See: NIST SP861, W. L. Grosshandler, et al., Editors

EXECUTIVE SUMMARY

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Bromotrifluoromethane (halon 1301 or CF_3Br) has been the fire-fighting agent of choice for decades to protect inaccessible spaces aboard aircraft in flight because of its inherent ability to inhibit combustion while possessing a high liquid density and stability, and low boiling point, electrical conductivity, corrosiveness, toxicity and cost. The bromine atom, which is credited with giving halon 1301 its strong inhibition character, reacts readily in a catalytic cycle to destroy ozone molecules. By international agreement, commercial production of CF_3Br has ceased in order to protect the stratospheric ozone layer. No alternative agents are available which have all the positive characteristics of halon 1301. Hence, there is an urgency to finding a replacement chemical in order to maintain aircraft safety. The affected government agencies and industries have a large stake in minimizing the impact of making a transition because of the potentially huge costs involved and military readiness implications.

The US Air Force, Navy, Army and the Federal Aviation Administration pooled their resources to support a comprehensive 17 month study at NIST to help them select the best chemicals to include in a full-scale fire suppression test program at Wright-Patterson Air Force Base. The sponsors were concerned with two specific applications: protection of commercial and military aircraft engine nacelles, and protection of military aircraft dry bay areas. The engine nacelle is the portion of the airframe which surrounds the main jet engines. In the event of a component failure, fuel and other flammable materials can accumulate, ignite from a hot surface, and threaten the integrity of the nacelle. The fire extinguishers are activated remotely following an alarm signal to the crew. Dry bays are located in the wings and fuselage of the aircraft and vary considerably in geometry. They contain a variety of electronic and mechanical components, and are either adjacent to fuel tanks or have fuel, hydraulic or lubricating fluid lines passing through them. The threat is from an anti-aircraft projectile which ruptures a fuel tank or flammable fluid line, necessitating rapid and automatic detection, agent release and suppression to avoid possible loss of the aircraft.

The specific objectives of the research program are listed below. New metrics have been developed along the way which can be used to rate other fire fighting compounds for a variety of applications.

1. Determine the best two candidates for each application from the following list of gaseous agents provided by the sponsors:

   C_2F_6 (FC-116), C_3F_8 (FC-218), C_4F_{10} (FC-31-10), and cyclo-C_4F_8 (FC-318);

   CH_2F_2 (HFC-32), C_2HF_5 (HFC-125), CH_2F_2 (60%)/C_2HF_5 (40%) (HFC-32/HFC-125), $C_2H_2F_4$ (HFC-134a), C_3HF_7 (HFC-227ea), and $C_3H_2F_6$ (HFC-236fa); and

   CHF_2Cl (HCFC-22), and C_2HF_4Cl (HCFC-124).

2. Identify the best practical alternative from among chemicals not on the list of twelve.

3. Ascertain whether or not sodium bicarbonate powder is a viable option.

The resources of three NIST organizations [the Building and Fire Research Laboratory (BFRL), the Chemical Science and Technology Laboratory (CSTL) and the Materials Science and Engineering Laboratory (MSEL)] were enlisted to conduct the research, involving close to forty NIST staff members. Subcontracts were made to Lawrence Livermore Laboratory, the University of California at San Diego and Yale University in support of the coordinated effort. Tasks were organized around the following topics: thermodynamic properties of alternative agents; fluid dynamics of agent discharge; flame suppression effectiveness; flame inhibition chemistry and the search for additional fire fighting chemicals; agent stability under storage and discharge residue; metals corrosion; elastomer seal compatibility; and human exposure and environmental impact.

New experimental methods were developed to screen the multitude of chemicals in a manner which would allow extrapolation to the full-scale test. The agents were rated according to their following innate physical properties which are independent of the release mechanism or performance in the fire, with the desired magnitude given in parentheses: saturation liquid density {high}, normal boiling point {low}, thermal expansion {low}, thermal stability {high}, solubility of nitrogen in agent {low}, atmospheric lifetime {short}, agent residue {low}, corrosion of metals {low}, swelling of polymers {low} and durability of elastomers and greases {high}. The performance criteria for evaluating fire suppression effectiveness were the concentrations {low} necessary to extinguish a laminar opposed-flow diffusion flame (OFDF), a small pool fire (cup burner), a turbulent spray flame, a high speed premixed deflagration, and the amount of acid gases (HF and HCl) formed during the suppression process. Discharge performance was evaluated from the time required {short} for the agent to be discharged, dispersed, mixed and evaporated upon sudden release at high pressure. Agent toxicity and potential exposure to humans was also rated on a relative basis. The likely availability of an alternative (and indirectly, its cost) were important considerations as well because the Air Force testing schedule dictated that enough be available for them to perform a full-scale test matrix in 1994, and to begin installing the agent in the fleet beginning in 1996.

The research uncovered deficiencies in a number of compounds which were of enough concern to recommend against testing them in the full-scale test program. FC-116 required the largest storage volume of the twelve agents on the original list. This is because its critical temperature is only 20 °C, leading to uncertainty in the design of the storage vessel and the rate at which material could be discharged. The mixture of HFC-32 and HFC-125 required the second highest storage volume; and in addition, high over-pressures in the detonation/deflagration tube were experienced. HFC-236fa could not be recommended for the present aircraft applications because it has the highest boiling point and is the most difficult to vaporize at the low temperatures which are likely to be encountered. FC-318 and FC-31-10 also suffer from high boiling points and poor evaporation. In addition they are compatible with fewer materials and have very long atmospheric lifetimes. The HCFC-22 was compatible with the fewest materials, and has the highest ODP of the core agents evaluated.

The positive attributes of an agent needed to suppress one kind of fire are not necessarily the same needed to suppress a different kind of fire. As a result, a different set of recommendations is made for the simulated full-scale engine nacelle and dry bay testing. HCFC-124 required the least amount of material to extinguish the nonpremixed flames and HFC-125 vaporizes well at low temperatures; both are recommended for testing in the engine nacelle. FC-218 is recommended as the first alternate. The most efficient agent of all is the sodium bicarbonate powder. A partial full-scale test matrix is recommended to determine if possible operational difficulties can be overcome. One additional gaseous candidate was identified that was more effective than halon 1301 in suppressing the nonpremixed flames, iodotrifluoromethane (CF_3I). It is recommended that it also be included in the engine nacelle test program, but limited availability may prevent the test matrix from being completed. Atmospheric chemistry, stability, compatibility and toxicity testing is still underway, so that the recommendation for full-scale testing of CF_3I comes with a caution.

The primary candidate for simulated full-scale dry bay testing is FC-218. It vaporizes relatively easily, which is critical for quickly dispersing the agent through the dry bay in cold weather, and is relatively effective in attenuating shock wave pressure and speed in the premixed closed tube experiments. HFC-125 should also perform well in cold weather, and is the second recommended candidate for dry bay testing. However, high over-pressures were noticed in the premixed closed tube experiments. Should these occur during full-scale tests, HFC-227ea is recommended as a back-up. Sodium bicarbonate is not recommended for this application because, as a powder, rapid dispersion is hindered by clutter within the dry bay. The CF_3I suppressed the premixed flame at lower concentrations than the other agents, but was not as effective as halon 1301. A partial test matrix is recommended for CF_3I, with the previously mentioned precautions holding.

Details of all aspects of the research program are provided in different sections of this special publication. The rationale for arriving at critical conclusions and the scientific basis supporting the above recommendations are discussed. A significant amount of resources went into selecting the best candidates for full-scale evaluation, and work is continuing at NIST to determine long term compatibility of the recommended agents with metals and polymers. A method for predicting the acid gases produced when alternative agents pass through the fire is under development, parameters which can increase the effectiveness of the agents by optimizing their release are being investigated, and techniques are being developed for measuring the concentration of the agent once it is discharged.