EVALUATION OF FIRE EXTINGUISHANTS FOR SPACE STATION FREEDOM

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ABSTRACT

To aid Space Station Freedom designers in selecting a fire extinguishant for the Space Station, the NASA White Sands Test Facility designed and conducted a test program to determine the minimum concentrations of gaseous nitrogen (N_2), carbon dioxide (CO_2), helium (He), and bromotrifloromethane (Halon 1301) required to extinguish self-sustained combustion of various materials under selected atmospheric conditions. The results of this test program were used to rank the extinguishants based on their performance in extinguishing some common Shuttle and Space Station materials. The test method developed was based on ***Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion***, **NHB** 8060.1C Test 1. The test system was specially constructed to allow for the sample to be ignited in a quiescent atmosphere with no extinguishant present and then allow the sample to be exposed to a known, consistent, quiescent extinguishant atmosphere. For the purposes of this test program, extinguishment was defined as the termination of flaming combustion with test material left over. Self-sustained combustion was defined as the combustion process that continues after the removal of the ignitor from the sample. If the entire sample was consumed, the test was repeated with a higher extinguishant concentration. If extinguishment occurred, the test was repeated with a lower extinguishant concentration. The concentrations of N2, CO_2, and He were varied in increments of 5-volume percent, and the concentration of Halon 1301 was varied in increments of 1-volume percent. Each extinguishant was tested until the minimum extinguishant concentration required to extinguish the test sample was obtained. Results clearly indicate that Halon is the most effective fire extinguishant, followed by CO_2 N_2 and He are equally the least effective of the extinguishants. Based on the baseline test results and the bum rate of the materials, the worst condition for flammability occurred at 24-percent oxygen concentration and 608.1 kPa (88.2 psia). The worst condition for extinguishment (based on concentration required to extinguish) occurred at 30-percent oxygen concentration and 70.3 kPa (10.2 psia). The

test results are repeatable both with respect to the burn times and burn lengths obtained at the minimum concentration of the extinguishants used.

INTRODUCTION

The NASA White Sands Test Facility (WSTF) designed and conducted a test program to determine the minimum concentrations of gaseous nitrogen (GN_2), carbon dioxide (CO_2), helium (He), and bromotrifloromethane (Halon 1301) required to extinguish self-sustained combustion of various materials under selected atmospheric conditions. This test program ranked the extinguishants using some of the common materials used in the space station. The results from this test program will aid Space Station Freedom (SSF) designers in selecting a fire extinguishant for the Space Station.

BACKGROUND

The design of the fire protection system for SSF is currently underway. Four fixe extinguishants have been proposed for use in SSF. CO_2 has been baselined by Work Package 1 for the crew modules. In addition, N_2 and He are under consideration for the hyperbaric chamber, and Halon 1301 has been pposed for the Columbus module. Currently, Halon 1301 is used as a fire extinguishant on the space shuttle; however, the use of Halon 1301 is limited in SSF because Halon 1301 is incompatible with the Environment Control Life Support System. Space Station designers would prefer one common extinguishant for the entire Space Station, but require data to select a single extinguishant for all applications.

The fire extinguishant agent that the designers choose will need to be effective in extinguishing fires over a range of oxygen (O_2) concentrations (16 to 30 percent) and pressures [70.3 to 608.1 kPa (10.2 to 88.2 psia)]. Current baseline atmospheres are 30 percent at 70.3 kPa (10.2 psia), 24 percent at 101.3 kPa (14.7 psia), and 21 percent at 304.1 kPa (44.1 psia). Additional data were obtained for a more complete data set that could be used in the future. Decisions will be made as to which agent to use in a local (handheld) application (crew-occupied areas) and which to use in a total flood application (electronic racks). In addition, the effects of microgravity on fire structure and extinguishant effectiveness should be analyzed. The major effects of microgravity on fire structure stem from a reduction in buoyancy driven flows in the flame region. The effect of microgravity on flame structure and how this may affect fire suppressants used in microgravity has been recently reviewed (Reuther 1989). Because the flow-field effects are not well understood for extinguishment in microgravity, tests need to be conducted where externally induced flows (other than buoyancy driven flows) are minimized and where the global Concentration of the extinguishing agent is well characterized.

Several studies were conducted to evaluate the effectiveness of the extinguishants under conditions where the agent is applied directly and locally (similar to application by a handheld extinguisher) to the fire. In general, these studies determined that the flow rate of the agent to the !ire is as important as the global concentration of the extinguishant. In fact, the concentration of extinguishant in the flame region was not determined. In early studies, Kimzey determined that above an O_2 concentration of 60 percent, clean gaseous agents (Halon, nitrogen, helium) were ineffective at extinguishing polyurethane foam (1971). In fact, the intensity of the fire was increased by agent application. At lower O_2 concentrations of 25 to 35 percent, the rate of application must be much greater than that required at 21-percent O_2 (Kimzey 1971; Zallen and Morehouse 1988).

While several investigations evaluating the effectiveness of agents in a total flood application have been conducted, the majority of these investigations have been conducted on liquid fuels (heptane) using a cup burner similar to the O_2 index test (Hirst and Booth 1977). This method was used to evaluate the effects of O_2 concentration on extinguishment for halons; it was found that an increase in O_2 concentration from 21 to 28 percent required an increase in halon concentration required to extinguish the flame from 2.9 to 7.3 percent (Zallen and Morehouse 1988). In a recent test series, several agents, including many halon alternatives, were evaluated using standard size and scaled-down versions of the cup burner (Moore et al. 1990). The test data show the strong effect from the induced flows in the cup burner on the concentration of agent required to extinguish a heptane flame.

The effects of microgravity on agent effectiveness has been investigated, and the concentration of Halon and N_2 required to inert a fuel-air mixture was determined (Ronney 1985); however, because the study determined the minimum concentration where the fuel would not ignite, the physics involved with extinguishment (in the classical sense) were not evaluated. For example, there is evidence that the application of an agent may cause the fire to flare up in microgravity because the agent flow field will overcome the effect of reduced buoyancy driven flows and carry O_2 into the flame region (Kimzey 1986).

EXPERIMENTAL APPROACH

Prior to performing the extinguishant tests, baseline tests were conducted on various materials to determine the material flammability. The method developed for testing material flammability was based on NHB 8060.1C, Test 1 (NASA 1991). To establish a minimum total flooding concentration for the extinguishants without externally induced flows, a two-chamber test system was designed and built. The test system was specially constructed to allow the sample to be ignited in a quiescent atmosphere with no extinguishant present and then allow the sample to be exposed to a known, consistent, quiescent extinguishant atmosphere. For this test program, extinguishment was defined as the termination of flaming combustion with test material remaining. Self-sustained combustion was defined as the combustion process that continues after the removal of the ignitor from the sample. For most tests involving a 30.5 cm x 6.5 cm (12 in x 2.5 in) sample or a 30.5 cm x 5.08 cm (12 in x 2 in) sample, the self-sustained combustion was set at 5.08 cm (2 in) of burning; however, this requirement was not applicable in test series when the sample ceased to burn either prior to or shortly after 5.08 cm (2 in) in the ignition chamber.

Baseline Tests

The baseline tests were conducted in a 1400-liter flammability chamber which was sealed and then filled with O_2 and N_2 as per test requirements. Five materials were used in the baseline tests and no extinguishant was present in the chamber. These tests were used to determine the parameters of O_2 concentration and pressure under which the samples were consumed completely. In addition, the bum rate of the sample was determined. To determine if there was a depletion of the O_2, the posttest O_2 concentration was analyzed. Based on these preliminary baseline tests, materials were chosen at the O_2 concentration and test pressure which would allow for complete consumption of the sample and for an optimal burn rate that would ensure consistent data.

Additional baseline tests were conducted in a 8.2-liter ignition chamber to determine (1) the length that the sample would burn before the O_2 was depleted inside the chamber and to provide data for determining when to open the ignition chamber, (2) the effects of pressure differential between the flammability and the ignition chambers on the flame structure, and (3) the rate at which the ignition chamber was to be opened, such that no effect was observed on the burning of the materials.

The materials used in the baseline tests were as follows:

- Pyrell foam [2.54-cm (1-inch) thick and 0.635-cm (0.25-inch) thick]
- Nylon Velcro (1000 loop)
- Polyester/cotton T-shirt (50-percent polyester and 50-percent cotton)
- Polyethylene sheets (approximately 125-μm thick)
- Cotton towels

All baseline materials were tested with 16-, 21-, and 24-percent O_2 concentrations at 101.3, 304.1, and 608.1 kPa (14.7, 44.1, and 88.2 psia, respectively). In addition, the materials were tested with 30-percent O_2 concentration at 70.3 kPa (10.2 psia).

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The extinguishant tests were conducted using three of the five materials chosen as a result of the baseline tests. Taut (unwrinkled), vertically oriented samples were ignited at the bottom of the sample, allowing for combustion to proceed upwards. The test sample was ignited in an ignition atmosphere containing no extinguishant. After ignition, the burning sample was exposed to an atmosphere containing a known composition of 02, N2, and extinguishant. The burning sample was observed and recorded on video. If the entire sample was consumed, the test was repeated with a higher extinguishant concentration. If extinguishment occurred, the test was repeated with a lower extinguishant concentration.

The concentrations of N_2, CO_2, and He were varied in increments of 5-volume percent, and the concentration of Halon 1301 was varied in increments of 1-volume percent. This test procedure was repeated for each extinguishant tested until the minimum concentration required to extinguish the test sample was obtained. Three tests were conducted at the determined minimum extinguishant concentration to establish repeatability.

The test atmosphere was required to be static, therefore, the test pressures inside both the flammability chamber and the ignition chamber were maintained at an average of 0.2 kPa (0.03 psid) to avoid any pressure differential driven convective flow of the gases. Another requirement was that the ratio of O_2 and N_2 be the same in both the ignition and the extinguishment atmospheres except when N_2 was the extinguishant gas. The two atmospheres were maintained by a seal which separated the ignition and extinguishant atmospheres. This seal, located between the ignition chamber and the flammability chamber, was checked to ensure that leakage of extinguishant into the ignition chamber prior to the ignition and withdrawal of the ignition chamber was minimized, less than 7 kPa (1 psi) pressure drop in 15 minutes at 34.5 kPa (5 psig).

The materials used in the extinguishant tests were as follows:

- Pyrell foam 0.635-cm (0.25-in) thick
- Nylon Velcro (1000 loop)
- polyester/cotton T-shirt (50-percent polyester and 50-percent cotton)

The Pyrell foam and Nylon Velcro were tested with 21- and 24-percent O_2 concentrations at 101.3, 304.1, and 608.1 kPa (14.7, 44.1, and 88.2 psia, respectively) and also with 30-percent O_2 concentration at 70.3 kPa (10.2 psia). The polyester/cotton T-shirt was tested with 16-percent O_2 concentration at 101.3, 304.1, and 608.1 kPa (14.7, 44.1, and 88.2 psia, respectively).

TEST SYSTEM AND PROCEDURES

The test system consists of an 8.2-liter ignition chamber that was placed inside a 1400-liter flammability chamber (Figure 1). The flammability chamber was connected to a vacuum pump to evacuate the chamber prior to filling the chamber with the test atmosphere. The flammability chamber is equipped with two circulating fans which mix the gases prior to each test. It also consists of a pressure transducer to measure the internal pressure, a sampling port for gas analysis, and a viewport for video observation and recording. The ignition chamber was connected to the test atmosphere supply lines. The ignition chamber was positioned by two dual-acting pneumatic actuators that rapidly withdrew the ignition chamber from around the sample after ignition, removing the ignitor from the sample and exposing the burning sample to the extinguishant atmosphere. A nichrome wire and hexamethalene tetra-amine-based ignitor, the ignitor used in NHB 8060.1C Test 1, were used to ignite the samples.

Baseline tests were conducted in the flammability chamber according to NHB 8060.1C using a standard sample holder.

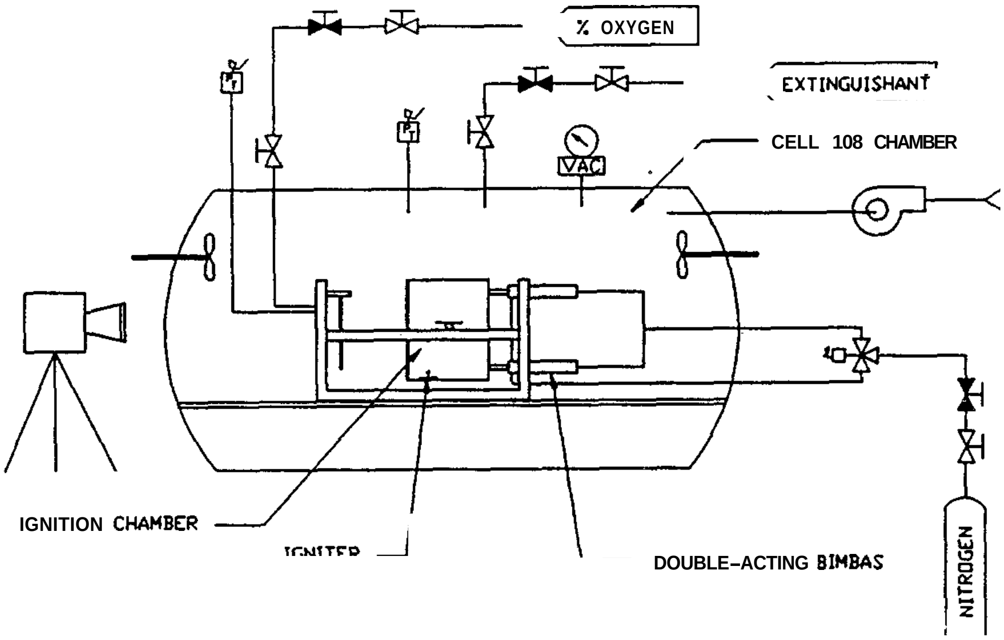

Figure 1. Test System

For extinguishant tests, the sample was installed in the sample holder, and the ignition chamber was positioned around the sample holder with the ignitor positioned approximately 0.5 cm below the lower end of the sample. Both the flammability and ignition chambers were evacuated, then the ignition chamber was sealed against the viewing window. The two chambers were filled simultaneously with different atmospheres; the flammability chamber was filled with O_2, **N_2**, and extinguishant while the ignition chamber was filled with **an** O_2/N_2 ignition atmosphere each at their respective composition. The two chambers were maintained at a pressure differential ≤ **2.1** kPa (0.3 psid), typically **0.2** kPa (0.03 psid), during the process of pressurization. The same ratio of O_2/N_2 concentration was maintained in the ignition chamber as in the flammability chamber. The two circulating fans, each capable of circulating 5 times the flammability chamber volume per minute, were activated for **2** minutes to obtain a homogeneous blend of the extinguishants prior to ignition. After blending, the gases were allowed to reach quiescence prior to testing. The following data were also recorded:

- Flammability chamber O_2 and extinguishant concentrations (pretest and posttest)
- Ignition chamber O_2 concentration (pretest)
- Flammability chamber pressure (initial)
- Time for extinguishment
- Sample burn length

RESULTS AND DISCUSSION

Baseline Tests

Typical baseline test results are depicted in Figures 2 and 3, which show the strong effect of O_2 enrichment and pressure on the bum rates of all the materials tested. The results show an increase in bum rates with increasing O_2 concentrations. In addition, a small change in the O_2 concentration had a much greater effect on the bum rates as compared to the pressure effects. Results also indicate that the 16-percent O_2 concentration at 101.3 kPa (14.7 psia) is the least severe testing condition while the 24-percent O_2 concentration at 608.1 kPa (88.2 psia) is the most severe testing condition with respect to sample bum rate.

Of the materials tested, only the Pyrell foam, Nylon Velcro, and polyester/cotton T-shirt were completely consumed at the specific combination of test pressure and O_2 concentration. In addition, these materials burned at a rate which enabled the ignition chamber to be opened at a rate that did not visibly induce flows, therefore, decreasing the possibility of interfering with the burning process.

Extinguishant Tests

The percentage values of extinguishants required to extinguish each material at each condition tested are shown in Tables 1 through 4. Table 1 shows the results of tests performed on polyester/cotton T-shirts tested in 16-percent O_2 concentration. The results indicate that both N_2 and He are equally potent as an extinguishant agent, and approximately 5-percent volume concentration of each extinguishant was required at 101.3 kPa (14.7 psia) and 304.1 kPa (44.1 psia) to extinguish the burning polyester cotton. At 608.1 kPa (88.2 psia), the volume concentration of N_2 and He required to extinguish the polyester/cotton T-shirt was approximately 10 percent. CO_2 also required approximately 5-percent volume concentration for extinguishment at 101.3 and 304.1 kPa (14.7 and 44.1 psia, respectively); however, at 608.1 kPa (88.2 psia), CO_2 required only 5-percent volume concentration. The experimental design does not distinguish between 0.5 to 4.5 percent volume for He, CO_2, and N_2 extinguishants, therefore, any values between these points is interpreted as 5 percent. The experiment design also does not distinguish between 5.5 to 9.5 percent volume; values between these points are interpreted as 10 percent.

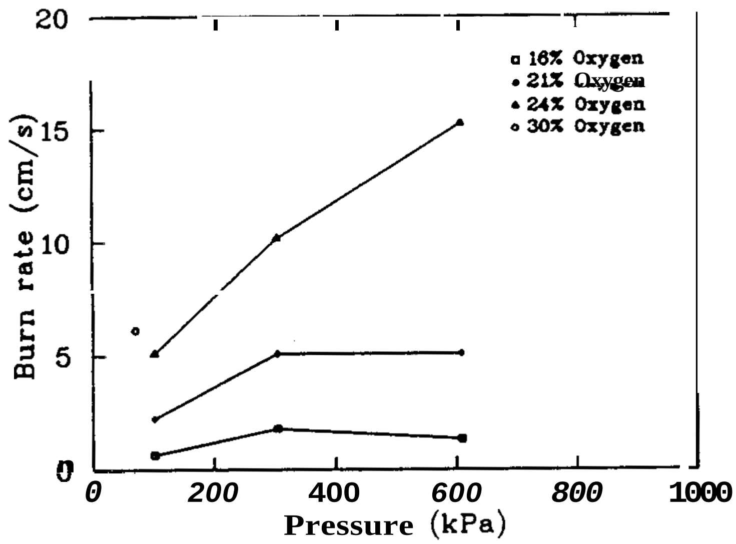

Figure 2. Baseline Test Results Showing Effect of Pressure on Bum Rate at Various Concentrations for 0.634-cm (0.25-in) Pyrell Foam.

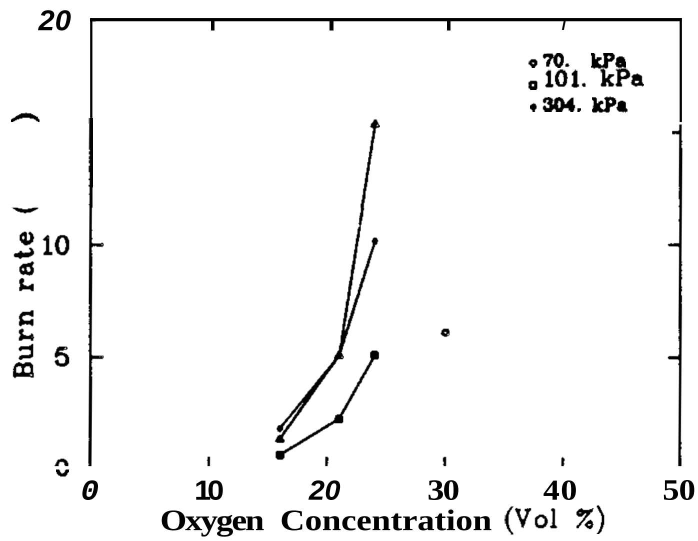

Figure 3. Baseline Test Results Showing Strong Dependence of Bum Rate on Oxygen Concentrations at Various Ambient Pressures for 0.635-cm (0.25 - in) Pyrell Foam.

While the experimental design is sufficient for determining system requirements on the Space Station, it does not allow for precise concentration information concerning the three extinguishants. Hence, it becomes extremely difficult to determine precisely if an increase in test pressure requires an increase in the extinguishant concentration for CO_2. The reactivity of CO_2 with the fire, which produces more endothermic reactions than He or N_2, could explain the results at increased pressures. It is extremely difficult to differentiate between He and N_2 in terms of their potency. For Halon 1301, 1-percent volume concentration was required at all pressures for extinguishment.

Table 2 shows the results of experiments performed on Nylon Velcro and Pyrell foam with 21-percent O_2 concentration. These results show a consistent and predictable trend of extinguishant concentration required to extinguish Nylon Velcro as a function of pressure. For N2, CO_2, and Halon 1301, an increase of the extinguishant concentration with an increase of pressure was apparent; however, for He, the concentration remained constant at 20-percent volume concentration. This result may be due to the experimental design as described above. The least amount of Halon 1301 required to extinguish the Pyrell foam was approximately 1 percent for all the pressures tested. For CO_2, the amount required to extinguish the Pyrell foam increased with increasing pressures from 5 to 10 percent; this value ranged from 5 to 15 percent for N_2 and 5 to 20 percent for He.

The results for Nylon Velcro in Table 3 indicate that the concentration of Halon 1301 increased to 4 percent at 24-pent O_2 (as compared to the 1 to 2 percent obtained for the 16- and 21-percent O_2 concentration tests) and remained constant at all pressures. For CO_2 and He, there was an increase in the required extinguishant concentration when the pressure was increased from 101.3 to 304.1 kPa (14.7 psia to 44.1 psia, respectively); however, when the test pressure was increased to 608.1 kPa (88.2 psia), the required extinguishant concentration decreased. This result may be due to the experimental design as described above; however, in general, the concentration of CO_2 required to extinguish the burning material does not appear to be as affected by increasing the O_2 concentration and pressure as N_2 and He. It is also possible that at higher pressures there is a combustion product which forms and acts as an extinguishant and reduces the extinguishant concentration required for total extinguishment. Formation of CO_2 during the combustion process is a strong possibility, and the CO_2 presence in the chamber could conceivably reduce the required extinguishant concentration. The high concenmtion of O_2 in the system (24 pent) could convert some of the unburnt carbon and carbon monoxide to CO_2. The enhanced rate of reaction at higher pressures could accelerate the rate of this CO_2 production. This concept was confirmed using simple kinetic and thennodynamic calculations; however, for the sake of brevity these calculations are not included.

Table 1
Percent Extinguishant Required to Extinguish Nylon Velcro and Pyrell Foam with 21-Percent Oxygen

Pressure		xtinguishant (%)	
(kPa)	(psia)	Nylon Velcro	Pyrell Foam
	N_2[a]		
101.3	14.7	15	5
304.1	44.1	20	15
608.1	88.2	25	15
	CO_2		
101.3	14.7	10	5
304.1	44.1	15	10
608.1	88.2	15	10
	Halon 1301		
101.3	14.7	1	1
304.1	44.1	1	1
608.1	88.2	2	1
	He		
101.3	14.7	20	5
304.1	44.1	20	15
608.1	88.2	20	20

[a] Total nitrogen concentration was 82.15% for 101.3 kPa (14.7 psia), 83.2% for 304.1 kPa (44.1 psia), and 84.24% for 608.1 kPa (88.2 psia)

Table 2
Percent Extinguishant Required to Extinguish
Polyester/Cotton with 16-Percent Oxygen

Pressure (kPa)	(psia)	Extinguishant (%)
	N_2[a]	
101.3	14.7	5
304.1	44.1	5
608.1	88.2	10
	CO_2	
101.3	14.7	5
304.1	44.1	5
608.1	88.2	5
	Halon 1301	
101.3	14.7	1
304.1	44.1	1
608.1	88.2	1
	He	
101.3	14.7	5
304.1	44.1	5
608.1	88.2	10

[a] Total nitrogen concentration was 84.8% for 101.3 and 304.1 kPa (14.7 and 44.1 psia, respectively) and 85.6% for 608.1 kPa (88.2 psia).

Table 3
Percent **Extinguishant Required to Extinguish**
Nylon Velcro **and** Pyrell **Foam** with 24-Percent Oxygen

Pressure		Extinguishant (%)	
(kPa)	(psia)	Nylon Velcro	Pyrell Foam
		N_2[a]	
101.3	14.7	30	15
304.1	44.1	35	35
608.1	88.2	35	30
		CO_2	
101.3	14.7	20	10
304.1	44.1	25	20
608.1	88.2	20	25
		Halon 1301	
101.3	14.7	4	1
304.1	44.1	4	2
608.1	88.2	4	3
		He	
101.3	14.7	25	10
304.1	44.1	35	30
608.1	88.2	30	25

[a] **Total** nitrogen concentration was 83.2% for 101.3 kPa (14.7 **psia)**, 84.4% for 304.1 **kPa** (44.1 **psia)**, and 608.1 kPa (88.2 **psia)**

Results for Pyrell foam **tested** with 24-percent O_2 concentration at various pressures **are** also given in Table 3. For CO_2 and **Halon** 1301, the results indicate that a higher concentration of the extinguishant is required at higher pressures for extinguishment. For N_2 and He, there was an increase in the required extinguishant Concentration when the pressure was increased from 101.3 to 304.1 kPa (14.7 to 44.1 psia, respectively); however, when the test pressure was increased to 608.1 kPa **(88.2** psia), the required extinguishant concentration decreased.

The test results obtained for Nylon Velcro and **Pyrell** foam **tested** with 30-percent O_2 concentration at 70.3 kPa (10.2 psia) are shown in Table 4. Similar to the previous cases, the Nylon Velcro required more concentration of the extinguishant for total extinguishment than the Pyrell foam.

Table 4
Percent Extinguishant Required to Extinguish Nylon Velcro and
Pyrell Foam[a] with 30-percent Oxygen **at** 70.3 kPa **(10.2** psia)

	Extinguishment (%)	
	Nylon Velcro	**Pyrell** Foam
N_2[b]	45	30
CO_2	**35**	**25**
Halon 1301	7	7
He	**40**	30

[a]Pyrell **foam** was 0.625-cm (0.25-in) thick.
[b]Total nitrogen concentration was 83.5% for **45%** extinguishant and 79.0% for 30% extinguishant.

In general, at all pressures and O_2 concentrations, the extinguishant concentration required to extinguish Nylon Velcro was greater than that required for **Pyrell** foam. **As** expected, the concentration of extinguishant required ***to*** extinguish a given material increased with increasing O_2 concentration. The effects of O_2 concentration appeared to be greater than **the** effects of pressure **on** the required extinguishing concentration. When comparing the results **in** Table **4** to the results in Tables **1** through 3, the worst condition for extinguishment occurred with 30-percent O_2 at 70.3 kPa (10.2 psia). This is different from the result of the baseline tests where, based **on** consumption rate, the worst **condition** occurred with 24-percent O_2 at 608.1 kPa **(88.2** psia). One possible explanation for this result is that the effects of increasing the O_2 concentration to 30-percent combine with the effects of a decreased heat capacity of the system at 70.3 kPa **(10.2** psia) (which would limit the efficiency at which heat can be removed from the sample during extinguishment) to yield conditions where the extinguishing process is more difficult.

In all cases, the results indicate that Halon 1301 is the most efficient of the fire extinguishants, followed by CO_2, and then either N_2 *or* He, depending on the material chosen to test. In general, the data obtained for Halon 1301 **are** comparable to data reported by Zallen and Morehouse for extinguishing heptane and cotton flames in a cup burner in an @-enriched environment (1988). The materials tested showed a distinct difference in the way they were consumed. Nylon Velcro is more flammable than **Pyrell** foam based on the O_2 index and the NHB 8060.1C, Test 1 data on the two materials. When ignited, Pyrell foam burned on the surface, and the flame propagated to the top of the sample very quickly; however, the sample was consumed at a much slower rate than the flame propagation rate, and sample dripping was observed. This result is because Pyrell foam is a combustion-modified polyester-polyurethane foam that when ignited intumesces to form a char layer which makes the material less flammable and decreases the consumption rate. Hence, for a partially burnt sample, Pyrell foam has a large heat-affected zone. Nylon Velcro burned differently than the Pyrell foam. The flame propagated almost at the same rate at which the sample was consumed; however, the sample tended to drip. For both **Pyrell** foam and Nylon Velcro, if the sample dripping extinguished the flame, the test was redone. The polyester/cotton T-shirt burned similar to Nylon Velcro, but unlike Nylon Velcro, even after the flame propagated, the products **of** combustion appeared to glow for some time.

The bum lengths and burn times at the minimum extinguishant concentrations were also compared. Most of the values of the standard deviations indicate that the test system and design yield to give reproducible results; however, some of the results indicate a large scatter of the burn lengths and bum times at a given O_2 concentration and pressure. It is believed that the magnitude of this scatter depends on the value of the extinguishant concentration for the particular test and the nearness of this concentration value to the minimum concentration required for extinguishment. The closer the test concentration is to the threshold concentration for extinguishment, the more scatter of values is expected, resembling events taking place close to flammability limits. However, this cannot be confirmed using the current test design. The results analyzed do not show definite trends to indicate any relationship between bum length and bum time with increasing pressure and O_2 concentration.

CONCLUSIONS

Indicate that Halon 1301 is the most effective tire extinguishant, followed by CO_2. N_2 and He are equally the least effective extinguishants. The worst condition for combustion (based on the baseline test results and the bum rate of the materials as opposed to ignition) occurred at 24-percent O_2 concentration and 608.1 kPa (88.2 psia). The worst condition for extinguishment (based on O_2 concentration required to extinguish) occurred at 70.3 kPa (10.2 psia) and 30-percent.

The results on the polyester/cotton material indicated that increasing amounts of extinguishant were required for increasing pressures. The Nylon Velcro material required more extinguishant than the Pyrell foam to extinguish under the same conditions. While this result is expected based on the flammability of the two materials, the addition of fire retardants to the Pyrell foam during manufacture may contribute to this result. The test results were repeatable, both with respect to the burn times and the bum lengths obtained at the minimum concentration of the extinguishants used.

The test system designed to perform the tests under total flooding conditions is functional. The small volume capacity of the ignition chamber limits the types of materials that can be tested using this system; however, the small volume capacity of the ignition chamber does not dilute the extinguishants in the flammability chamber appreciably during testing. This test system is applicable to testing a variety of materials and extinguishants, and the results obtained compare favorably with results from cup-burner experiments.

REFERENCES

Hirst, B. and K. Booth, "Measurement of Flame Extinguishing Concentrations," *Fire Technology*, Vol. 13, No. 4, 1977.

Kimzey, J. H., *Fire Extinguishment in Hypobaric and Hyperbaric Environments*, Conference on Materials for Improved Fire Safety, NASA SP-5096, 1971, pages 163 - 169.

Kimzey, J. H., *Skylab Experiment M-479 Zero Gravity Flammability*, Report JSC 22293, NASA Johnson Space Center, Houston, Texas, August 1986.

Moore, T. A., J. P. Moore, J. S. Nimitz, M. E. Lee, H. D. Beeson, and R. E. Tapscott, *Alternative Training Agents Phase II - Laboratory-Scale Experimental Work*, ESL-TR-90-39, New Mexico Engineering Research Institute, Albuquerque, New Mexico, August 1990.

NASA, *Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion*, Washington, D.C.: NHB 8060.1C, NASA Office of Safety and Mission Quality, 1991.

Reuther, J. J., *Definition of Experiments to Investigate Fire Suppressants in Microgravity*. Columbus, Ohio: Battelle, 1989.

Ronney, P. D., "Effect of Gravity on Halocarbon Flame Retardant Effectiveness," *Acta Astronautica*, Vol. 12, No. 11 (1985): pages 915 - 921.

Zallen, D. M. and E. T. Morehouse, Jr., "Fire Extinguishing Agents for O_2-Enriched Atmospheres," *Flammability and Sensitivity of Materials in Oxygen-Enriched Atmospheres, Volume 3, ASTM STP 986*, D. W. Schroll, Ed., American Society for Testing and Materials, Philadelphia, 1988.