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SPACECRAFT MATERIAL FLAMMABILITY TESTING AND CONFIGURATIONS

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BACKGROUND

As a result of the Apollo AS204 fire, NASA made a commitment to the Congress that the agency would be aware of the type and quantity of each material in the habitable area of manned spacecraft. NASA also committed to conduct flammability tests on material and configuration to verify the fire safety of manned space vehicles. Major points resulting from investigations were to (1) control the launch environment (i.e., control oxygen concentration), (2) have onboard a fire extinguishing system, (3) have a standard and controlled set of flammability requirements, and (4) conduct configuration and full-scale flammability tests.

Since the AS204 fire, NASA has had other accidents that caused a reevaluation of materials flammability in high-pressure oxygen systems. The first was the Apollo 13 incident, which was an in-flight fire in a cryogenic pressure vessel that resulted in the vessel rupture and caused an abort of a lunar landing mission. The second incident was a Shuttle ground test, where an Extravehicular Mobility Unit oxygen fire destroyed a test unit and a spacesuit and seriously injured a technician.

PRESENT REQUIREMENTS AND TRACKING

As a result of these accidents, NASA has imposed standard flammability requirements on all spacecraft material. The requirements are prescribed at Level I (NASA HQ) via NHB 8060.1B (ref. 4). At Level II (STS Program Office) JSC 07700, vol. X, paragraph 3.5.2.1, states "Materials and processes shall be selected in accordance with JSC-SE-R-0006." This document imposes the NHB 8060.1 requirements in addition to other materials requirements such as corrosion, stress corrosion, fracture control, age life, and vacuum stability. The JSC-SE-R-0006 also requires that each element and major contractor prepare a materials control and verification plan. The Orbiter project plan is in JSC 11739 "Shuttle Orbiter Project Materials Control and Verification Program Management Procedures."

The material control procedures for the Orbiter are accomplished by the Materials Analysis Tracking and Control (MATCO) system. This system is essentially a central computerized system where all materials used in the Orbiter in both the original design and the as-built design (changes by Material Review (MR), Discrepancy Reports (DR's), and Test and Checkout Procedures (TCP)) are recorded. The documentation requirements tracked by MATCO include material usage, flammability acceptability, toxicity, age life, vacuum stability, and fluid compatibility acceptability. This system assures that all materials are reviewed, approved, and have their waivers tracked. Figure 1 has a flow diagram for this procedure.

The philosophy NASA uses in fire prevention is (1) assume an ignition source exists and a fire can start, and (2) require that any fire once started shall be self-extinguishing within a short distance. This is accomplished in the design by assuring that exposed materials are self-extinguishing as a material or when tested in the use configuration. Flammable materials must be stowed in a nonflammable container, have fire breaks along the material to prevent propagation, or be protected with a flammability barrier. There is also extensive use of fire breaks as well as proper housekeeping during the mission.

Material and configuration testing for the Shuttle is mainly at 30 percent oxygen concentration at 70 kPa (10.2 psia). This is the worst-case atmosphere during a mission and occurs 10 hr prior to an extravehicular activity (space walk). The pressure is reduced from the nominal 101 kPa (14.7 psia) and the oxygen concentration is increased to 30 percent for medical reasons to prevent the "bends" during an EVA.

The nominal atmosphere is 101 kPa (14.7 psia) with a 23.8 mass-percent oxygen concentration. However, the maximum oxygen concentration that can occur before the Caution and Warning system will initiate an alarm is 25.9 percent. NASA has tested many materials at the 23.8-, 25.9-, and 30-percent-oxygen levels for the Shuttle program. In addition, NASA has a large data base at 100 percent oxygen at 35 kPa (5 psia) and 115 kPa (16.5 psia). The data in figure 2 show how flammability of material is affected by percentage of oxygen for those materials that would be considered for spacecraft applications. This may represent the whole population of materials.

FLAMMABILITY CONTROL IN PRACTICE

One method used in the Shuttle vehicle to reduce flammability is to control spacing of flammable materials such as Velcro and wire ties. The Velcro is flammable, but NASA has a spacing requirement that all Velcro usage should be not more than 25 cm^2 (typically 2 by 2 in.) and each piece must be separated by 5 cm (2 in.) from each other piece in three dimensions. The wire tie spacing states that all wire ties must be 5 cm (2 in.) apart unless a nonflammable tie such as Teflon-coated glass ties are used.

Flammable materials must be stowed in nonflammable containers such as metal boxes or the polycarbonate stowage boxes used in the Orbiter. Other nonflammable bags may be used, such as bags made of double layer Nomex (at least 230 g/m (7.5 oz/yd) each) with a Teflon-coated glass fabric in between. NASA used Teflon-coated beta cloth for stowage bags in Apollo, but these were not durable enough for a reuse vehicle like the Shuttle. Nonflammable bags for wet stowage have been made by making a bag out of two layers of Nomex fabric (230 g/m (7.5 oz/yd)) with an inside layer of neoprene-coated nylon.

The inside of the Orbiter is additionally protected from a major fire by compartmentation of the electronics. For example, the many electronic areas are each in their own compartment to minimize the spread of a fire. Each compartment has either fire extinguisher nozzles from the central fire extinguishing system or has fire extinguisher access ports in front of the panel for the hand-held fire extinguisher to be used to put out a fire. In addition, wire bundles are routed in trays when exposed to the cabin to ensure that the wire bundles cannot be damaged.

NASA has used several techniques to protect flammable materials or components that must be used either in the design or the operations of the Shuttle. Examples include wrapping plastics with aluminum tape as a fire barrier. This has been used on many small off-the-shelf items such as power screwdrivers, calculators, and other hand-held devices. Also employed are nonflammable sleeves made of beta cloth or double layers of Nomex, nonflammable coatings, etc.

There have been over 30 tests on electronic "black boxes". These range from hermetically sealed units backfilled with an inert gas to air-cooled electronic boxes. Most of those made of a nonflammable container passed the configuration test. Those that failed had flammable materials on the outside or used urethane foam in the box with a large void space. The boxes that were air cooled had to meet the following conditions to pass a configuration test (i.e., no flames outside the box): (1) have air flows below 3.7 m/sec (12 ft/sec) or above 9 m/sec (30 ft/sec), (2) have the vent holes covered with a steel screen of 100 mesh or greater, and (3) assure that the flowing air did not create a "chimney effect" by having a straight path from the inlet to outlet.

FUTURE NEEDS

There are still some flammability problem areas or applications that could be improved. One of the areas that could be improved is the fire extinguisher. The present extinguisher medium is Halon 1301. This material has several shortcomings, including (1) the products produced in fighting a fire are corrosive to electronics and are toxic, (2) it has limited effectiveness above 33 percent oxygen concentration, (3) it requires care in usage to ensure that sufficient quantity is put on the fire.

The water emulsion system used on Apollo was very effective, but there was always the concern about water on electrical systems.

Other areas that could use some innovation are (1) clothing for the crew during the mission, (2) nonflammable foams for cushions, and (3) paper and cardboard for flight data files and cuecards.

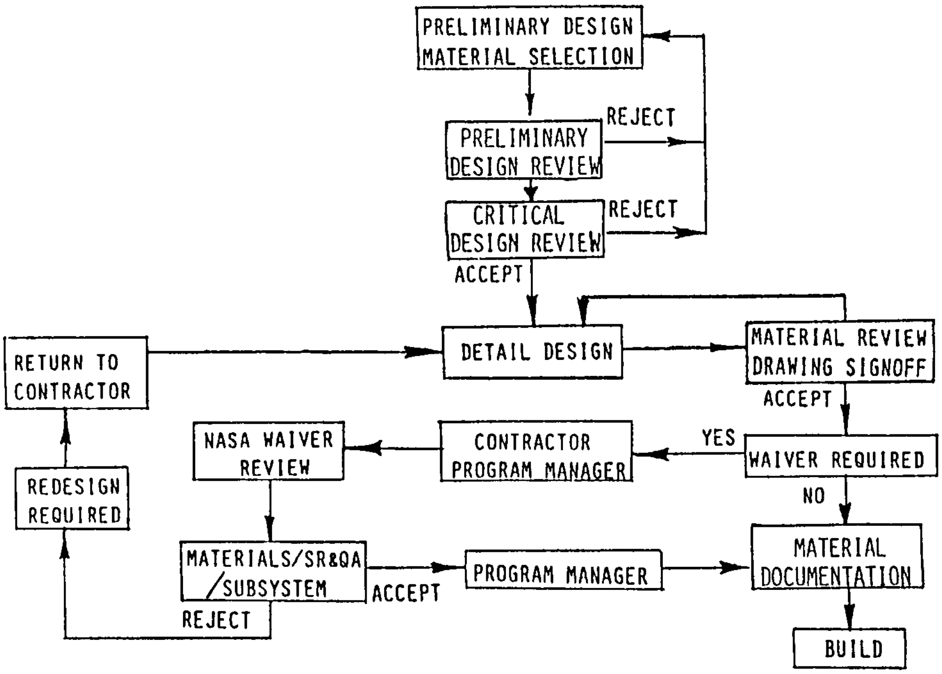

Figure 1. - Review logic for Shuttle material acceptance.

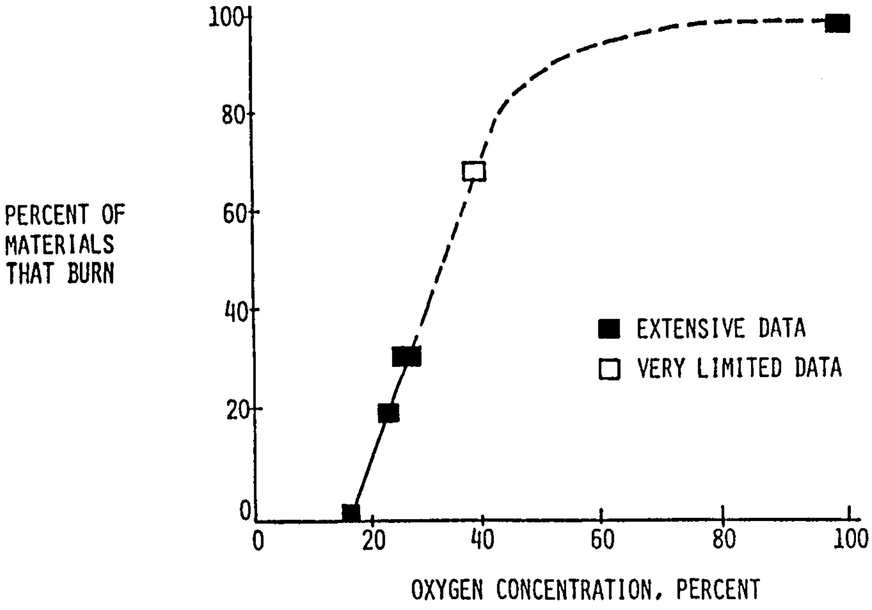

Figure 2. - Data on material flammability as function of oxygen concentration.