate of Polymers. Fire Calorimetry, Marcelo M. Hirschler and Richard E. Lyon, eds., DOT/FAA/CT–95/46, 1995, pp. 195–204.

The paper presents equations and graphical data charts on ignitability, average heat release, mass-loss rate, and heat of gasification for several plastic materials.

*666. Fernandez-Pello, Carlos; and Pagni, Patrick J.: A Fundamental Study of Smoldering With Emphasis on Experimental Design for Zero-G. NASA CR–198378, 1995.

This report covers smoldering knowledge prior to the Spacelab Glovebox tests in space (Refs. 605 and 669). Basic findings in normal gravity are that for opposed (co-current air flow) smoldering, propagation velocity and temperature increase as flow velocity increases to 2.5 mm/s, but they decrease at greater velocities. Eventually, at higher velocities, smolder ceases. For forward (countercurrent air flow) smoldering, propagation velocity always increases and temperature decreases with air-flow velocity. Low-gravity tests on an airplane indicate that induction of smoldering is favored at low forced-flow rates.

667. King, Merrill K.: Overview: NASA Microgravity Combustion Science Program. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 3–9. (N96-15552).

This is the keynote presentation for the April 11–13, 1995, workshop. The author cites two goals of combustion science: (1) fundamental understanding and (2) enhanced utilization and fire safety. He expands on the practical benefits of combustion research in fire safety, pollution reduction, efficiency of conversion, and combustion synthesis. Most emphasis is on the program and topic areas.

*668. Bundy, Matthew; West, Jeff; Thomas, Peter C.; Bhattacharjee, Subrata; Tang, Lin; Altenkirch, Robert A.; and Sacksteder, Kurt: Solid Surface Combustion Experiment Flame Spread in a Quiescent, Microgravity Environment: Implications of Spread Rate and Flame Structure. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 11–17. (N96-15553).

This paper is another update on the Solid Surface Combustion Experiment, but it is not as current in terms of reporting of flight data as that in Reference 640. The paper does include observations on the burning of 0.32-cm half thickness poly(methyl methacrylate) (PMMA), 0.635 cm wide by 2 cm long. Tests were at conditions of 70 %O_2, 1 atm (carried on shuttle mission STS–54), 50 %O_2, 1 atm (STS–63), and 50 %O_2, 2 atm (STS–64). Only data for the latter condition are in the paper. The data indicate that the flame-spread rate is unsteady, decreasing with length and time, and the flame may eventually extinguish.

*669. Stocker, Dennis P.; Olson, Sandra L.; Torero, Jose L.; and Fernandez-Pello, A. Carlos: Microgravity Smoldering Combustion on the USML–1 Space Shuttle Mission. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 19–24. (N96-15554).

Basically, this is a good condensation of Reference 605.

*670. Greenberg, Paul S.; Sacksteder, Kurt R.; and Kashiwagi, Takashi: The USML–1 Wire Insulation Flammability Glovebox Experiment. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 25–30. (N96-15555).

This paper is largely a repeat of Reference 606. More discussion is given to the implication to spacecraft fire safety, such as the dispersion of molten bubbles, the large quantity and size of soot particles, the ignition of vapors, and the transient quenching in quiescent atmospheres. The authors suggest ventilation cutoff as a fire fighting procedure.

*671. Abbud-Madrid, Angel; Branch, Melvyn C.; and Daily, John W.: Ignition and Combustion of Bulk Metals Under Elevated, Normal and Reduced Gravity Conditions. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 123–128. (N96-15570).

This paper is largely a review of normal and elevated gravity results already reported in References 594 and 653. New data are transition and critical temperatures for several metals, shown in a table. Despite the title, the paper does not cover zero-gravity combustion other than in a statement about plans for airplane tests.

*672. Dreizin, Edward L.; Molodetsky, Irina E.; and Law, Chung K.: Internal and Surface Phenomena in Metal Combustion. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 129–134. (N96-15571).

This is the initial report on the project of arc-generated and ignited falling metal droplets. The paper shows results for Al, a vapor burner, and Zn, a surface burner, in plots of temperature and composition histories. Both metals show solution of O_2 (and N_2 for Zn) in the product melt prior to formation of stoichiometric oxides with longer combustion times.

*673. Goldmeer, Jeffrey S.; Urban, David, and T'ien, James: Effect of Pressure on a Burning Solid in Low-Gravity. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 135–140. (N96-15572).

The purpose of these tests is to examine the effect of pressure reduction on burning and extinguishment. Initial tests on a 1.9-cm-diameter by 2.5-cm-long cylinder of poly(methyl methacrylate) (PMMA) with 10 cm/s air flow normal to the cylinder axis in normal gravity establish that the extinction pressure decreases as fuel centerline temperature increases. Parameters that influence the fuel temperature, such as initial pressure or depressurization rate, also affect the extinction pressure. The authors conducted low-gravity tests in the NASA Lewis Learjet airplane at either a constant pressure level or a variable decreasing pressure level. The flammability boundaries at zero gravity are not yet determined. It is inferred that the zero-gravity flammability limit in quiescent conditions will be above the International Space Station specifications for venting from 101 to 33 kPa within 10 min. During the time required to reach the limit, based on vent valve conditions, the fire may continue to burn.

*674. McKinnon, J. Thomas; and Duan, H.M.: Thermal Degradation of Polytetrafluoroethylene in Tube Reactors. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 147–151. (N96-15574).

This paper presents preliminary, mainly qualitative, results on the degradation of polytetrafluoroethylene (PTFE) powder in a tube furnace in normal gravity. Under dry air, the researchers noted that reaction times are shortest, the smoke greatest, and C_2F_4 in the product gas greatest. Under N_2, they noted that reaction times are longest, smoke and C_2F_4 are least. Under wet air, results are intermediate.

*675. Urban, David L.; Griffin, DeVon W.; Gard, Melissa Y.; and Hoy, Michael: Smoke Detection in Low-G Fires. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 175–180. (N96-15579).

All previous zero-gravity studies of smoke particulates have been in essentially the early stages of fires because of the severe time limitations of drop towers. The Comparative Soot Diagnostics (CSD) experiment is a shuttle project to model longer phases of the fire processes. In the CSD apparatus, a shuttle and an International Space Station smoke detector are each exposed to emissions from a concurrent-flow ventilated candle, and overheated file paper, silicone rubber, polytetrafluoroethylene- (PTFE-) insulated wire, and Kapton-insulated wire. Samples allow repeatable mass losses of ~2 mg. Issues to be resolved include dust discrimination, sampling, fire signatures, and alarm levels.

676. West, Jeff; Thomas, Pete; Chao, Ruian; Bhattacharjee, Subrata; Tang, Lin; Altenkirch, Robert A.; and Olson, Sandra L.: Low Velocity Opposed-Flow Flame Spread in a Transport-Controlled Environment DARTFire. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 189–194. (N96-15581).

This is a preliminary report with the requirements and models for the DARTFire project. The project plans to conduct six sounding rocket tests of flame spread over poly(methyl methacrylate) (PMMA) with 1 to 20-cm/s opposed flow, 0 to 2 W/cm^2 external flux, and 35 to 70 %O_2.

*677. Egorov, S.D.; Belayev, A. Yu.; Klimin, L.P.; Voiteshonok, V.S.; Ivanov, A.V.; Semenov, A.V.; Zaitsev, E.N.; Balashov, E.V.; and Andreeva, T.V.: Fire Safety Experiments on “Mir” Orbital Station. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 195–199. (N96-15582).

The authors (first five are from the Keldysh Scientific-Research Institute of Thermal Processes in Moscow, the rest are from Energia) describe the Skorost combustion chamber (Ref. 657) and cite tests in the standard Mir atmosphere of 23 %O_2 at 88 kPa. First tests with smoldering cotton showed that the burning rate increases from 2.9 mm/s at an air flow of 2 cm/s to 43 mm/s at 20 cm/s. Second tests with poly(methyl methacrylate) (PMMA) burned a 1-mm-thick slab, which showed an increase in spread with air flow. The investigators also note the results of tests where samples with 2- and 3-mm thicknesses are ignited. When the samples are half burned, the air flow is turned off. The flames become spherical and turn blue from the initial yellow-orange. Fuels extinguish in 7 to 15 s after air flow ceases.

*678. Ito, Kenichi; and Fujita, Osamu: Research on Ignition and Flame Spread of Solid Materials in Japan. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 201–206. (N96-15583).

The paper describes two experiments. In the first, fine wires (AWG 24 to 30) with polyethylene insulation are ignited. At 30 %O_2, the microgravity flames as observed in tests in the Japan Microgravity Center (JAMIC) 10-second facility are spherical and spread at a rate about 2.5 times less than in normal gravity. If the wires are preheated to 125 °C prior to ignition by a Nichrome coil, the microgravity flame spread doubles, but the ratio of microgravity/normal gravity spread rate remains the same. Flame-spread rates both in normal gravity and microgravity increase slightly as pressure is decreased to 0.4 atm. In the second experiment, conducted in the Hokkaido University 1.4-second drop tower and JAMIC, the investigators ignited polystyrene beads as a model of porous materials. Propagation increases as O_2 concentration increases from 20 to 50 percent, but at all concentrations the normal-gravity rate is twice the microgravity rate.

679. Kashiwagi, Takashi; McGrattan, Kevin; and Baum, Howard: Ignition and Subsequent Transition to Flame Spread in a Microgravity Environment. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 207–212. (N96-15584).
This paper describes a continuation of the modeling of Reference 627. Results indicate that for axisymmetric flame spread with an imposed wind (~2 cm/s) over a thin paper sheet, the flame propagates upstream (against the wind) but extinguishes downstream because of a lack of oxygen and radiative heat losses.

*680. Ronney, Paul D.: Premixed Atmosphere and Convective Influences on Flame Inhibition and Combustion (PACIFIC). Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 213–217. (N96-15585).
This is a presentation of the requirements for a project to determine thin-paper and poly(methyl methacrylate) (PMMA) flammability with opposed flow under atmospheres with various diluents, such as CO and CH_4. This project will be conducted in the NASA Lewis 2.2-second drop tower. Its purpose is to simulate the effects of unburned fuel and leakage hazards on spacecraft cabin flammability.

*681. T'ien, James S.; Sacksteder, Kurt R.; Ferkul, Paul V.; Greenberg, Paul S.; Jiang, Ching-Biau; and Pettegrew, Richard D.: Flame Spread Over Solid Fuel in Low-Speed Concurrent Flow. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 219–225. (N96-15586).
The paper first reviews modeling of radiation effects on microgravity flame spread. Then it describes the Forced Flow Flame-Spread Test (FFFT) and Solid Inflammable Boundary at Low Speeds (SIBAL) projects. The FFFT uses a small wind tunnel, originally from the Wire Insulation Flammability project (Ref. 606) to conduct burning tests on flat paper and cellulose cylinders in various air flows. In the Glovebox accommodation on the Russian Mir-Priroda space module, FFFT will test the combustion of flat paper specimens of different thicknesses. The SIBAL project, still in review, will add the capability to vary the atmospheres to measure extinction boundaries of thin-paper fuels.

*682. Urban, David L.: Interactions Between Flames on Parallel Solid Surfaces. Third International Microgravity Combustion Workshop, H.D. Ross, ed., NASA CP–10174, 1995, pp. 233–238. (N96-15588).
This paper describes microgravity experiments conducted in the NASA Lewis 2.2-second drop tower, in which two parallel sheets of thin paper (lab wipes) were ignited in 30 %O_2 atmospheres and corresponding normal-gravity experiments at 21 %O_2. Observations showed the microgravity separation regimes: (1) for gaps up to 10 mm, no flame is in the gap (flames are on the outer sides of the sheets only), (2) for gaps from 10 to 30 mm, a flat to notched flame is in the gap, and (3) for gaps greater than 30 mm, separate flames are on each sheet. In normal gravity, flame fills the gap at separations up to 6.4 mm, and separate flames exist for greater separations. In microgravity for separation distances greater than 10 mm, the flame-spread rate is uniform at 1.5 to 1.8 cm/s, equivalent to the single-sheet spread. At lower separations, the spread rate decreases sharply. When He is used as the atmospheric diluent, microgravity spread rates are nearly doubled, and the flame does not form in the gap until the separation is >30 mm.

683. National Research Council (National Materials Advisory Board): Fire- and Smoke-Resistant Interior Materials for Commercial Aircraft Interiors. Publication NMAB–477–1, National Academy Press, Washington, DC, 1995.
This is the conclusions and recommendation of a conference, of which References 684 and 685 are individual papers. The publication covers research opportunities in materials, material testing, and fire modeling. The committee findings cover topics in materials, designs, testing, and modeling.

684. Murray, Thomas M.: Airplane Accidents and Fires. Improved Fire- and Smoke-Resistant Materials for Commercial Aircraft Interiors: A Proceedings. E.M. Pearce, ed., Publication NMAB–477–2, Federal Aviation Administration, Washington, DC, 1995, pp. 7–24.

This report presents statistics, cited in later Boeing presentations, on commercial fleet size, departures, accidents, accident rates, fatalities, causes, and fire fatalities over the period of 1959 to 1993. Four accidents are discussed as fire scenarios: Salt Lake City, Cincinnati, Calgary, and Manchester.

685. Tewarson, Archie: Fire Properties of Materials. Improved Fire- and Smoke-Resistant Materials for Commercial Aircraft Interiors: A Proceedings, E.M. Pearce, ed., Publication NMAB–477–2, National Academy of Sciences, Washington, DC, 1995, pp. 61–91.

This is a good review of fire concepts, extending the 1994 review of Reference 621. The report covers pyrolysis, combustion, ignition, propagation, heat release, and nonthermal damage, with examples and correlations of the concepts.

686. Apostolakis, G.E.; Catton, I.; Issacci, F.; Jones, S.; Paul, M.; Paulos, T.; and Paxton, K.: Risk-Based Spacecraft Fire Safety Experiments. Reliability Engineering & System Safety, vol. 49, no. 3, 1995, pp. 275–291.

This is a final condensation of the NASA Risk-Based Spacecraft Fire Safety Experiments project, and it goes into a certain amount of detail. The article covers the concepts of probabilistic risk assessment, risk management, shuttle experience, logic, and the experiments. Results cite wire temperature, mass loss, particle size, and smoke.

687. Frank, M.V.: Choosing Among Safety Improvement Strategies—A Discussion With Example of Risk Assessment and Multicriteria Decision Approaches for NASA. Reliability Engineering & System Safety, vol. 49, 1995, pp. 311–324.

This study analyzes the failure of hydrogen leakage and its consequences for 1 to 3 Shuttle auxiliary power units (APUs). The introduction discusses the needs of spacecraft compared to those of nuclear power plants, the scenario, approach, and alternatives. Six strategies are assessed on the basis of benefit to cost ratio and analytical hierarchies with a matrix calculation. Interestingly, NASA modified the APU later, and the approach of this study is no longer relevant to the current models.

688. Edwards, John C.; and Morrow, G.S.: Evaluation of Smoke Detectors for Mining Use. U.S. Bureau of Mines Report of Investigations, no. 9586, 1995.

Smoke chamber tests evaluated two optical and four ionization smoke detectors, some with diffusion sampling and some with pumped sampling. Smoke was generated by smoldering and flaming coal combustion. The paper contains reference measurements of the smoke optical density. The authors note that an optical density of 0.022 m^{-1} corresponds roughly to 10 m visibility (reference is made to a paper, Rasbach, J.D.; Sensitivity Criteria for Detectors Used to Protect Life. Fire International, vol. 5, no. 49, September 1975, pp. 30–44). CO measurements noted an increase of 5 ppm corresponding to 0.022 m^{-1} from both flaming and smoldering coal fires. Two of the four ionization detectors were more sensitive to flaming fires, and both optical detectors were more sensitive to smoldering, no doubt because of the larger smoke particles produced in smoldering.

689. Brozovsky, E.; Motevalli, V.; and Custer, R.L.P.: A First Approximation Method for Smoke Detector Placement Based on Design Fire Size Critical Velocity, and Detector Aerosol Entry Lag Time. Fire Tech., vol. 31, no. 4, 1995, pp. 336–354.

Experimental wind tunnel work with propylene glycol aerosol and photoelectric smoke detectors establishes a rough correlation useful for detector sizing. Results show that the optical density within the detector is lower than and lags behind the optical density in the ambient. A critical velocity is defined below which the detector response time is very long. Critical velocities are of the order of 10 to 20 cm/s, consistent with Underwriters Laboratories, Inc. standards, which require a response sensitivity of 0.5 to 4.0 percent obscuration per foot.

*690. Schulze, Norman: NASA Wiring for Space Applications Program. Third NASA Workshop on Wiring for Space Applications, NASA CP–10177, 1995, pp. 3–20.

This is a reprint of a viewgraph presentation, with a table of wiring system incidents, causes, and results.

*691. Cahill, Patricia: Electrical Short Circuit and Current Overload Tests on Aircraft Wiring. Third NASA Workshop on Wiring for Space Applications, NASA CP–10177, 1995, pp. 41–48.

This Federal Aviation Administration paper cites some airplane incidents, describes the electrical current overload tests, and indicates the danger from “arc-tracking” faults.

692. Johnson, Harry T.; and Hirsch, David: NASA Wiring for Space Applications Program Test Results. Third NASA Workshop on Wiring for Space Applications, NASA CP–10177, 1995, pp. 69–84.

This is a reprint of a viewgraph presentation. There are charts of standard White Sands Test Facility tests at 30 $\%O_2$ in which Kapton and most polytetrafluoroethylene (PTFE) insulations (except extruded ethylene tetrafluoroethylene, ETFE) pass the flammability tests. Other charts show analyses of off-gas products at 120 °F.

*693. Stueber, Thomas J.; and McCall, David: Comparison of Arc Tracking Tests in Various Aerospace Environments. Third NASA Workshop on Wiring for Space Applications, NASA CP–10177, 1995, pp. 93–99.

Tables and charts compare normal gravity, normal gravity vacuum, and low-gravity DC–9 airplane tests of three wire insulations: Kapton/PTFE (polytetrafluoroethylene), Filatex, and Tensulite. Very limited data show the longest arc travel is in low gravity, the shortest in normal gravity, and an intermediate travel in normal gravity vacuum.

694. Hshieh, Fu-Yu; and Beeson Harold D.: Evaluation of the Controlled-Atmosphere Cone Calorimeter for Determining Fire Properties of Materials According to NASA Handbook 8060.1C Test 2. NASA TM–104809, 1995. (N96-22208)

This is a NASA White Sands Test Facility study on the Custom Scientific Model CS–237 controlled-atmosphere cone calorimeter testing (continuing the studies of Refs. 546 and 570) of space-rated plastics, rubber and foam, and fire-retarded cotton. Generally, materials were tested over a range of heat fluxes of 25 to 75 kW/m^2 and from 15 to 30 $\%O_2$. Extensive plots of results are shown. For most materials, mass-loss rate and heat release rates are linear functions of O_2 concentration and heat flux. The authors recommended that materials be tested at 35 kW/m^2 to represent small spacecraft fires (NHB 8060.1C Test 2 requires 25, 50, and 75 kW/m^2), and gas flow be maximized at 30 g/s.

695. Hshieh, Fu-Yu; and Beeson Harold D.: Cone Calorimeter Testing of Epoxy/Fiberglass and Brominated Epoxy/Fiberglass Composites in Normal Oxygen and Enriched Oxygen Environments. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres. Seventh vol., Dwight D. Janoff, William T. Royals, and Mohan V. Gunaji, eds., ASTM Special Technical Publication 1267, ASTM, Philadelphia, PA, 1995, pp. 152–167.

This is a NASA White Sands Test Facility study, similar to that of Reference 694, on three composite materials using a controlled-atmosphere cone calorimeter. Results show that the time of ignition is inversely proportional to the 1.5 power of heat flux and is independent of O_2 mole fraction. Results also show peak and average heat release and the CO_2/CO ratio. Interesting results are for NASA upward flammability test, where upward spread rate and flame length correlate roughly linearly with peak heat release ratio.

696. Branch, Melvyn C.; Daily, John W.; and Abbud-Madrid, Angel: Ignition and Combustion of Bulk Metals at Normal, Elevated and Reduced Gravity. NASA CR–200007 (CCR–95–05), 1995. (N96-17775).

This work continues the University of Colorado combustion of bulk metals study (Refs. 653 and 671) with the first results of low-gravity, DC–9 airplane, tests on Ti and Mg combustion. The Mg samples have faster ignition time (by 15 percent) and slower burning rates (by 100 percent) in low gravity compared to normal gravity. In contrast, Ti samples have slower ignition times (by 20 percent) and slower burning rates (by 100 percent) in low gravity.

697. Ivanov, A.V.: A Study of the Material's Combustion Process in Microgravity. Keldysh Research Center. Report no. 2294 on Treaty N920/9–5208/95: 400–1/34–95; December 29, 1995.

This expands on Reference 657. It briefly reviews past work in the United States and Europe on microgravity solid combustion. Previous results in Russia showed that combustion can occur in quiescent conditions only for a gravity level $>2\times10^{-2}$g. This was confirmed by measurements of the limiting forced convective flow for poly(methyl methacrylate) (PMMA) in the Moscow Aviation Institute drop tower (0.5 to 1.5 s). Other past work cited are studies at the All-Russian Research Institute for Fire Protection, VNIIPO, in a narrow slot chamber and at the Russian National Institute of Thermal Processes, NIITP, in a pressure balanced chamber design, both apparatuses designed to suppress natural convection (reduced Grashof number). The report also describes the Skorost combustion tunnel for microgravity testing on the Mir space station. It gives only qualitative results for cotton and PMMA for Skorost. (Ref. 677 has more data.)

698. Abbud-Madrid, A.; Branch, M.C.; and Daily, J.W.: On the Burning Behavior of Radiatively- Ignited Bulk Titanium and Magnesium in Low Gravity. AIAA Paper 96–0262, 1996.

This paper is identical to that of Reference 696, except for the omission of a FUTURE RESEARCH section.

699. Bhattacharjee, S.; Altenkirch, R.A.; and Sacksteder, K.: The Effect of Ambient Pressure on Flame Spread Over Thin Cellulosic Fuel in a Quiescent, Microgravity Environment. J. Heat Trans., vol. 118, 1996, pp. 181–190.

This is another paper based on the results of the Solid Surface Combustion Experiment. The paper offers pictures and models of burning paper at 50 $\%O_2$, and 1.0, 1.5, and 2.0 atm pressure. The radiation modeling gives close agreement to experiment for flame-spread rate (slightly altered from those derived earlier and reported in Ref. 640), and reasonable agreement for maximum temperature.

700. Aerospace Safety Advisory Panel Annual Report. NASA TM–110474, 1996.

The previous year's report had a recommendation (Ref. 650, Finding 4) to obtain data on CO_2 extinguishing reliability. The current Aerospace Safety Advisory Panel report states that NASA has found that data for closed volumes, such as racks, show adequate CO_2 concentrations for extinguishing. Additional testing is underway.

701. Anon.: Fatal Fire. NFPA J., vol. 1, 1996, p. 68. This is a brief story of the January 27, 1967, Apollo-1 fire.

This is a brief recount of the events during the January 27, 1967, Apollo-1 fire.

702. Friedman, Robert: Fire Safety Designs and Operations in Spacecraft. Proceedings of the 1996 Design Engineering Conference, Session D13, Chicago, IL, March 19, 1996, pp. 137–147.

This is another review of spacecraft fire safety. It stresses design issues in atmospheric control, material selection, ignition-source elimination, containment, isolation, as well as fire detection and suppression.

703. Sarkos, Constantine P.: Future Fire Safety R&D, in Galaxy Scientific Corp.: International Conference on Cabin Safety Research. DOT–FAA–AR–95/120, 1996, pp. 293–304.

This paper reviews aircraft fire-safety activities of the Federal Aviation Administration Aircraft Systems Fire Safety Program. The paper has a brief mention of past accomplishments. Greater attention is given to current research and development and future needs: particularly, Halon replacement, cabin water spray for extinguishment, fire detection, lavatory fire protection, aerosol-can hazards, in-flight fires, fuselage burn through in crash fires, and onboard oxygen-generating systems.

704. Eklund, Thor I.: NRC Findings and Recommendations on Fire Resistant Aircraft Materials. International Conference on Cabin Safety Research Conference Proceedings. DOT/FAA/AR–95–120, 1996, pp. 357–385.

The relevant portion of this paper is figures that give breakdowns of the proportion of airplane accidents with fatalities and with fire-related fatalities.

*705. Stueber, Thomas J.; Hammoud, Ahmad; and McCall, David: Comparison of Arc Tracking Tests in Various Aerospace Environments. NASA CR–198463, 1996.

This is a brief statistical treatment of arc-tracking lengths in normal gravity, low gravity, and normal gravity with a vacuum, from tests originally reported in Reference 693. Mean arc-tracking lengths of the baseline Kapton/polytetrafluoroethylene (PTFE) insulation increase about 30 percent in microgravity and decrease by a factor of 6 in a vacuum. Filotex arc lengths also increase in microgravity but increase 10 percent in a vacuum. Those of Tensolite decrease by 10 percent in microgravity and also decrease by a factor of 3 in a vacuum.

705A. Polk, Robert L.: Smoke Detectors for Spacecraft and Aircraft. AIAA Life Science and Space Medicine Conference, Houston, TX, Abstract AIAA 96–LS–21, 1996, p. 42.

The Space Station design of photoelectric smoke detection is to be adapted to the 777 aircraft cargo bay. The paper notes the differences in environment and needs. The Space Station requires six times the 777 alarm sensitivity, a narrow temperature range (the 777 range is -65 to +71 °C), and a means of signal reporting. The 777 model uses a light emitting diode (LED) light source rather than a laser.

706. Edwards, John C.; and Friel, Gene F.: Comparative In-Mine Evaluation of Carbon Monoxide and Smoke Detectors. U.S. Bureau of Mines, RI 9622, 1996.

The studies of Reference 688 are extended to measurements in an experimental mine. Two CO detectors and five smoke detectors (both optical and ionization, pumped and diffusion sampling) were compared at various stations from 0.360 to 451 m from a diesel-fuel fire, with ventilation flows of 0.4 to 1 m/s. Pump-sampling detectors alarm earlier than the CO detector. Diffusion-sampling detectors also alarm early for fires with fairly intense smoke. The average CO alarm occurs at an optical density of 0.085/m, while the average ionization alarm occurs at 0.021/m, and the average optical alarm at 0.15/m.

*707. Lekan, Jack; Gotti, Daniel J.; Jenkins, Andrew J.; Owens, Jay C.; and Johnston, Michael R.: Users Guide for the 2.2 Second Drop Tower of the NASA Lewis Research Center. NASA TM–107090, 1996.

This is the latest description and operating manual for the 2.2-Second Drop Tower.

708. Su, Joseph Z.; Kim, Andrew K.; and Mawhinney, Jack R.: Review of Total Flooding Gaseous Agents as Halon 1301 Substitutes. J. Fire Protection Engineering, vol. 8, no. 2, 1996, pp. 45–64.

The Canadian National Research Council authors present a literature review with a number of references, tables of properties, and a brief discussion of suppression performance, physical properties, toxicity, and test results at various scales for flooding Halon substitutes. The paper also includes inert N_2, CO_2, water mists, and dry chemicals as possible Halon substitutes.

708A. Ross, Howard D.: Combustion Processes and Applications in Reduced Gravity. Stewart W. Johnson, ed., Proceedings of the Fifth International Conference on Space, Engineering, Construction, and Operations in Space V, 1996, American Society of Civil Engineers, New York, NY, 1996, pp. 527–532.

This is a review of combustion and applications. Fire safety research is justified by noting the failure of the “worst-case” hypothesis and future needs for fire-safety improvements and tradeoffs. The author discusses partial-gravity combustion, referring to the findings of Sacksteder and T'ien (Refs. 544 and 635) on partial-gravity flame spread and flammability limits. He cites the understanding of zero-gravity combustion as contributing to the International Space Station fire-safety regulations (a 21-percent oxygen atmosphere and immediate flow shutdown upon alarm).

709. Lyon, Richard E.: Material Properties and Flammability of Polymers, in Sorathia, U.; Kelly, J.; Lyon, R.; Gann, R.G.; Skocypec, R.; and Nash, L.: Proceedings of the Sixth Meeting, Interagency Working Group on Fire and Materials, Naval Surface Warfare Center Report NSW.CCD-TR-64-96/68, May 1996, pp. 70-79.

This is an Interagency Working Group on Fire and Materials meeting paper on material properties in ignitability, mass-loss rate, heat of gasification, and heat release rate, with some values for common polymers shown—including a list of pyrolysis products, similar to that of Reference 665.

710. Friel, Gene F.; and Edwards, John C.: Mine Fire Detection by Ultrasonic Ranging Systems. U.S. Department of Energy, RI 9624, 1996.

Fire-detection studies in an experimental mine used ultrasonic rangers, which are ordinarily devices for measuring distances by the time delay of a returned echo. In the case of a fire, the acoustical waves and refractions will alter this signal. This method is less subject to dilution losses than thermal sensing. Two commercials models were used with a diesel-fuel fire located 3.0 to 19.2 m from the transducers mounted across a mine corridor. Both transducers responded. One, using a capacitor, generated an erratic signal compared to the normal signal. The second, using piezoelectric generation, also generated an erratic signal that decayed to zero.

*711. McKinnon, Thomas; Todd, Paul; and Oberdörster, Günter: Combustion of PTFE: The Effects of Gravity on Ultrafine Particle Generation. NASA CR–201112, 1996.

This is the second annual progress report on this project. The pyrolysis of electrically heated polytetrafluoroethylene- (PTFE-) insulated copper wires is examined in a 1.5-second drop tower at the Colorado School of Mines. Laser illumination shows the plume of particles streaming upward in normal gravity. In microgravity, this plume becomes an annular halo that is established only 133 ms after the commencement of the drop. Transmission electron microscopy analyses show distinct differences in the particles due to the color of the wire insulation (black, white, red, and yellow). In normal gravity, all but the red wire show individual-particle emissions; red shows 4- to 10-particle agglomeration. In microgravity, all but white insulation show considerable agglomeration. The shapes of aggregates differ. The corresponding plume temperatures were assessed by computational analysis.

712. Beardsley, Tim: Science in the Sky. Sci. Amer., vol. 274, no. 6, 1996, pp. 64–70.

The review of the International Space Station focuses on cost and utility. It discusses the pros and cons of this station, with emphasis on the negatives. Microgravity combustion is mentioned, quoting Rhome of NASA Headquarters. The paper assumes that microgravity combustion will be more important for fire safety than for commercialization.

713. Anon.: Zero-g A300 Operations. Aviat. Week Space Technol., vol. 145, no. 4, 1996, p. 53.

This is a brief news article describing the new A300B2 low-gravity airplane of Novespace, a Centre National d'Etudes Spatiales (CNES) affiliate.

*714. Blake, David: Evaluation of Large Class B Cargo Compartment's Fire Protection. DOT/FAA/AR–96/5, 1996. (19970013766N).

The Federal Aviation Administration laboratories conducted tests on fire control in cargo compartments in B707, DC–10, and open simulators. These tests simulated fires in Class B airplane compartments. Results show that a crew member would not have sufficient visibility or agent to control the pallet fires. Results also show that the Halon 1301 suppression system is effective. Also useful are fiberglass/Kevlar covers and resistant cargo containers. The report evaluates smoke detectors and notes that photoelectric smoke detector responds slower than infrared radiation detectors, which did respond prior to heat buildup. An appendix defines the classes of airplane cargo compartments.

715. Chauveau, C.; Vieille, B.; and Gökalp, I.: High Pressure Droplet Burning Experiments in Reduced Gravity. AIAA Paper 96–2627, 1996.

The paper describes studies of fiber-supported droplet combustion of five fuels (methanol, ethanol, hexane, heptane, and octane) in low gravity on the Centre National d'Etudes Spatiales (CNES) Caravelle and the NASA KC–135 airplanes. Results show that the d-squared law holds at both normal and low gravity and all pressures. Burning rate increased with pressure in both gravities, but for ambient pressures above critical in low gravity, burning rate and burning lifetime are more or less constant with much scatter. Fuel critical pressures range from 2.5 to 7.95 MPa and test pressures range up to 12 MPa.

716. Winkler, H. Eugene; Cerna, Nanette F.; Rotter, Henry A., Jr.; Ouellette, Fred A.; Hoy, D. Michael; and Brasseaux, Hubert J., Jr.: Shuttle Orbiter Environmental Control and Life Support System—Flight Experience. SAE Technical Paper 961334, 1996.

This is an update of Reference 526, which covered experience with the Environmental Control and Life Support System during the first 46 shuttle missions. This paper extends the observations to 30 more missions, STS–50 to STS–76. One relevant observation is, on the sixth day of STS–66, the Avionics Bay 2 Smoke Detector showed periodic dropouts and was replaced.

717. Williams, David E.: International Space Station Environmental Control and Life Support System Phase Two Design Overview. SAE Technical Paper 961470, 1996.

This paper describes the location and installation phasing of the International Space Station (ISS) Environmental Control and Life Support System. For the fire detection and suppression (FDS) subsystem, the author claims that the fixed suppression was deleted because no long periods of time exist with the ISS unmanned. Two CO_2 portable fire extinguishers (PFE) are in the U.S. Lab and one each in the Node 1 and airlock. (These modules are collectively called the U.S. Operating Segment, (USOS)). Area smoke detectors monitor all three modules, plus as many as thirteen rack locations. Those racks will have red light emitting diodes (LEDs) for alarm indications in addition to the caution and warning panel and the portable computer. The Russian segment (RS) will have smoke detectors distributed behind closeout panels. The RS design combines intramodular ventilation with avionics air cooling. The RS will have new ionization sensors eventually, but presently they are to have Mir photoelectric detectors. The Russian tug (FGB) and service module (SM) will have 10 detectors each. The Russian PFEs use an aqueous-foam agent. There are three in the FGB and two in the SM. The RS will have warning panels to show alarms. The multipurpose logistics module (MPLM) will have three smoke detectors and one PFE; the latter is stored in the USOS when the MPLM is not docked to the ISS. Its FDS is similar to that of the USOS.

718. Carrasquillo, R.L.; Wieland, P.O.; and Reuter, J.L.: International Space Station Environmental Control and Life Support System Technology Evolution. SAE Technical Paper 961475, 1996.

This paper describes the assembly sequence and future needs in the Environmental Control and Life Support System for the Station, with no mention of the fire detection and suppression subsystem.

719. Ivanov, A.V.: A Study of the Material's Combustion Processes in Microgravity. Keldysh Research Center Technical Report No. 2366 on Treaty N920/9–5208/95: 400–I/34–95, 1996.

This report continues the report series of Reference 697. The horizontal and vertical “low-convection” combustion testing facilities at the All-Russian Research Institute for Fire Protection (VNIIPO) are sketched, along with a new facility at Keldysh. In all tests, the materials are ignited outside and then inserted into the flow chamber. The report shows results for limiting concurrent flow velocities at oxygen concentrations of 21, 30, and 40 percent, for several materials including polyethylene, poly(methyl methacrylate) (PMMA), textolite, polyvinyl chloride (PVC), paper, and so forth. The results include measurements of the limiting oxygen concentration for flame propagation. The report also gives some modeling and results and then concludes with a proposal for space investigations with the Skorost apparatus.

*720. Jiang, Xi; Shen, Liping; Zheng, Chuanxian; Zeng, Qingtang; and Fan, Weicheng: Combustion Under Microgravity and Technique of Fire Prevention and Suppression in Space Cabin. Space Medicine and Medical Engineering, vol. 9, no. 4, 1996, pp. 302–307. (19980143210 A)

This is a review of spacecraft fire safety including flame inhibiting atmospheres (English abstract, Chinese text).

721. Lott, Jerry L.; Christian, Sherril D.; Sliepcevich, Cedomir M.; and Tucker, Edwin E.: Synergism Between Chemical and Physical Fire-Suppressant Agents. Fire Tech., vol. 32, no. 3, 1996, pp. 260–271.

Cup burner tests on gaseous heptane flames at the University of Oklahoma show that mixtures of physical-effect extinguishing agents (CO_2 and N_2) and chemical-effect extinguishing agents (Halon 1301 and 1211) are more effective in combination than expected as linear blends. For example, extinguishment requires either 21 percent CO_2 or 3.8 percent H1301alone, but if only 1.1 percent H1301 is added to CO_2, the CO_2 requirement drops to 9.9 percent. A figure of merit is that the total requirements can be as little as 75 percent of that expected in linear blending. This synergism only works with physical-chemical combinations and not with chemical-chemical or physical-physical blends, presumably because a physical-effect agent reduces the O_2 concentration, flame temperature, and free radicals, aiding the chemical agents.

*722. Branch, M.C.; Daily, J.W.; and Abbud-Madrid, A.: Ignition and Combustion of Bulk Metals in a Microgravity Environment. NASA CR–202241 (CCR–96–09), 1996.

This annual report continues the documentation of the research reported in Reference 696 and earlier. This report describes another set of low-gravity airplane tests on Ti and Mg combustion. The decreased propagation rate at low gravity agrees with reaction-rate predictions and Grashof numbers, confirming that the diffusion and convection of O_2 is rate controlling. The report also discusses radiation-induced metal explosions in Mg combustion.

723. Harper, Richard V.; and Solter, David A.: Integration and Test of the International Space Station U.S. Laboratory Module. AIAA Paper 96–4255, 1996.

This Boeing paper has sketches of the U.S. Lab Module, and it describes planned tests for hardware and software integration. Testing of the environmental control and life support system, in ground laboratories will use smoke simulation to determine responses to Class 1 alarms in racks and in the cabin. Cabin response includes shutdown of intermodule ventilation (IMV) fans, closure of IMV valves, and shutdown of the common air assembly.

*724. Friedman, Robert; and Lyons, Valerie J.: Potential Commercial Applications From Combustion and Fire Research in Space. AIAA Paper 96–4439 (NASA TM–107260), 1998. 0140526 A, 19970001589 N.

The report briefly describes microgravity combustion and cites selected results in solid flame appearance, flow effects, droplet combustion, and soot formation. Among the commercial applications presented are normal-gravity fire detection and suppression, combustion, sensors, and materials.

725. McGrattan, K.B.; Kashiwagi, T.; Baum, H.R.; and Olson, S.L.: Effects of Ignition and Wind on the Transition to Flame Spread in a Microgravity Environment. Comb. Flame, vol. 106, no. 4, 1996, pp. 377–391.

This describes tests with thin-paper (Kimwipes) in the NASA Lewis 2.2-Second Drop Tower, with central ignition in a 5- by 15-cm specimen. Flows of 0, 2, or 5 cm/s and O_2 concentrations of 21 and 30 percent in N_2 are investigated. At flow velocities of 2 and 5 cm/s, flames spread into the wind (opposed flow) more rapidly than in quiescent conditions. Downstream spread dies out because of "oxygen shadowing." The authors comment on the radiative influences on ignition delay and on the transition to steady spread.

726. Madou, Marc; and Somps, Chris: Evaluation of Technology for Fire Detection in SSBRP Habitats. NASA A7SP–9702–XR01, 1996.

This is a systems study in the Ames Sensors 2000! Program. The report covers the use of CO, CO_2, humidity, and/or O_2 sensors for fire detection in Space Station biological habitats. The approach is to evaluate 10 or more principles for the sensors. Criteria are commercial availability, room temperature operation, low power, small size, high selectivity, simple calibration, and so on. The selection is not quantitative, only "pass-fail." The study recommends several models, namely amperometric or biomimetric sensors (electrochemical and optical) for CO, IR absorption for CO_2, and electrochemical sensors for O_2.

727. Friedman, Robert: Fire Safety in Spacecraft. Fire Mater., vol. 20, 1996, pp. 235–243.

While this review is based on that of Reference 639, it is greatly expanded to cover microgravity fire characteristics and spacecraft fire protection. It describes specific features in the new International Space Station designs, with a brief summary of research needs.

*727A. Tapscott, Robert: Halon Replacement Options for Use in Aircraft Fire Suppression Systems. DOT/FAA/AR–96/90, 1996. (N97–20516) (AD–A 318188)

This is a good review of extinguishment in general and Halon replacements and alternatives (CO_2, water mists, inert gases) in particular. A tradeoff rating is given for Halon replacements for different aircraft locations.

728. Saito, Naoshi; Ogawa, Yoshio; Saso, Yuko; Liao, Chihong; and Sakei, Ryuta: Flame-Extinguishing Concentrations of N_2, Ar, CO_2 and Their Mixtures for Hydrocarbon Fuels. FSJOD, vol. 27, 1996, pp. 185–200.

The paper by Japanese investigators describes cup and tube burner tests to determine minimum concentrations for the extinguishment of heptane, CH_4, and C_3H_8 flames. Inert gases are N_2, Ar, and CO_2, and the mixtures are (1) IG–541 (Inergen), which is 51.5 %N_2, 41.6 %Ar, and 6.9 %CO_2; (2) IG–55, which is 50 %N_2, and 50 %Ar; (3) 70 %N_2 and 30 %CO_2; and (4) 50 %N_2 and 50 %CO_2. Typical results for minimum extinguishment concentrations for methane and heptane are 33.6 percent for N_2, 43.3 percent for Ar, 22 percent for CO_2, 35.6 percent for Inergen, and 25.9 percent for the 50-50 N_2 and Ar mixture. The results agree well with thermodynamic calculations and previous results. The paper shows flammability limits versus inert concentration for methane and propane. Extinguishment occurs for each diluent when the flame temperature is reduced to a minimum limit (note Ref. 721).

729. Abbud-Madrid, A.; Branch, M.C.; and Daily, J.W.: Reduced-Gravity Effects on the Ignition and Combustion of Bulk Titanium and Magnesium. Presented at the 1996 Western States Section Combustion Institute Fall Meeting, Paper WSS CI 96F–068 (CCR Report no. 96–10), The Combustion Institute, Los Angeles, CA, 1996.

The paper is about the same as Reference 722, except that this paper is slightly shortened and a good conclusion section substitutes for "Future Work."

730. Honda, Linton; and Ronney, Paul D.: Flow and Ambient Effects on Flame Spread at Microgravity. Presented at the 1996 Fall Technical Meeting, Western States Section, The Combustion Institute, Los Angeles, 1996.

Microgravity burning tests of thin paper (Kimwipes) in the NASA Lewis 2.2-Second Drop Tower show that a “partially” premixed atmosphere of CO or CH_4 (below their flammability limits) increases flame spread in normal gravity and microgravity. The effect is stronger at microgravity. With diluent addition, results are surprising. With He and N_2 in the atmosphere, the normal-gravity flame spread is greater than the microgravity spread. With CO_2, the spread rate in microgravity increases to approximately normal-gravity values. With SF_6, the microgravity flame spread increases to a rate greater than that in normal gravity. The authors attribute these phenomena to Lewis number or radiation effects.

731. Goldmeer, Jeffrey S.; Urban, David L.; and T'ien, James S.: Extinguishment of a Diffusion Flame Over a PMMA Cylinder by Depressurization in Low-Gravity, in Beall, Kelly A.: Annual Conference on Fire Research: Book of Abstracts, NISTIR 5904, October 1996, pp. 63-64. (19970028144); also in Proceedings of the 1997 4th International Microgravity Combustion Workshop, no. 10194, 1997, pp. 435–440.

This is a continuation of Reference 673 with more modeling of extinction boundaries. The flammability at low pressures is greatest at an imposed flow of 10 cm/s. The authors recommend that, for venting suppression, depressurization should be rapid (perhaps >20 cm/s) to a limit of 10 kPa (0.1 atm).

732. Edwards, J.C.: Laboratory and Mine Scale Evaluation of Smoke Detectors. National Institute of Standards and Technology Annual Conference on Fire Research: Book of Abstracts, NISTIR 5904, 1996, pp. 109–110. (19970028144)

This is a summary of References 688, 706, and 710. Smoke chamber tests indicate that optical detectors are superior for smoldering, and ionization detectors for flaming. Other studies in this project covered ultrasonic detectors.

733. Hall, John R, Jr.: Whatever Happened to Combustion Toxicity? Fire Tech., vol. 32, no. 4, 1996, pp. 351–371.

This article is a very good, basic presentation of combustion toxicity, with four references. A table shows that most fire deaths in the United States are due to "smoke inhalation"; for example in 1992, 2866 of 3966 deaths (or 72 percent) are from toxic effects. The discussion concludes that in the United States, most toxicity deaths (80 percent) occur beyond the room of fire origin. In general, CO causes or contributes to all deaths. Three tests, International Organization for Standardization (ISO), National Fire Protection Association (NFPA), and American Society for Testing and Materials (ASTM), measure toxicity, but they require animal testing. For modeling and multigas effects, the N-gas and fractional effective dose models are noted. The article also has comments on nonthermal smoke damage—that is, corrosion occurring after fires—and the lack of data on this hazard.

734. Smith, Edwin E.: Heat Release Rate Calorimetry. Fire Tech., vol. 32, no. 4, 1996, pp. 333–347.

The author is the originator of the Ohio State University (OSU) heat release apparatus and describes it in this report along with a compensation method for radiative and convective heat losses. For materials with high radiative to convective heat-loss ratios, the Federal Aviation Administration method for OSU (ASTM E 906) gives low rate of heat release values by 50 percent compared with compensated values.

*735. Goldmeer, Jeffrey Scott: Extinguishment of a Diffusion Flame Over a PMMA Cylinder by Depressurization in Reduced-Gravity. NASA CR–198550, 1996.

This document is the PhD thesis covering the work reported in References 673 and 731. It has extensive background information on venting suppression, along with estimates of International Space Station venting flows (in an Appendix).

736. Kono, Michikata; Ito, Kenichi; Niioka, Takashi; Kadota, Toshikazu; and Sato, Jun'ichi: Current State of Combustion Research in Microgravity. Twenty-Sixth Symposium (International) on Combustion, Vol. One, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1189–1199.

This is a literature review, with extensive literature citations, but little detail. The paper addresses fire safety in a statement on flow effects. It notes that practical, thick materials are a missing feature in fire safety research. Wire insulation and smoldering studies are also cited.

737. West, Jeff; Tang, Lin; Altenkirch, Robert A.; Bhattacharjee, Subrata; Sacksteder, Kurt; and Delichatsios, Michael A.: Quiescent Flame Spread Over Thick Fuels in Microgravity. Twenty-Sixth Symposium (International) on Combustion, Vol. One, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1335–1343.

The experimental work covers the Solid Surface Combustion Experiment tests on poly(methyl methacrylate) (PMMA), with two samples in each flight, 25.4 mm long by 6.35 mm wide by 3.18 mm thick. Tests were conducted at 70 $\%O_2$ in N_2 at 1 atm pressure (shuttle mission STS–54), and 50 $\%O_2$ in N_2 at 2 atm (STS–64). Resistance-heated Kanthal ignited the strips. The burning rate decreases with time, but continues to the end of the test (250 to 300s). Modeling implies that flames should extinguish. There appears to be a critical thickness for steady spreading in microgravity.

738. Kashiwagi, T.; McGrattan, K.B.; Olson, S.L.; Fujita, O.; Kikuchi, M.; and Ito, K.: Effects of Slow Wind on Localized Radiative Ignition and Transition to Flame Spread in Microgravity. Twenty-Sixth Symposium (International) on Combustion, Vol.One, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1345–1352.

This is a continuation of Reference 725, with tests on 10-cm by 8.7-cm by 0.13-mm-thick Kimwipes in the 10-second Japan Microgravity Center drop tower. The atmosphere is 50 $\%O_2$ in N_2, with quiescent conditions plus air flows of 2 and 5 cm/s. Ignition delay from central radiant ignition is about 3.6 s for all cases. The flames spread in the upstream direction only. Linear char-front propagation is 0.36 cm/s for quiescent conditions, 0.48 cm/s for 2 cm/s flow, and 0.76 cm/s for 5 cm/s flow.

739. Stocker, Dennis P.; Olson, Sandra L.; Urban, David L.; Torero, Jose L.; Walther, David C.; and Fernandez-Pello, A. Carlos: Small-Scale Smoldering Combustion Experiment in Microgravity. Twenty-Sixth Symposium (International) on Combustion, Vol. One, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1361–1368.

This describes the United States Microgravity Laboratory USML-1 Glovebox (a shuttle payload) smoldering test of a polyurethane cylinder fuel. Four tests were performed, with combinations of resistively heated axial and plate igniters, and quiescent and 10 cm/s flow. In microgravity, smolder does not propagate unless the igniter is left on. The most significant result is the large generation of light gases: for example, CO in normal-gravity smoldering is <4.0 ppm, but it is 90 to 3900 ppm in microgravity.

740. Bucher, P.; Yetter, R.A.; Dryer, F.L.; Parr, T.P.; Hanson-Parr, D.M.; and Vicenzi, E.P.: Flame Structure Measurement of Single Isolated Aluminum Particles Burning in Air. Twenty-Sixth Symposium (International) on Combustion, Vol. Two, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1899–1908.

The study covered the combustion of aluminum particles generated by slicing a wire. The initial cylinders melt and are ignited by a laser beam to form freely falling 210-µm-diameter spheres. Quenching is by impingement on a Si wafer. Results show two stages of burning: (1) steady and (2) unsteady with gas ejection. Analyses indicate that AlO forms in the gas phase, and Al_2O_3 in the condensed phase.

741. Molodetsky, I.E.; Dreizin, E.L.; and Law, C.K.: Evolution of Particle Temperature and Internal Composition for Zirconium Burning in Air. Twenty-Sixth Symposium (International) on Combustion, Vol. Two, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1919–1927.

A micro-arc apparatus generated electrically ignited, freely falling Zr particles, 200 µm in diameter. Particles were quenched on impact on a 12-µm-thick Al foil. Analyses of the collected particles show that both O_2 and N_2 are in solution within the quenched particles. Release of gases from supersaturated solutions cause temperature jumps and explosions at later stages of burning.

742. Abbud-Madrid, A.; Branch, M.C.; and Daily, J.W.: Ignition and Combustion of Bulk Titanium at Normal and Reduced Gravity, Twenty-Sixth Symposium (International) on Combustion, Vol. One, The Combustion Institute, Pittsburgh, PA, 1996, pp. 1929–1936.

Except for the title and a sentence or two, this paper is identical to Reference 722.

743. Shih, Hsin-Yi; and T'ien, James S.: Modeling Wall Influence on Solid-Fuel Flame Spread in a Flow Tunnel. AIAA Paper 97–0236, 1997.

Analytical calculations determine the flame-spread rate with concurrent flow in normal gravity over thin paper with a bounding wall, as in a combustion tunnel. Compared with results obtained for an open domain (Ref. 628), the two-branch flammability diagram shifts towards lower velocities and O_2 concentrations. The minimum oxygen concentration (critical oxygen limit) is 12 %O_2 at 4.2 cm/s. The quenching branch limiting flow is about 0.8 cm/s at 21 %O_2. If the tunnel height above the horizontal fuel sheet is reduced from 10 to 2 cm, the flame length increases from 3.5 to 9.6 cm, but as the wall height decreases further, the flame length decreases greatly. The same behavior is noted for flame spread rate.

744. Bahadori, M.Y.; Zhou, L.; and Stocker, D.P.: Effects of Partial Gravity and g-Jitter on Radiation From Jet Diffusion Flames. AIAA Paper 97–0670, 1997.

Tests of methane diffusion flames at low gravity in the NASA Lewis DC–9 airplane show that flame radiation, flame width, and flame axial velocity increase uniformly as the logarithm of the ratio of the gravitational accelerations, log (g/g_0). Hence partial gravity values are intermediate to normal gravity and microgravity.

745. Clarke, Frederic B.: Physiological Effects of Smoke: Managing Escape. ASHRAE Trans., vol. 103, no. 1, 1997, pp. 411–417.

The paper cites statistics that the majority of fire victims die from CO, most are <6 or >60 years in age, and about half have intoxicating blood alcohol levels. In well-ventilated fires and typical laboratory tests, materials vary widely in their CO production; in typical fires however, toxicity is influenced by details of the fire and the availability of O_2, but not on the nature of the burning materials. As flashover approaches, CO evolution is about 0.2 kg/kg fuel burned. Hence, toxic potency tests by themselves cannot rank materials for fire hazards.

*746. Lyons, Valerie; and Friedman, Robert: Overview of Microgravity Combustion Research at NASA Lewis Research Center and Its Potential Commercial Impact. NASA TM–107353, 1997.

This is the same as Reference 724 with the removal of the microgravity combustion background discussion.

747. Hshieh, Fu-Yu; and Beeson, Harold D.: Flammability Testing of Flame-Retarded Epoxy Composites and Phenolic Composites. Fire Mater., vol. 21, no. 1, 1997, pp. 41–49.

Flammability tests of the composite materials used NASA NHB 8060.1C, Test 1 (upward flammability) at 30 %O_2 and 70.3 kPa pressure and Test 2 (controlled cone calorimeter) at 18, 21, and 30 %O_2, 85 kPa pressure and 50 kW/m^2 heat flux. Previous poly(methyl methacrylate) (PMMA) tests showed that the 85 kPa results are little different from those at 101.3 kPa. All the composites passed Test 1, with better fire resistance for phenolics. Test 1 simulates the beginning of a fire at 75 kW/m^2 for 25 seconds. Test 2 results are reported as time to ignition, peak heat release, smoke production rate, and CO yield.

748. Quintiere, J.G.: Fire Growth: An Overview. Fire Tech., vol. 33, no. 1, 1997 pp. 7–31.

This is a literature review and survey of practical fire growth in solid, liquid, and gaseous fuels. The paper discusses the differences among charring, noncharring, thick, and thin fuels and the characteristics of opposed and wind-aided fires.

749. West, J.B.: Fire Hazard in Oxygen-Enriched Atmospheres at Low Barometric Pressures. Aviat. Space Environ. Med., vol. 68, no. 2, 1997, pp. 159–162.

The author cites several previous studies of paper strip and cotton burning in controlled atmospheres. For a constant partial pressure of O_2, the burning rate increases with altitude as expected, since the concentration (percentage) of O_2 increases.. For a constant O_2 concentration (air), the burning rate decreases with altitude, which is somewhat surprising (since fire is thought to be weakly dependent on partial pressure). The author claims that enriched air at altitude is less of a hazard than sea-level air, but data show that enrichment must be modest—perhaps to levels no greater than 3000 m altitude.

750. Paul, M., Issacci, F.; Catton, I.; and Apostolakis, G.E.: Characterization of Smoke Particles Generated in Terrestrial and Microgravity Environments. FSJOD, vol. 28, no. 3, 1997, pp. 233–252.

While the paper repeats some of the previous background of probabilistic safety assessment from References 587 and 686, the new contributions 3 years after the completion of the project are pictures of particles and discussion of the agglomeration of Teflon and Tefzel particles in microgravity.

751. Urban, D.L.; Griffin, D.W.; and Gard, M.Y.: Detection of Smoke From Microgravity Fires. Proceedings from the Technical Meeting of the Central States Section of The Combustion Institute, Point Clear, AL, 1997.

The description of the Comparative Soot Diagnostics project includes some background on smoke detection in space. The paper presents data from 25 shuttle tests on the response of International Space Station (ISS) and Space Transportation System (STS) detectors on flaming and smoldering paper, flaming candles, and pyrolyzing silicone rubber, Teflon, and Kapton. The ISS detector (with 6.6 times amplification) generally responds faster than the STS detector. The paper shows sample images of magnified particle agglomerates of Teflon (0.6 to 1.0 μm in size), Kapton (0.25 μm), and the candle (0.4 to 1.3 μm). There are no normal-gravity data.

*752. Wilson, M.A.; and Moran, J.D.: Advanced Fire Suppression Technology (AFST) Research and Development Program. USAF WL–TR–97–3092, 1997.

Olin Aerospace ran tests of a solid propellant gas generator as a Halon replacement. The project involved testing a canister system in a chamber with hydraulic fluid and JP–8 fires. The generator used proprietary reactants to generate an exhaust mixture of 47 vol% N_2, 31% CO_2, and 22% H_2O. The extinguishment performance, however, was worse than that of the Halon replacement FE–25.

*753. Burgio, F.; Gargioli, E.; and Parodi, P.: Design and Development Approach for the Localised Fire Detection and Suppression Function of Columbus APM. Proceedings of the Sixth European Symposium on Space Environmental Control Systems, Noordwijk, The Netherlands, 1997.

The fire detection and suppression function is required for credible risk areas where failure detection, isolation, and recovery are not available. Such locations are one deck rack, one upper standoff, and two starboard cone panels. Reaction to an alarm consists of several steps: power off, ventilation off, manual suppression, and (a last resort) module depressurization. Typical smoke detection time is 2 to 3 min. Manual fire suppression calls for oxygen reduction to <10.5 percent within 1 min. The paper shows designs of local compartments with swinging door relief. Development tests and modeling are described for ventilation and CO_2 distribution.

754. Chow, W.K.; Wan, Eric T.K.; and Cheung, K.P.: Possibility of Using Laser-Fibre Optics as a Fire Detection System. Opt. and Lasers Eng., vol. 27, 1997, pp. 201–210.

This describes tests of a system where a fiber optic loop connects a He-Ne laser to a photodetector. An adjustable gap of 0.5 to 5.0 mm creates a detection pathway. Smoke passing through the gap attenuates the laser signal. The sensitivities of optical and ionization detectors are compared using data from various smoke sources.

755. Bennett, M.V.; and Bennett, J. M.: Aircraft Engine/APU Fire Extinguishing System Design Model (HFC–125). AFRL–VA–WP–TR–1999–3068, 1997.

Calculations determine concentrations and masses of HFC125 (also known as pentafluoroethane or DuPont FE25) for total flooding of aircraft engine nacelles, dry bays, or auxillary power units. The agent concentrations range from 14 to 26 percent, compared with the Air Force requirement of 6 percent Halon 1301 concentration for 0.5 s (Ref. 306). Of interest is the observation that Halon and its substitutes are not effective in preventing re-ignition by hot surfaces.

*756. Branch, Melvyn C.; Abbud-Madrid, Angel; and Daily, John W.: The Effect of Gravity on the Combustion of Bulk Metals. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 43–48. (19970020555)

This is basically the material of References 722 and 742. A conclusion section explains that the low regression rates in metal combustion in microgravity differ from the results of Steinberg because of the different experimental configurations.

*757. Dreizin, Edward L.: Internal and Surface Phenomena in Heterogeneous Metal Combustion. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 49–54. (19970020556)

This presents preliminary results of observations of 90- to 350-μm Al particles generated and ignited as a micro-arc. The metal particles show nonsymmetrical burning and brightness in both normal gravity and low gravity.

*758. Urban, David L.; Griffin, DeVon W.; and Gard, Melissa Y.: Comparative Soot Diagnostics: Preliminary Results. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 205–210. (19970020580)

This is a shortened version of Reference 751 with the same tables of results and plots but no pictures of the smoke detectors or the shuttle apparatus.

*759. McKinnon, J. Thomas; Srivastava, Rajiv; and Todd, Paul: Combustion of PTFE: The Effects of Gravity and Pigmentation on Ultrafine Particle Generation. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 255–260. (19970020588)

This paper summarizes the overheating tests on polytetrafluoroethylene- (PTFE-) insulated wire in the Colorado School of Mines 1.2-second drop tower. The investigators collected particles for analyses from yellow-, red-, black-, and white-colored insulation in microgravity and normal gravity. Fine and agglomerated particles are emitted in both microgravity and normal gravity, but agglomerates predominate in microgravity. The morphology and size of particles are quite dependent on the insulation color.

*760. Walther, David C.; Fernandez-Pello, A. Carlos; and Urban, David L.: Smoldering Combustion Experiments in Microgravity. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 369–374. (19970020606)

The Microgravity Smoldering Combustion experiment is a “Getaway Special” payload-bay installation (GASCAN). Two sets of experiments were conducted on two shuttle flights, essentially offering four data points. In all cases, the fuel was a polyurethane cylinder. The four data points in microgravity were opposed flow at 1 mm/s and 21 $\%O_2$; opposed flow at 2 mm/s and 21 $\%O_2$; quiescent 35 $\%O_2$; and quiescent 40 $\%O_2$. Even with the enriched O_2 conditions, quiescent smoldering does not propagate. However, both forced flow cases propagate with velocities about the mean of normal-gravity upward propagation and downward propagation.

*761. Altenkirch, Robert A.; Bhattacharjee, Subrata; West, Jeff; Tang, Lin; Sacksteder, Kurt; and Delichatsios, Michael A.: Solid Surface Combustion Experiment: Thick Fuel Results. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 381–386. (19970020608)

This is a summary of the thick fuel results of the Solid Surface Combustion Experiment. The paper is the same as that of Reference 737, except for the omission of much of the modeling equations.

*762. Olson, Sandra L.; Altenkirch, Robert A.; Bhattacharjee, Subrata; Tang, Lin; and Hegde, Uday: Diffusive and Radiative Transport in Fires Experiment: DARTFire. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 393–398. (19970020610)

The DARTFire Experiment is conducted in a 6-min sounding rocket campaign. The apparatus consists of two combustion tunnels with opposed flow. Black poly(methyl methacrylate) (PMMA), 2 by 0.635 by 2 cm long is the fuel. The investigation consisted of three flight campaigns, covering six tests with combinations of 35 and 50 $\%O_2$, 1 to 10 cm/s velocities, and 0 to 20 kW/m^2 imposed fluxes. Results show no ignition at 35 $\%O_2$. In the 50 $\%O_2$ tests, the flame spread increases with air flow. The fuel burns with no imposed heat flux, but a radiant flux increases the flame-spread rate.

763. T'ien, James S.; Sacksteder, Kurt R.; Ferkul, Paul V.; Bedir, Hasan; Shih, Hsin-Yi; Greenberg, Paul S.; Pettegrew, Richard D.; Piltch, Nancy; and Frate, David: Solid Inflammability Boundary at Low Speed (SIBAL). Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 399–404.

The paper presents the plans and preliminary results of the Shuttle Glovebox Forced Flow Flame Spreading Tests. The test apparatus is a low-speed wind tunnel, operated at 1 to 8 cm/s concurrent flow, to determine the combustion characteristics of thin filter paper and cast cylindrical cellulose fuels. For the former, the interesting finding is cracking and curling of paper casing three-dimensional flame spread.

*764. Kashiwagi, Takashi; Mell, William E.; McGrattan, Kevin B.; Baum, Howard R.; Olson, Sandra L.; Fujita, Osamu; Kikuchi, Masao; and Ito, Kenichi: Ignition, Transition, Flame Spread in Multidimensional Configurations in Microgravity. Fourth International Microgravity Combustion Workshop, NASA CP–10194, May 1997, pp. 411–416. (19970020613)

This paper reports on the continuation of research described in Reference 738. The testing matrix covers tests conducted at the Japanese Microgravity Center JAMIC drop tower at 35 and 50 %O_2 and tests on the shuttle at 21 %O_2 (air). Hot-wire ignition across filter paper produces a linear flame spread upstream. Flame spread occurs in quiescent 35 and 50 but not in 21 %O_2. Data are also shown for 5 cm/s opposed flow. Tests with central radiant ignition show narrow upstream spread at 0.5 cm/s and increasing fan-like spread at 2 and 6.5 cm/s in air, and at 5 cm/s at 35 and 50 %O_2. The investigators also observed surface smoldering in shuttle tests with filter paper treated with $KOCOCH_3$. Flame spread upstream with central ignition and 2 cm/s flow in air shows branched, “finger-like” spreading.

*765. Honda, Linton K.; and Ronney, Paul D.: Premixed Atmosphere and Convective Influences on Flame Inhibition and Combustion (PACIFIC). Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 417–422. (19970020614)

This paper is basically the same as Reference 738, describing tests on thin-paper Kimwipes in the NASA Lewis 2.2-second facility that show that CO in the atmosphere increases flame spread by a greater amount in microgravity than in normal gravity. For inert additions to the atmosphere, He, Ar, and N_2 decrease flame spread and flammability range in microgravity compared with normal gravity. CO_2 has about the same influence in both gravity regimes. SF_6 increases flame spread and flammability range to a much greater degree in microgravity than in normal gravity. A new contribution to the study is a general correlation of upward flame spread, referenced to the downward flame spread rate, as a function of Grashof number for all mixtures.

*766. Urban, David L.; Goldmeer, Jeffrey S.; and Yuan, Zeng-guang: Interactions Between Flames on Parallel Solid Surfaces. Fourth International Microgravity Combustion Workshop, Kurt R. Sacksteder, ed., NASA CP–10194, 1997, pp. 429–434. (19970020616)

The data are the same as those presented in Reference 682 on the influence of flames ignited on parallel sheets of paper. Tests were conducted in the NASA Lewis 2.2 Second Drop Tower and DC–9 airplane. Regimes of separation effects in microgravity and normal gravity are the same as in Reference 682. The paper has an expanded modeling of transport processes.

*767. Goldmeer, Jeffrey S.; T'ien, James S.; and Urban, David L.: Extinguishment of a Diffusion Flame Over a PMMA Cylinder by Depressurization in Low-Gravity. Fourth International Microgravity Combustion Workshop, NASA CP–10194, 1997, pp. 435–440. (19970020617)

This is basically a summary of Reference 731 and others on the low-pressure extinction of flames. Experiments conducted in the NASA Lewis Learjet determined the burning of 1.9-cm-diameter poly(methyl methacrylate) (PMMA) cylinders in 10 cm/s crossflow. Of interest is the conclusion to recommend a change in the International Space Station requirement of depressurization for fire control, from 1 to 0.3 atm in 10 min to a rapid depressurization to 0.1 atm, which limits heating effects.

768. Pfister, G.: Multisensor/Multicriteria Fire Detection: A New Trend Rapidly Becomes a State of the Art. Fire Tech., vol. 33, no. 2, 1997, pp. 115–139.

The author of the paper is with Cerberus of Switzerland. The paper shows test results of detector responses to fires, to promote the use of a combination of sensors. As one example, the author states that ionization-type detectors are insensitive to smoldering. Photoelectric types are sensitive to large, white aerosols, hence smoldering but also dust (false alarms). Photoelectric types are insensitive to small black aerosols (0.1-μm mean particle size). The author suggests two improvements: one, the use of scattering angles greater than 120°, and the other (better), the use of a combination of photoelectric plus temperature sensing.

769. Walters, Richard N.; and Lyon, Richard E.: Microscale Combustion Calorimeter for Determining Flammability Parameters of Materials, in Sorathia, Usman; Kelly, James; Lyon, Richard; Gilman, Jeffrey; Friedman, Robert; and Nash, Louis, eds.: Proceedings of the Eighth Meeting of the Interagency Working Group for Fire and Materials (IWGFM–8) NSWCCD–TR–64–97/14, June 1997; also in Proceedings of the 1997 42nd International SAMPE Symposium and Exhibition, vol. 42, no. 2, 1997, pp. 1335–1344.

The paper describes a test device that takes a material sample of 2 to 20 mg, pyrolyzes it in N_2 flow, and then adds heated O_2 for oxidation. From the O_2 consumption, the heat release and other thermal properties are determined. The measurements are equivalent to those of a cone calorimeter, but the microscale instrument uses very small samples and rapid screening.

770. Abbud-Madrid, A.; and Branch, M.C.: A Study of Heterogeneous and Homogeneous Combustion of Bulk Metals in a Reduced-Gravity Environment. Bull. Soc. Chim. Belg., vol. 106, no. 6, 1997, pp. 331–336.

Generally, this paper repeats the bulk metal combustion studies of References 722 and 756. The results are expanded to show more emission spectra for a metal with homogeneous combustion (Mg) and one with heterogeneous combustion (Ti).

771. Grosshandler, W.L.: Progress Report on Fire Detection Research in the United States. K.A. Beall, ed., UJNR Fire Research and Safety 13th Joint Panel Meeting, vol. 2, 1996, NISTIR 6030, 1997, pp. 363–369.

This is a literature survey on fire signatures, sensors, detection algorithm, and fire emulations covering 1994 to 1996.

772. Carrasquillo, Robyn L.; Reuter, James L.; and Philistine, Cynthia L.: Summary of Resources for the International Space Station Environmental Control and Life Support System. SAE Technical Paper 972332, 1997.

This is a good update on the purposes and resources of the Environmental Control and Life Support System and its seven subsystems. A table specifies and describes components of the subsystems. For the fire detection and suppression subsystem, the components are smoke detectors placed two each in Nodes 1 and 2 and Air Lock, four in the U.S. Laboratory Module (Lab), and eight in the Habitation Module (Hab). The portable fire extinguisher placement is one each in Nodes 1 and 2 and Air Lock and two each in the Lab and Hab. The component resources are also specified. A table shows the mass, volume, and average and peak power for the smoke detectors and the portable fire extinguishers.

773. Reuter, James L.; and Reysa, Richard P.: International Space Station Environmental Control and Life Support System Design Overview Update. SAE Technical Paper 972333, 1997.

This paper covers the schedule and assembly sequence for the International Space Station Assembly Rev. C (now obsolete). Several good sketches illustrate the assembly, including features of the Russian segment. The assembly sequence includes the delivery of the smoke detectors made by Allied Signal and the portable fire extinguishers made by Ande.

774. McKinnie, James M.: Fire Response Aboard the International Space Station. SAE Technical Paper 972334, 1997.

The paper describes the features and roles of the U.S. Operating Segment (USOS) smoke detectors (SDs), portable breathing apparatuses (PBAs), and portable fire extinguishers (PFEs). For a cabin SD alarm, cabin ventilation and intermodule ventilation are shut down. For a rack SD alarm, the same actions occur plus shutoff of all electrical power to the rack. All actions are to be completed within 30 s. Similar actions are cited for the Multipurpose Logistics Module. For the Russian segment (RS), the tug (FGB) has 10 ionization detectors in separate sections (type ESD–2). The Service Module has ten photoelectric detectors of the type used on Mir (DS–7A). Each module has two or three OCP–4 PFEs and several IPK–1 PBAs, both used on Mir. A sequence of power off and on in the RS is described. The annunciation is shared in the USOS and RS. The paper documents the fire response roles and responsibilities, prefire planning, and training. Special attention is noted for early flights without permanent habitation. A shuttle Halon 1301 extinguisher will be moved into Node 1. For the later, permanent habitation era, fire fighting will involve two crews—one with the PBA the other at a communication center. The Russian PBA is good for 20 to 40 min and the U.S. for 15 min before requiring replacement of the O_2 bottle. The paper notes the special attention needed for a potential airlock fire. It discusses postfire operations. The paper also notes that three crew members breathing PBAs can violate the 24.1 %O_2 cabin limit within 45 min.

775. Ivanov, A.V.: A Study of Material's Combustion Processes in Microgravity. Final Report no. 2625, Treaty no. 920/9–5208/95: 400–I/34–95, Russian Space Agency Keldysh Research Center, 1997.

This describes the narrow channel and vertical chamber apparatuses for studying nonbuoyant combustion. Also described are Mir tests in the Skorost combustion tunnel with poly(methyl methacrylate) (PMMA) cotton cord (1, 2, and 3 mm thick), and glass textolite composite. Limiting velocities are cited for PMMA, which is below 0.5 cm/s in air on Skorost, compared with 1.5 to 4.1 cm/s on the ground facilities. Glass textolite would not burn in air, and cotton cord smoldered.

776. Sorathia, Usman; Lyon, Richard; Ohlemiller, Thomas; and Grenier, Andrew: Review of Fire Test Methods and Criteria for Composites. SAMPE J., vol. 33, no. 4, 1997, pp. 23–31.

This article discusses fire-safety cautions for fiber-reinforced materials in surface, marine, and air transportation. The authors note the advantage of upward-spread tests as providing a severe case. A table summarizes fire requirements for composite materials in transportation. For commercial aircraft, test procedures are found in Federal Aviation Regulations FAR 25.853 and FAR 25.855. Rate of heat release is measured by ASTM E906, the Ohio State University calorimeter, which uses a thermocouple for heat-release measurement and a fixed radiant heat flux of 35 kW/m^2. The cone calorimeter, ASTM E1354, uses oxygen consumption for heat-release measurement and variable radiant heat flux.

777. Grand, Arthur F.: Heat Release Calorimetry Evaluations for Fire Retardant Polymer Systems. SAMPE J., vol. 33, no. 4, 1997, pp. 47–52.

Three materials, acrylonitrile-butadiene-styrene (ABS), polystyrene (PS), and polycarbonate/ABS, were tested in a cone calorimeter in both untreated and flame-retardant versions (bromine and antimony additives). Quantitative results show that the fire-retardant polymers have a reduced peak and total rate of heat release as well as a reduced heat of combustion. Time to ignition and $k\rho c$ properties are about the same (where k is thermal conductivity, ρ is density, and c is specific heat). However, the retardant polymers have reduced combustion efficiency; hence they generate more CO and smoke.

*778. Reher, H.J.; Klintworth, R.; Saurbier, D.; Hoeger, S.; and Bohle, D.: Comparison of ESA and Russian Test Methods for the Determination of Flammability, Toxicity, and Fungus Growth Characteristics of Space Materials. T.-D. Guyenne, ed., Proceedings of 7th International Symposium on Materials in Space Environment, ESA SP–399, 1997, pp. 507–512. (19980075504A)

For assessment of flammability, the European Space Agency (ESA) PSS–01–721 is a version of the U.S. upward flammability test. The Russian version ignites the sample with a burner, uses a larger sample, and has a variable O_2 concentration. The ESA acceptance criteria are nonburning or self-extinguishing within 15 cm affected length after ignition. The Russian acceptance criterion is limiting O_2 concentration (LOI). Tests of six materials show agreement between ESA pass-fail and Russian 25 percent LOI limit, except for a polyurethane paint that self-extinguished in the ESA test but had a Russian LOI of 18 percent.

779. Cahill, Patricia: Evaluation of Fire Test Methods for Aircraft Thermal Acoustical Insulation. DOT/FAA/AR–97/58, 1997.

Round-robin tests of insulation blankets for aircraft showed that the Boeing and Douglas aircraft cotton swab tests gives more consistent results than the Federal Aviation Regulation FAR 25.853 Bunsen burner upward-flammability test. A particular example is the test results for metallized Mylar, where half of the samples pass the Bunsen burner test but all fail the cotton swab tests.

780. Aggarwal, Sanjay; and Motevalli, Vahid: Investigation of an Approach to Fuel Identification for Non-Flaming Sources Using Light-Scattering and Ionization Detector Response. FSJOD, vol. 29, nos. 2–3, 1997, pp. 99–112.

This paper describes an experiment of measuring smoke properties from various cellulosic plastics and unusual fuels (wool, bread) using light scattering, ionization, obscuration, particle density, and fuel mass loss. The principal findings are that (1) in absolute ranking, fuels are in inverse order between scattering and ionization response, and (2) scattered light intensity does not vary linearly with optical density for most smoldering fuels.

781. Torero, J.; Bahr, N.; and Carman, E.: Assessment of Material Flammability for Micro-Gravity Environments. IAF–97–J.202 (48th International Astro. Cong.), Oct. 1997. (A97-45364)

The paper reviews the NASA NHB 8060.1C Test 1, Upward Flammability. For a “passing” item, with spread less than 15 cm beyond the ignition point, heat flux predictions indicate that flames are laminar and heat transfer is dominated by conduction. The studies of Ohlemiller and Villa (Ref. 471) show the strong effects of external heat flux. The authors note that nonpropagation occurs by quenching in microgravity and blow-off in normal gravity. Ignition size and duration have a strong influence on test propagation. The main argument against Test 1 is that its objective should not be a worst-case but a plausible fire scenario. The work concludes that no single test is capable of addressing the complex problems of material flammability, but different tests are needed to assess a range of fuel types, such as thin fuels, charring fuels, and so on.

782. Sorathia, Usman; Lyon, Richard; Gann, Richard; and Gritzo, Louis: Materials and Fire Threat. Fire Tech., vol. 32, no. 3, 1996, pp. 260–275.

This is a general review covering composite-material response to fire in topics of fire growth, habitability, residual strength, and fire extinguishment. The work is sponsored by the Interagency Working Group on Fire and Materials.

783. Ross, H.D.: Burning To Go: Combustion on Orbit and Mars. Paper presented at the Chemical and Physical Processes in Combustion 1997 Technical Meeting, Eastern States Section, The Combustion Institute, Hartford, CT, 1997, pp. 29–38.

This paper starts with a general review of the features of microgravity combustion. It also discusses the Mir fire and the features of fire detection and suppression on the shuttle, International Space Station, and Mir. Finally it describes a proposed Mars mission and the problems of partial-gravity flammability.

784. Steinberg, T.A.; and Stoltzfus, J.M.: Combustion Testing of Metallic Materials Aboard the NASA Johnson Space Center's KC–135. Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, Eighth vol., William T. Royals, Ting C. Chou, and Theodore A. Steinberg, eds., ASTM Special Technical Publication 1319, ASTM, West Conshohocken, PA, 1997, pp. 170–188.

The tests investigated the low-gravity combustion of metals in the NASA Johnson KC–135 airplane. The tests covered the burning of thin cylinders of Fe, Ni, Cu, Co, Al, Al-10% Si, Ti, Monel, and 316SS in O_2 atm at pressures of 0.3 to 9.3 MPa. Metals burn at the same minimum pressure in low gravity as in normal gravity, but the regression rate is always greater in low gravity.

785. Milke, J.A.; and McAvoy, T. J.: Analysis of Fire and Non-Fire Signatures for Discriminating Fire Detection. Y. Hasemi, ed., Fire Safety Science Proceedings of the Fifth International Symposium, International Association of Fire Safety Science, Boston, MA, 1997, pp. 819–828.

Researchers at the University of Maryland examined a variety of flaming, smoldering (pyrolyzing) and nuisance sources (sprays, polishes) along with various types of fire detection techniques such as temperature sensors, CO and CO_2 detectors, obscuration smoke detectors, and two metal-oxide detectors to determine the signatures for effective detection of true fires. A scoring system with a matrix of scores classified the sources. For single sources, the scores classified 100 percent of the flaming sources, 88 percent of the smoldering, and 73 percent of the nuisance (27 percent false alarms). Commercial photoelectric and ionization detectors responded to the flaming sources, 25 percent of smoldering, and 11 percent false alarms. The project also investigated the combustion of fire and nuisance sources. These tests were on a larger scale than those of Reference 654.

786. Lyon, Richard E.: Fire-Resistant Materials: Research Overview. DOT/FAA/AR–97/99, 1997.

The report emphasizes work in progress on materials for decorative panels, molded parts, foams, and fibers.

787. Friedman, Robert; and Lyons, Valerie J.: Potential Commercial Applications From Microgravity Combustion Research. NASA Tech Briefs, vol. 22, no. 1, 1998, p. 82.

Reference 724 is announced and in this Tech Brief.

*788. Francisco, David R.: Fluids and Combustion Facility—Combustion Integrated Rack. AIAA Paper 98–0257, 1998.

The Combustion Integrated Rack is one of three units of the Fluids and Combustion Facility for the International Space Station (ISS). It will be launched on the ISS utilization flight UF–3. The paper gives dimensions, resources, and capabilities of the rack. The rack is to accommodate 5 to 10 microgravity combustion experiments per year. Described is an environmental control system with two fans, a radiator, air filters, and an area smoke detector (in the back of the rack). The radiator is water cooled.

*789. Abbud-Madrid, A.; McKnight, C.; Branch, M.C.; and Daily, J.W.: Buoyancy and Pressure Effects on Bulk Metal-Oxygen Reactions. AIAA Paper 98–0570, 1998.

Airplane experiments on Ti and Mg pellets, 4 mm diameter by 4 mm long, are continued at a range of pressures. For Ti, the propagation rate at 100 $\%O_2$ and 1 atm pressure is 16.2 mm/s in normal gravity, 8.7 mm/s in microgravity. The propagation ratio of 1.86 agrees well with theory based on the Grashof number, Gr. The study also determined propagation rates at normal gravity and pressures of 0.1 to 4.0 atm. At 0.1 atm, the rate is 7.5 mm/s, close to the microgravity value at 1 atm, confirming a dependence on the square of the absolute pressure multiplied by the gravitational acceleration, p^2g. For Mg, the irregular shape of the burning samples permits only a comparison of burning times: 3.9 s at microgravity and 2.2 s at normal gravity.

790. Srivastava, Rajiv; McKinnon, J.T.; and Todd, Paul: Effect of Pigmentation in Particulate Formation From Fluoropolymer Thermodegradation in Microgravity. AIAA Paper 98–0814, 1998.

This is essentially the same paper as Reference 759, with some rewriting and omission of wire current histories but the same data table and conclusions.

*791. Wieland, P.O.: Living Together in Space: The Design and Operation of the Life Support Systems on the International Space Station. NASA/TM—1998-206956/VOL1, 1998. (19980037427).

This is a handbook covering an overview of distributed systems on the International Space Station, and descriptions of the Environmental Control and Life Support System for the United States Operating Segment (USOS), the European Space Agency Attached Pressurized Module (APM), the Japan Experiment Module (JEM), and the Italian Multipurpose Logistics Module (MPLM). Details of the Russian segment are in the limited-distribution Volume II. The report does include at least a general description and operational philosophy of the Russian fire detection and suppression subsystem. It has a table comparing U.S. and Russian design and failure requirements. Intramodule circulation is 0.05 to 0.20 m/s; intramodule ventilation is 66 ± 2.4 liter/s U.S.; 60 to 70 liter/s Russian. Tables show both U.S. and Russian maximum contaminants. For the USOS, the requirements for prevention, detection, and suppression are given. Also stated are requirements for isolation within 30 s of detection, forced ventilation to cease within 30 s, fire suppression within 1 min, and venting to an O_2 partial pressure <69 kPa within 10 min. The APM response to fire is the same, except suppression level is stated as $\%O_2$ concentration <10.5. The JEM and MPLM responses are the same as for APM. The handbook has sketches and descriptions for the caution and warning panel, smoke detector, portable breathing apparatus, suppression port, and the portable fire extinguisher.

*791A. Flammability, Odor, Off-Gassing and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion. NASA–STD–6001, 1998.

This is a current manual, originally Reference 458, with a new foreword, type font and page numbering but otherwise no revisions to the test procedures.

792. Molodetsky, I.E.; Vicenzi, E.P.; Dreizin, E.L.; and Law, C.K.: Phases of Titanium Combustion in Air. Comb. Flame, vol. 112, no. 4, 1998, pp. 522–532.

Micro-arc studies of single 240- to 280-μm Ti droplets quenched on Al foil showed that atmospheric O and N dissolve in the molten droplets. The N concentration reaches a maximum with time, but the O concentration increases with time until stoichiometric Ti_2O_3 is formed.

793. Nelson, G.L.: Carbon Monoxide and Fire Toxicity: A Review and Analysis of Recent Work. Fire Tech., vol. 34, no. 1, 1998, pp. 39–58.

A review of statistics and demographics on the CO and CN analyses of fire victims shows that the 50 percent lethal level of carboxyhemoglobin (COHb) is not universally true. The CO may poison tissues in addition to its blockage of O_2-carrying capacity.

794. Grosshandler, W.L.: Nuisance Alarms in Aircraft Cargo Areas and Critical Telecommunications Systems: Proceedings of the Third NIST Fire Detector Workshop. NISTIR 6146, National Institute of Standards and Technology, Gaithersburg, MD, 1998.

A conference summary discusses the background of commercial aircraft cargo-area smoke detection needs and false alarms. The reports of conference breakout groups generally agree on the need for statistics backed by experience and for National Institute of Standards and Technology (NIST) fire-emulation testing. The conferees urge the addition of a temperature monitor to smoke detectors.

795. Honda, L.K.; and Ronney, P.D.: Effect of Ambient Atmosphere on Flame Spread at Microgravity. Combust. Sci. Technol., vol. 133, nos. 4–6, 1998, pp. 267–291.

This is largely a repeat of the work reported in References 730 and 765. The tests, conducted mainly in the NASA Lewis 2.2-Second Drop Tower, but in some cases in the Lewis 5.2-second facility, burned thin paper (Kimwipes) in quiescent, controlled atmospheres. The addition of fuel gases CO and CH_4 in low equivalence ratios to 18 %O_2 in N_2 and 30 %O_2 in N_2 increases the flame spread in both microgravity and normal gravity. The CO addition affects flame spread more than CH_4. The addition of diluent gases as substitutes for atmospheric N_2 produces other remarkable effects. Substitution of He or Ar increases flame spreads compared with N_2, but the flame spread in microgravity is always less than in normal gravity. For CO_2 diluent, flame spreads are about the same in microgravity and normal gravity, but the flammability limits are greater in microgravity. For SF_6 diluent, the flame spread and flammability range in microgravity greatly exceed those in normal gravity.

*796. Singh, Bhim S.: Workshop of Research for Space Exploration: Physical Sciences and Process Technology. NASA CP—1998-207431, 1998.

This is a conference report on the contributions of microgravity research to human exploration of space. In the fire-safety breakout group, discussions covered initiating events, atmospheres, detection, suppression, and general combustion processes. Recommendations for research from the group are diagnosis of electrical problems, determination of flammability of thick materials in microgravity and one-third gravity, investigation of methane-oxygen combustion in one-third gravity, and research on extinguishment in one-third gravity and microgravity.

*797. Robert Friedman: Fire Safety in Extraterrestrial Environments. Space 98: Proceedings of the Sixth International Conference and Exposition on Engineering, Construction, and Operations in Space (NASA/TM—1998-207417), Rodney G. Galloway and Stanley Lokaj, eds., American Society of Civil Engineers, New York, NY, 1998. Fire Safety in Extraterrestrial Environments

This paper is based on the fire-safety breakout group's report in Reference 796, but it expands on the background of spacecraft fire safety, and it presents some of the previous partial-gravity data on the combustion of thin paper.

798. Di Blasi, Colomba: Dynamics of Concurrent Flame Spread Over a Thin Charring Solid in Microgravity. Fire Mater., vol. 22, no. 3, 1998, pp. 95–101.

Numerical (elliptical) models of microgravity flame spread over thin cellulose with concurrent air flow show profiles of flame position, temperature, and fuel-oxygen concentration with time. For an air velocity of 5 cm/s, steady flame spread is attained in 3.5 s. As air flow is reduced, flame spread is reduced and stand-off distance increases. At 0.25 cm/s or below, the flame eventually quenches.

799. Gage, Larry M.: Control of Cabin Pressure Venting and Emergency Relief for the International Space Station. SAE Technical Paper 981623, 1998.

The paper describes the International Space Station vent and relief valve made by Allied Signal. The valve can be used to control overpressure or to assure relief if a catastrophe (uncontrollable fire) occurs. The valve is mounted on a module end cone, and it is basically two valves in series in a single housing.

800. Reuter, James L.: International Space Station Environmental Control and Life Support System Status: 1997–1998. SAE Technical Paper 981662, 1998.

The status of the International Space Station Environmental Control and Life Support System (ECLSS) configuration reported the year before (Ref. 773) is updated to the current Rev. D. The baseline description of the ECLSS is found in Reference 717. The principal Rev. D changes are the increase in Node 2 outfitting from four racks to eight, the addition of a new Node 3 with eight racks, and the addition of another portable fire extinguisher.

801. Herber, Nikolaus; Müller, Roland; and Lucas, Jochen: Design and Development Status of the Columbus Orbital Facility Environmental Control and Life Support S/S and Equipment. SAE Technical Paper 981663, 1998.

An engineering change involving the fire-suppression requirements caused a redesign of the European Space Agency Columbus module ventilation system, which delayed the distributed-systems tests. Smoke detectors are now limited to two duct detectors in the cabin return air line. Flame detectors for the standoffs are under consideration.

802. McKinnie, James M.: ISS US ECLSS Mission Control Operations. SAE Technical 981664, 1998.

This is a general treatise on organization, operation, training, and Johnson Space Center coordination for the International Space Station. Items of interest are the categories of procedures: nominal, assembly, emergency, malfunction, and corrective. Emergency procedures must be executed within 5 min of an event. The events are limited to fire, depressurization, and toxic spill response.

803. Pu, Y.; Podfilipski, J.; and Jarosinski, J.: Constant Volume Combustion of Aluminum and Cornstarch Dust in Microgravity. Combust. Sci. Technol., vol. 135, nos. 1–6, 1998, pp. 255–267.

The study covered the ignition and combustion of Al dust (7.2 μm) and cornstarch particles (20 μm) in a chamber under microgravity generated in the Technical University of Lodz, Poland, 1.2-second drop tower. For Al, peak pressure decreases with increasing ignition delay in normal gravity, but remains nearly constant in microgravity. For cornstarch, pressure decay is greater in normal gravity, but again it is nearly constant with ignition delay in microgravity. The researchers believe that the greater explosion pressure in microgravity is due to the uniform concentration.

804. Grand, Arthur F.; and Weil, Edward D.: Cone Calorimeter Investigations of Fire Resistant Materials for Aircraft Applications. Proceedings of the 1998 43rd International SAMPE Symposium and Exhibition, Usman Sorathia, Michael Blum, Louis Nash, Gus Sarkos, and Jeffrey Gilman, eds., U.S. Navy NSWCCD–TR–64–98/07, vol. 43, no. 1, 1998, pp. 998–1009.

This paper describes cone calorimeter tests on a charring polyetherimide material. Tests with specimens in a pan held down with wires and with an edge frame show a higher rate of heat release than those in a pan without the frame. Results with the specimen 25 mm from the cone (the standard setting) show higher rates of heat release than those 60 mm from the cone. The repeatability of the 60-mm runs is poor, however.

805. Gandhi, Sanjeev; and Lyon, Richard E.: Health Hazards of Carbon Fibers From Burning Composite Materials. Proceedings of the 1998 43rd International SAMPE Symposium and Exhibition, vol. 43, no. 1, 1998, pp. 1010–1017. U.S. Navy NSWCCS–TR–64–98/07, July 1998, pp. 16–23.

This is a literature survey on the health hazards of the release of carbon and other fibers from the burning of fiber reinforced polymer composites.

806. King, Merrill K.; and Ross, Howard D.: Overview of the NASA Microgravity Combustion Program. AIAA J., vol. 36, no. 8, 1998, pp. 1337–1345.

As an overview, this paper is a summary of the justification for microgravity studies, a review of current understandings, and a presentation of the NASA program in seven categories: premixed gases, diffusion flames, droplets and sprays, particles and dust clouds, spread across solid and liquid surfaces, smoldering, and combustion synthesis. Particular relevance to fire safety is in the discussion of the results of thick- and thin-fuel Solid Surface Combustion Experiment (SSCE), the Radiative Ignition and Transition to Spread Investigation (RITSI), the Wire-Insulation Flame Behavior (WIF) experiment, the Forced Flow Flame-Spread Tests (FFFT) , the Diffusive and Radiative Transport (DARTFire) experiment, and the Comparative Soot Diagnostics (CSD) experiment.

807. Fernandez-Pello, A. Carlos: Test Method for Ranking the Fire Properties of Materials in Reduced Gravity. Proceedings of the International Workshop on Experiments in Microgravity, Drop Tower Days 1998 in Sapporo, Japan, 1998, pp. 61–63.

The paper describes progress in the forced-flow ignition and flame spread project (FIST). It shows a sketch of the apparatus and normal-gravity results for poly(methyl methacrylate) (PMMA). Ignition delay decreases with increasing heat flux and decreasing flow velocity. Flame-spread rate increases with increasing heat flux and decreasing flow velocity. Tests can also determine the critical heat flux for ignition.

808. Kikuchi, Masao; Fujita, Osamu; Ito, Kenichi; Sato, Atsuki; and Sakuraya, Takashi: Flame Spread Over Polymeric Wire Insulation in Microgravity. Proceedings of the International Workshop on Experiments in Microgravity, Drop Tower Days 1998 in Sapporo, Japan, 1998, pp. 64–66.

Tests at the Japan Microgravity Center cover the combustion of an insulated vertical wire, preheated to 100 °C in a chamber. For polyethylene insulation, the wire burns at 20 %O_2, and flame spread increases as concentration increases to 40 %O_2. Flame spread decreases with increasing insulation thickness. Preheat has only a minor effect on polyethylene combustion. The polytetrafluoroethylene- (PTFE-) insulated wires do not burn in concentrations below 40 %O_2.

*809. Sacksteder, Kurt R.; Greenberg, Paul S.; Pettegrew, Richard D.; T'ien, James S.; Ferkul, Paul V.; and Shih, Hsin-Yi: Forced Flow Flame Spreading Test: Preliminary Findings From the USMP–3 Shuttle Mission. Third United States Microgravity Payload: One Year Report, P.A. Curreri, D. McCauley, and C. Walker, eds., NASA/CP—1998-207891, 1998, pp. 83–96.

An International Space Station project, Solid Inflammable Boundary at Low Speeds (SIBAL), will determine flammability boundaries in a single test, varying O_2 concentration or concurrent air-flow rate over a moving fuel sample. The substrate carrying the fuel moves from a supply roll to a take-up roll. The Forced Flow Flame Spread Test (FFFT) is a preliminary Glovebox experiment as part of SIBAL. In FFFT, tissue-paper fuels mounted on steel “cords” are burned with air flows (fan driven) of 1 to 3 cm/s. Steady flame lengths can be achieved. Other tests use hollow, molded cellulose rods preheated from 75 to 125 °C by internal rods, with air flows of 2 to 8 cm/s. At a constant 100 °C preheat, the flame length is constant at 2 cm/s, but it increases with time at higher flows. At a constant 2 cm/s air flow, flame length is constant at 75 and 100 °C preheat, but it increases at 125 °C.

*810. Kashiwagi, Takashi; and Olson, Sandra L.: Radiative Ignition and Transition to Spread Investigation (RITSI). Third United States Microgravity Payload: One Year Report. NASA/CP—1998-207891, 1998, pp. 97–117.

This reports on the continuation of the work reported in References 738 and 764, with experiments in a Glovebox facility on the shuttle USMP–3 (a microgravity-science payload). Line ignition of tissue paper (called two dimensional) in air does not propagate at 0 flow, but spreads upstream at 2 and 5 cm/s air flows. Central lamp ignition (no pilot) spreads at air velocities of 0.5 to 5 cm/s (called three dimensional). Flame spread is in an upstream direction (against the airflow) in a fan configuration with the angle increasing with air flow. Above 3.5 cm/s, the flame starts to spread downstream along the edges. Central ignition of treated paper showed the complex branched smoldering, observed in earlier tests of Reference 764.

*811. Urban, David L.; Griffin, DeVon W.; and Gard, Melissa Y.: Comparative Soot Diagnostics: 1 Year Report. Third United States Microgravity Payload: One Year Report. NASA/CP—1998-207891, 1998, pp. 119–134.

This paper repeats much of what has been reported previously in References 751 and 758, with more details of the apparatus but the same data. The authors conclude, with no quantitative support, that detector sensitivity to smoke emissions from a material in normal gravity does not indicate a strong sensitivity to the smoke emissions from the same material in microgravity.

812. Kikuchi, Masao; Fujita, Osamu; Ito, Kenichi; Sato, Atsuki; and Sakuraya, Takashi: Experimental Study on Flame Spread Over Wire Insulation in Microgravity. Twenty-Seventh Symposium (International) on Combustion, Vol. Two, The Combustion Institute, Pittsburgh, PA, 1998, pp. 2507–2514.

The paper describes microgravity investigations in the 10-second Japanese Microgravity Center JAMIC drop tower of a vertical length of ethylene tetrafluoroethylene- (ETFE-)insulated wire ignited at the top. The tests covered quiescent conditions, 298 K and 398 K internal preheat, and three wire diameters. Flame spread rate increases from 30 to 50 % O_2, and microgravity flame spread is always greater than normal-gravity spread, except that no spread occurs at the 30 %O_2 and no preheat condition. Flame spread in both environments decreases as wire diameter increases. The high spread rate in microgravity is attributed to the curvature effect of a cylinder compared to sheet materials (see Ref. 489). Also, at 30 %O_2 and preheated, flames do not propagate in microgravity if pressure is reduced to 70 kPa. Increased total pressure has little effect on flame spread in both microgravity and normal gravity. Substitution of CO_2 for N_2 results in an even stronger increase in flame propagation in microgravity at concentrations above 35 % O_2. In a comment section following the main paper, the authors note the possibility of natural convection cooling through the wire as an explanation of the slower flame spread in normal gravity.

813. Altenkirch, Robert A.; Tang, Lin; Sacksteder, Kurt; Bhattacharjee, Subrata; and Delichatsios, Michael A.: Inherently Unsteady Flame Spread to Extinction Over Thick Fuels in Microgravity. Twenty-Seventh Symposium (International) on Combustion, Vol. Two, The Combustion Institute, Pittsburgh, PA, 1998, pp. 2515–2524.

In the latest flight of the Solid Surface Combustion Experiment, a poly(methyl methacrylate) (PMMA) sample 3.18 mm thick by 60 mm long is burned in quiescent microgravity at 50 %O_2. The flame advances to about 15 mm for 186 s, then slowly retreats to extinction in 532 s. The experimenters observed a single bubble and ejection of material at 420 s.

814. Olson, S.L.; Baum, H.R.; and Kashiwagi, T.: Finger-Like Smoldering Over Thin Cellulosic Sheets in Microgravity. Twenty-Seventh Symposium (International) on Combustion, Vol. Two, The Combustion Institute, Pittsburgh, PA, 1998, pp. 2525–2533.

This paper expands on the analysis and discussion of surface smoldering first reported in Reference 810. The paper notes that centrally ignited smoldering spreads radially in normal gravity, but it spreads in finger-like patterns predominately upstream (into the flow of at least 0.5 cm/s) in microgravity.

815. Ferkul, Paul; Sacksteder, Kurt R.; Greenberg, Paul S.; Dietrich, Daniel L.; Ross, Howard D.; T'ien, James S.; Altenkirch, Robert A.; Tang, Lin; Bundy, Matt; and Delichatsios, Michael: Combustion Experiments on the Mir Space Station. AIAA Paper 99–0439, 1999.

The experiments described are Forced Flow Flame Spreading Test (FFFT), Opposed Flow Flame Spread (OFFS), and Candle Flames in Microgravity (CFM). The FFFT investigates the combustion of paper sheets of different thicknesses and 1.5-mm-diameter cylinders of polyethylene (PE) heated internally to 85 and 100 °C. Air flow is 2 cm/s concurrent for the sheets and 1 to 3 cm/s both concurrent and opposed for the PE cylinders. For the sheets, flame spread decreases as thickness increases. For the PE cylinders, flame spread is 40 percent greater for concurrent flow compared to opposed, and the spread increases slightly (around 10 percent) for increases of 1 to 2 cm/s concurrent flow; or 1 to 3 cm/s opposed flow. The OFFS experiment investigates the combustion of paper cylinders 7 to 12 mm in diameter, both solid and hollow, with no preheat. The large-diameter cylinders show a limiting air velocity of 5 cm/s (burning requires greater velocities). The CFM experiment shows smaller flames and longer burning times for smaller wick diameters. One candle burned for 45 min in quiescent microgravity and left a fog of droplets after extinguishment. An observation of liquid fuels (PE and a candle) is that total heat release can be greater in microgravity because of the lack of dripping. The PE flame was observed to eject particles.

816. Abbud-Madrid, A.; Stroud, C.; Omaly, P.; and Branch, M.C.: Combustion of Bulk Magnesium in Carbon Dioxide Under Reduced-Gravity Conditions. AIAA Paper 99–0695, 1999.

The apparatus used previously for metal combustion tests is now used for NASA Johnson KC–135 airplane tests of Mg burning in CO_2 and CO (Ref. 742). The fuels are Mg pellets of 2, 3, and 4 mm diameter and length, suspended by a thermocouple wire. The flames are spherical surrounding the fuel, which also assumes a spherical shape. Burning time increases with the sample diameter squared. For the 4-mm pellet, burning times are 4.5 to 5 times longer than for Mg in O_2 (Ref. 789) and twice as long as in normal gravity. Burning in CO is self-sustaining only as long as the ignition lamp remains on. Explosions due to internal vapor superheating are observed for Mg in CO_2.

817. Gandhi, Sanjeev; Lyon, Richard; and Speitel, Louise: Potential Health Hazards From Burning Aircraft Composites. J. Fire Sci., vol. 17, no. 1, 1999, pp. 20–41.

This is a literature survey of the hazards from breathing carbon fibers generated by burning graphite fiber composites. Samplings at aircraft crash sites and in laboratories show that most fire-produced fibers are 2 to 10 times greater than the critical size for pulmonary toxicity. One danger is absorbed combustion products on the fibers, but there is no evidence of toxic effects.

818. Goldmeer, Jeffrey S.; T'ien, James S.; and Urban, David L.: Combustion and Extinction of PMMA Cylinders During Depressurization in Low-Gravity. FSJOD, vol. 32, no. 1, 1999, pp. 61–88.

This paper expands the discussion of the low-gravity DC–9 airplane tests of burning poly(methyl methacrylate (PMMA) cylinders in 10 cm/s cross-flow (Ref. 767, etc.). The work now includes numerical results as well as experimental data. The paper shows the extinction boundary by a plot of the solid-fuel center temperature versus pressure. The boundary is lowest (most flammable) at a flow of 10 cm/s and increases for greater or lesser velocities. A cross-plot gives temperature versus velocity at different pressure levels. The authors recommend rapid depressurization to a pressure of 0.1 atm for International Space Station last-resort fire suppression.

819. Urban, David L.; and King, Merrill K.: NASA's Microgravity Combustion Research Program: Past and Future. Comb. Flame, vol. 116, no. 3, 1999, pp. 319–320.
This is a very brief introduction to microgravity combustion projects, giving some numbers on the space-based projects and current supported investigations.

820. Walther, David C.; Fernandez-Pello, A. Carlos; and Urban, David L.: Space Shuttle Based Microgravity Smoldering Combustion Experiments. Comb. Flame, vol. 116, no. 3, 1999, pp. 398–414.
The article expands on the STS–69 and STS–77 GASCAN experiment, already described in Ref. 760. The opposed-flow smolder velocity and temperature in microgravity are greater than in corresponding upward normal gravity, but less than in downward normal gravity. Smoldering in microgravity requires forced flows of 1 to 2 mm/s. The polyurethane fuel will not propagate in quiescent conditions, even at 40 %O_2. The yield of CO and CO_2 in microgravity is also intermediate to that in upward and downward normal gravity. This conflicts with the findings of Reference 739 of large increases in CO emissions in microgravity smoldering. The authors explained that the great difference is due to the effects of larger samples and directed flow through the sample in the present case.

*821. Goldmeer, Jeffrey S.; Urban, David L.; and T'ien, James: The Effect of Velocity on the Extinction Behavior of a Diffusion Flame During Transient Depressurization. Proceedings of the First Joint Meeting of the U.S. Sections of The Combustion Institute, The Combustion Institute, Pittsburgh, PA, 1999, pp. 457–460. (STI 2000000189)
This is a condensation of the article in Reference 818. New calculations extend the numerical model to show extinction temperatures versus pressure for higher air flows to 40 cm/s. The greatest flammability is still at a flow of 10 cm/s.

*822. Steinhaus, T.; Olenick, S.M.; Sifuentes, A.; Long, R.T.; and Torero, J.L.: A Method for Assessing Material Flammability for Micro-Gravity Environments. Proceedings of the First Joint Meeting of the U.S. Sections of The Combustion Institute, The Combustion Institute, Pittsburgh, PA, 1999, pp. 681–684. (STI 2000005016)
This paper describes the forced-flow ignition and flame spread (FIST) apparatus and documents some normal-gravity results. Ignition delays and critical ignition delay are not affected by sample size for 12.5- mm-thick poly(methyl methacrylate (PMMA) slabs. Hence, one can scale results to other methods, particularly to the full-size lateral ignition and flame spread test (LIFT) results.

823. Vietoris, Thomas; Joulain, Pierre; and Torero, Jose L.: Flow Considerations on the Stability of a Laminar Diffusion Flame in Micro-Gravity. Proceedings of the First Joint Meeting of the U.S. Sections of The Combustion Institute, The Combustion Institute, Pittsburgh, PA, 1999, (STI 19990117211)
Tests covered burning of poly(methyl methacrylate (PMMA) plates (50 by 50 by 10 mm thick) mounted on a stainless steel plate in a horizontal combustion chamber with forced flow. Low-gravity testing was conducted in the Centre National d'Etudes Spatiales (CNES) Airbus A300 and the University of Bremen ZARM Center of Applied Space Technology and Microgravity 4.7-second drop tower. Results show a map of flammability limits and regions of blue and blue-yellow flames as functions of O_2 concentration (20 to 40 %O_2) and flow 13 to 20 cm/s. Yellow flames that are produced at higher O_2 concentrations and flows show some evidence of convection as well as diffusion. Diffusion normally produces blue flames.

*824. Collins, Michelle M.: NASA Issues Related to Use of Halon: Past, Present, and Future. Third Aerospace Environmental Technology Conference, A.F. Whitaker, D.R. Cross, S.V. Caruso, and M. Clark-Ingram, eds., NASA/CP—1999-209258, 1999, pp. 141–143.

Although NASA began an official Halon phase-out program in 1990, present activities are in evaluating needs, documentation, and minimizing leakage of Halon from storage tanks. For the future, NASA plans to invest in research and development and team up with other agencies to address the study and selection of Halon alternatives.

*825. Cordova, J.L.; Walther, D.C.; Fernandez-Pello, A.C.; Steinhaus, T.; Torero, J.L.; Quintiere, J.G.; and Ross, H.D.: Flow Effects on the Flammability Diagrams of Solid Fuels: Microgravity Influence on Ignition Delay. Fifth International Microgravity Combustion Workshop, Kurt Sacksteder, ed., NASA/CP—1999-208917, 1999, pp. 35–38. (ST19990053975)

The paper presents results for the Forced Flow Ignition and Flame Spread (FIST) apparatus determining piloted ignition delay at 25 and 35 kW/m^2 imposed heat flux for 12-mm-thick poly(methyl methacrylate (PMMA). In normal gravity, ignition delay decreases as flow velocity decreases from 250 to 50 cm/s (buoyancy limit). Delays are reduced 60 percent for a heating increase from 25 to 35 kW/m^2. In low gravity on the KC–135, ignition delays are very short because of the low velocities attainable from 5 to 30 cm/s.

*826. Sanchez-Tarifa, C.; and Rodriguez, M.: Combustion and Flammability Characteristics of Solids at Microgravity in Very Small Velocity Flows. Fifth International Microgravity Combustion Workshop, Kurt Sacksteder, ed., NASA/CP—1999-208917, 1999, pp. 39–42. (ST19990053974)

This paper covers the work on the combustion of hollow, 6-mm-diameter poly(methyl methacrylate (PMMA) cylinders in the European Space Agency Caravelle airplane and a Mini Texus sounding rocket. Flame spread increases with air velocity over a range of 2 to 20 cm/s. The paper describes a research project for the International Space Station to use a combustion tunnel for the study of PMMA cylinders.

*827. Ivanov, Anatoliy; Alymov, V.F.; Smirnov, A.B.; Shalayev, S.P.; Belov, D. Ye.; Balashov, Ye.V.; Semenov, A.V.; Andreeva, T.V.; Melikhov, A.S.; Bolodyan, I.A.; and Potyankin, V.I.: Preliminary Results of the Third Test Series of Nonmetal Material Flammability Evaluation in SKOROST Apparatus on the Space Station Mir. Fifth International Microgravity Combustion Workshop, Kurt Sacksteder, ed., NASA/CP—1999-208917, 1999, pp. 47–50. (ST19990053976)

Tests on Delrin, poly(methyl methacrylate) (PMMA), and high-density polyethylene showed a limiting concurrent velocity is necessary for flame spread. This velocity is very low (0.3 to 0.5 cm/s) for the polymers tested. Flame suppression following air-flow cessation is more rapid in microgravity than in normal gravity. The paper also comments on flame appearance, spread rate, bubble ejection, and combustion instabilities.

*828. Altenkirch, R.A.; Olson, S.L.; Deering, J.L.; Tang, L.; Bhattacharjee, S.; and Hegde, Uday: Diffusive and Radiative Transport in Fires (DARTFire): Opposed-Flow Flame Spread in Low-Velocity Flows. Fifth International Microgravity Combustion Workshop, Kurt Sacksteder, ed., NASA/CP—1999-208917, 1999, pp. 317–320.

The DARTFire apparatus for microgravity tests on a sounding rocket has twin combustion tunnels and burns black poly(methyl methacrylate) (PMMA) samples, 2 cm long by 2 cm thick by 0.635 cm wide. The system achieves stable flames at 50 %O_2; 0, 10, and 20 kW/m^2 imposed heat flux; and as low as 1 cm/s opposed flows. Spread rate increases with velocity to about the 0.5 power. A flux of 10 kW/m^2 does not affect the spread rate; a flux of 20 kW/m^2 increases the rate.

*829. Melikhov, A.S.; Bolodyan, I.A.; Potyankin, V.I.; Ivanov, A.V.; Alymov, V.F.; Smirnov, A.B.; Belov, D. Ye.; Balashov, Ye. V.; and Andreeva, T.V.: The Study of Polymer Material Combustion in Simulated Microgravity by Physical Modeling Method. Fifth International Microgravity Combustion Workshop, Kurt Sacksteder, ed., NASA/CP—1999-208917, 1999, pp. 361–364.

Results of combustion tests on the Russian nonconvective narrow-channel apparatus are compared with space results of Reference 827. Limiting velocities determined in the ground tests are close but generally higher than in space. Flame spread rates are lower on the ground than in space. Centrifuge and drop tower tests determine a limiting gravity for combustion as a function of O_2 concentration. Thus some materials may be acceptable on a Moon habitat at partial gravity but not on Earth.

830. King, Merrill K.: Microgravity Studies Offer Insights Into Combustion. Aero. Amer., vol. 37, no. 6, 1999, pp. 20–23.

A general review notes that for fire safety, research provides data for prevention, detection, and extinguishment. Technological barriers include lack of understanding of flammability and ignition mechanisms, smolder-to-fire transitions, and fire growth processes.

*831. Friedman, Robert; Gokoglu, Suleyman A.; and Urban, David L.: Microgravity Combustion Research: 1999 Program and Results. NASA/TM—1999-209198, 1999. (ST19990062669).

This report continues the 3- to 4-year summaries of the past (Refs. 347, 512, and 652). The contents are reorganized into three main sections: Fundamental Studies, Applications to Fire Safety and Other Fields, and General Measurements and Diagnostics. The report also describes facilities and the program participation. There is an extensive bibliography.

*832. Branch, M.C.; Daily, J.W.; and Abbud-Madrid, A.: Ignition and Combustion of Bulk Metals in a Microgravity Environment. Annual Report, NASA CR–202241 (NASA Grant NAG3–1685), 1999.

This is a summary of the bulk metal combustion studies (Refs. 770, 789, etc.) and the results on Mg and Ti, with a list of publications.

833. Cleary, T.; and Grosshandler, W.: Survey of Fire Detection Technologies and System Evaluation/Certification Methodologies and Their Suitability for Aircraft Cargo Compartments. NISTIR–6356, 1999. (ST19990084061).

Cargo compartment detectors are set high (13 to 50 percent per meter obscuration), yet false alarms to fire ratios are as high as 500:1. The report summarizes aircraft cargo protection and rules, and it describes fire-detection technology of all types. A figure compares the response of photoelectric and ionization types to particle sizes. A concise literature survey covers detector types and pertinent patents.

834. Dreizin, Edward L.; and Hoffman, Vern K.: Constant Pressure Combustion of Aerosol of Coarse Magnesium Particles in Microgravity. Comb. Flame, vol. 118, nos. 1/2, 1999, pp. 262–280.

Mg particles, 150 to 220 μm in size, were aerosolized and ignited in microgravity in the NASA Lewis 2.2-Second Drop Tower. The aerosol flame consists of a preheat zone and a combustion zone. The preheat zone propagates more rapidly than the combustion zone; hence the preheat zone width increases with times. Single particles are seen to reignite after apparent extinguishment.

Glenn Research Center
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14. ABSTRACT
Knowledge of fire safety in spacecraft has resulted from over 50 years of investigation and experience in space flight. Current practices and procedures for the operation of the Space Transportation System (STS) shuttle and the International Space Station (ISS) have been developed from this expertise, much of which has been documented in various reports. Extending manned space exploration from low Earth orbit to lunar or Martian habitats and beyond will require continued research in microgravity combustion and fire protection in low gravity. This descriptive bibliography has been produced to document and summarize significant work in the area of spacecraft fire safety that was published between 1956 and July 1999. Although some important work published in the late 1990s may be missing, these citations as well as work since 2000 can generally be found in Web-based resources that are easily accessed and searched. In addition to the citation, each reference includes a short description of the contents and conclusions of the article. The bibliography contains over 800 citations that are cross-referenced both by topic and the authors and editors. There is a DVD that accompanies this bibliography (available by request from the Center for Aerospace Information) containing the full-text articles of selected citations as well as an electronic version of this report that has these citations as active links to their corresponding full-text article.

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