POTENTIAL CF_3I DEPLOYMENT — AN AIRFRAME PERSPECTIVE

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INTRODUCTION

Halon 1301 is the standard fire extinguishing agent for protecting aircraft engine nacelles, secondary/auxiliary power and gearbox compartment?, dry bays, and even fuel tanks on some aircraft. For some time, CF_3I has been recognized as an effective fire-extinguishing agent and a potential "drop-in" replacement for Halon 1301 in some of these non-occupied applications. Two characteristics have limited its acceptance:

1. **A** relatively high boiling point ($\approx$ -9 °F for CF_3I vs. = -72 °F for Halon 1301)
2. The perceived health hazard associated with its relatively low toxicity/cardiac sensitization level (LOAEL $\approx$ 0.4% for CF_3I vs. $\approx$ 7.5% for Halon 1301)

Over the last several years additional data, design concepts, and evaluation strategies have combined to revive interest in CF_3I. This paper will summarize some of the more significant of these issues and place them in context with competing alternatives including HFC-125.

AIRCRAFT APPLICATIONS

All types of air vehicles require fire protection for a variety of applications. Both military and commercial aircraft protect engine nacelles, and secondary power and gearbox compartments. Some military aircraft also protect fuel tanks and some of the dry bays adjacent to them. These are all normally non-occupied spaces that allow the designer greater freedom in "agent" selection. Commercial aircraft also need fire protection in passenger/crew compartments and lavatories, which are normally occupied, and in the cargo bays, which impose special concerns. These applications are more restrictive. The following discussion excludes these specialized commercial applications. **A** comparison of military and commercial needs is presented in Figure 1.

PERCEIVED HEALTH HAZARDS OF VARIOUS TECHNOLOGIES

All fire extinguishing technologies impose some degree of risk. Gas generators may cause burns, inert gases cause asphyxiation, high-pressure/low boiling point gasses may cause frostbite, and almost all could cause physical injury from the crew's "surprise response" to an unanticipated discharge. Even Halon 1301 shares many of these characteristics. **A** balanced assessment of the relative benefit/hazard for all alternatives is needed to ensure that potentially viable technologies are not prematurely dropped from consideration. **A** summary of the more obvious hazards for several leading halon alternatives is presented in Table 1.

Military Needs	Commercial Needs
–Engine Nacelles	–Engine Nacelles
–SPU/Gearbox	–SPU/Gearbox
	–Passenger / Crew
	–Lavatories
	–Cargo Bays
–Dry Bays	
–Fuel Tanks	

Figure 1. Wide application for fire protection.

TABLE I. SUMMARY OF OBVIOUS HAZARDS.

	Halon 1301	HFC-125	Gas Gen	CF_3I	Dry Chem
"Surprise" Response	X	X	X	X	X
"Frostbite"	X	X		X	
HF/HBr/HI Effects	X	X		X	
"Hot" Exhaust			X		
"Dust" Impact			X		
Toxicity		X		X	
Cardiac Sensitization		X		X	

TOXICIIY AND CARDIAC SENSITIZATION

Exposure Conditions

"Agents" with perceived toxicity and/or cardiac sensitization risks impose an additional concern. The proccss for filling, transporting, and storing thc "agent" containers should he addressed as industriul-hygiene issues. Protective clothing, special transportation containers, and special storage may be required. It is assumed that the impact associated with thesc issues would be reflected as increased acquisition and ownership costs. Since aircraft, especially military aircraft, are extraordinarily weight sensitive, these additional costs are not likely to limit their use for aircraft applications if they have significantly lower equipment weights than competing technologies.

Engine nacelles, secondary power and gearbox compartments, dry bays. and fuel tanks arc not occupied in flight, therefore discharging an even truly toxic "agent" into these spaces in-llight imposes no risk unless discharge results in residue that may adversely impact the repair crew. A similar argument can he made for discharging the agent during taxi and during normal engine run-up prior to taxi. The potential for human risk appears to be highest during "engine nacelle door open" maintenance, checkout, etc., and when there may be some impact on the ground crew in or around the vehicle during unintentional discharge.

Risk Comparison

Evaluation of the perceived high risk "agents" for acceptance need to be based on several factors including the following, each of which will be discussed in the figures below.

1. Toxicity and cardiac sensitization values for the "agent" in comparison with other materials having similar health and exposure risks
2. In-service history of unintentional exposure
3. Impact of unintentional discharge
4. Design/maintenance/operational strategies to protect ground crew members exposed to unintentional discharge

Toxicity and Cardiac Sensitization Values

DoD has a long history of working with materials that have low No Observable Adverse Effect Level (NOAEL) and Lowest Observable Adverse Effect Level (LOAEL) levels and the resulting potential for significant health risks. These materials include some of the early halons (2402, 1011, 1202) and refrigerants (Fe-11). The relative cardiac sensitization for several of these materials is summarized in Figure 2.

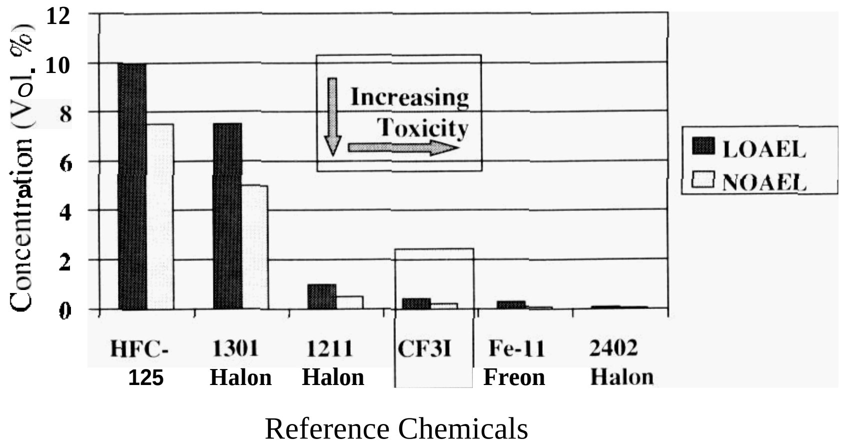


Figure *2*. Comparative cardiac sensitization NOAEL/LOAEL levels.

It should be noted that Fe-11 and Halon 2402 both have cardiac sensitization levels more restrictive than CF_3I, while Halon 1211 is only somewhat **less** restrictive than CF_3I—yet all are in the DoD inventories. These materials have all been in service for decades and one could consider CF_3I as imposing a risk no higher than many of these materials. Engineers and managers associated with these decisions need to rely much more heavily on the toxicology experts when addressing these issues.

Service History of Unintentional Exposure

There is a wide variation of probability of exposure of the ground crcw, depending on the individual aircraft. An unpublished review of the records for two widely deployed USAF fighter/attack aircraft has found no report of unintentional discharge in thousands of aircraft over several decades. A similar review of a widely deployed USN fighter/attack aircraft indicated approximately *SO* unintentional discharges each year in approximately 1000 aircraft. Deployment of some of the "agents" with higher perceived risk on either of the USAF aircraft might impose essentially no additional risk while deployment on this specific USN F/A aircraft. without addressing the root cause of unintentional discharge, would have to be more carefully evaluated.

Special Currier Considerations

Deployment on USN carriers is **a** special case. Unintentional discharge on the flight deck **is** likely to result in conditions similar **to** those encountered in the 1996 Boeing F-IS CF_3I ground discharge test described in Reference 1 and discussed in following paragraphs. Unintentional discharge on the hangar deck, especially with the doors closed, is a more complex case. Fighter/attack aircraft are frequently placed on the hangar deck. The discharge of a high density "agent," like CF_3I, in that spacc would have to be carefully evaluated to ensure that crew members in the hangar, below the hangar deck, and near ventilation exits arc adequately protected. Much more work needs to he done before CF_3I could he responsibly proposed for this application.

Any vehicle experiencing SO unintentional discharges a year is ***a*** cause for concern with any "agent." but particularly with an "agent" with perceived toxicity and/or cardiac sensitization concerns. These issues can he addressed in several ways. The root cause can be identified and corrected not only to reduce exposure, hut also to improve Reliability, Maintainability, and Supportability (RM&S). The ground crew could be required to wear protective gear when working in and around the aircraft, but that would not likely be accepted. The potential impact for a representative fighter/attack aircraft and notional crew protection concepts will be discussed in the following paragraphs.

Impact of Unintentional Discharge

The Boeing Company. USAF, and Pacific Scientific conducted a series of tests in late 1996 to determine the exposure level of the ground crew to an unintentional discharge of CF_3I while working in and around an F-IS with engine nacelle doors "open" [1]. An **F-IS** was placed in a 78 by 60 by 30-foot hangar at WRALC. Concentration sensors were positioned around the aircraft at several locations at heights of 6 in, 3 ft, and 5 ft above the ground (Figure 3).

The engine nacelle doors were opened, the hangar evacuated, and CF_3I was discharged through the aircraft fire protection plumbing with the hangar doors closed. Time histories of CF_3I concentration were recorded. After approximately **S** min. the hangar doors werc opened, and **a** few minutes later people re-entered the hangar and prepared for the next tcst. The test was repeated three times with the engine doors open and once with the engine doors closed. Some sensors werc relocated between tests to improve area coverage. The highest concentration recorded at the 3- or 5-foot level outside the open nacelle was approximately 10 ft behind the aircraft (Figure 4).

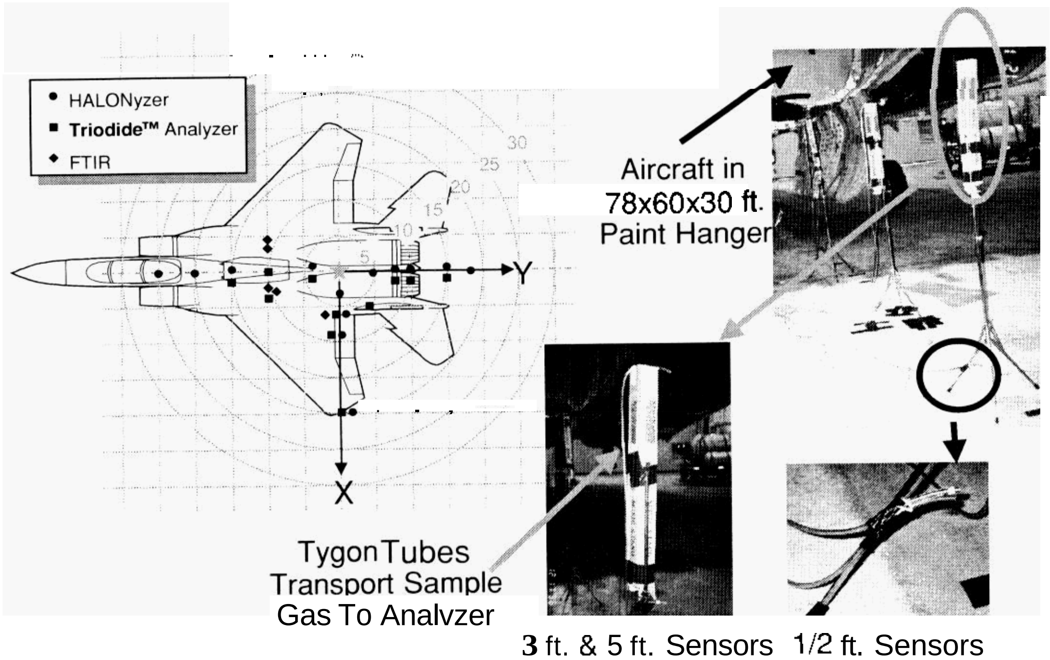


Figure 3. Open nacelle – sensor coverage.

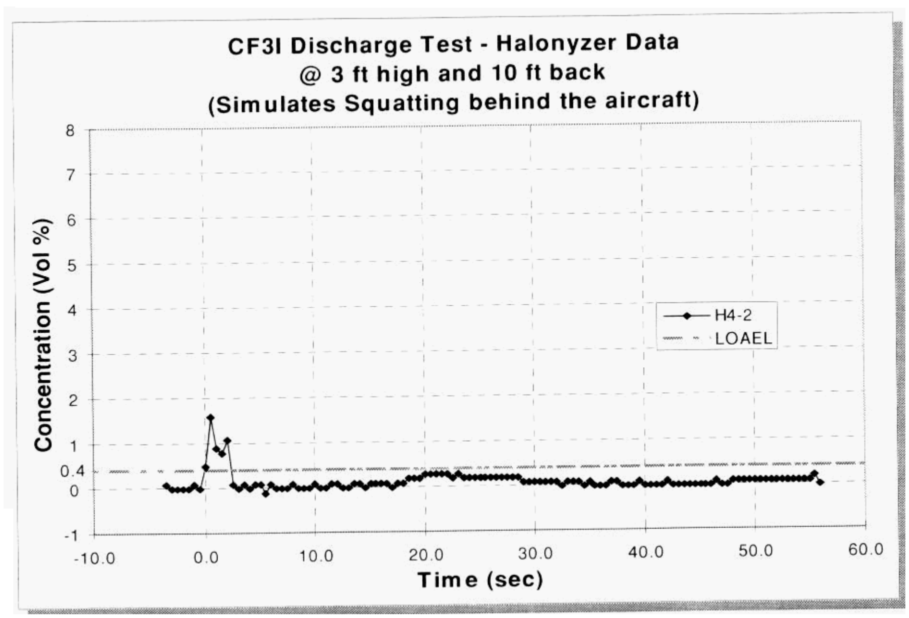


Figure 4. Highest concentration location at 3-5 ft (kneeling *outside* the nacelle).

These data were analyzed by Dr. Vinegar of ManTech who used the concentration data as input for his man-breathing simulation model to determine blood concentration levels of the inhaled CF_3I. These results were compared to a similar evaluation of the blood concentration levels from the cardiac sensitization studies in artificially epinephrinezed dogs. The "target" human LOAEL concentration, based on the dog study. was 19 mg/L. All the concentrations recorded outside the nacelle were below this value. The conccntration recorded inside the nacelle was double this value. Reconstructed anecdotal data from an intentional human exposure with no reported short-term adverse effects was evaluated in a similar simulation. The predicted concentration for this exposure was ~ 1500mg/L. These results were reported [2] and are summarized (Figure 5).

- Data Provided to Toxicologist for Assessment
- Inserted Data into PBK Model to Predict Blood Concentration
- Results lndicatc That:

– Target Value (based on artificially epinephrineized dog @ 0.4% for 5 min)	= 19 mg/L
– Inside the Nacelle	40 mg/L
– Kneeling Outside the Nacelle	6 mg/L
– Standing Outside the Nacelle	16 mg/L
– Lying Outside the Nacelle	15 mg/L
– Anecdotal with No Apparent Effect	1500 mg/L

Figure 5. Data interpretation

These data suggest that even if the ground crew outside the nacelle were unintentionally exposed to an inadvertent discharge of CF_3I, the risk would be acceptable if the NOAEL/LOAEL of the "agent" of choice were to have similar discharge characteristics and be no more restrictive than CF_3I, and if the quantity of "agent" discharged was no larger than that used in the F-15 test.

Different results might be expected were the agent to possess a more restrictive NOAEL/LOAEL level or were a significantly larger quantity of "agent" to be discharged. Further study is required to address exposure to someone inside the nacelle.

Design Approaches to Protection

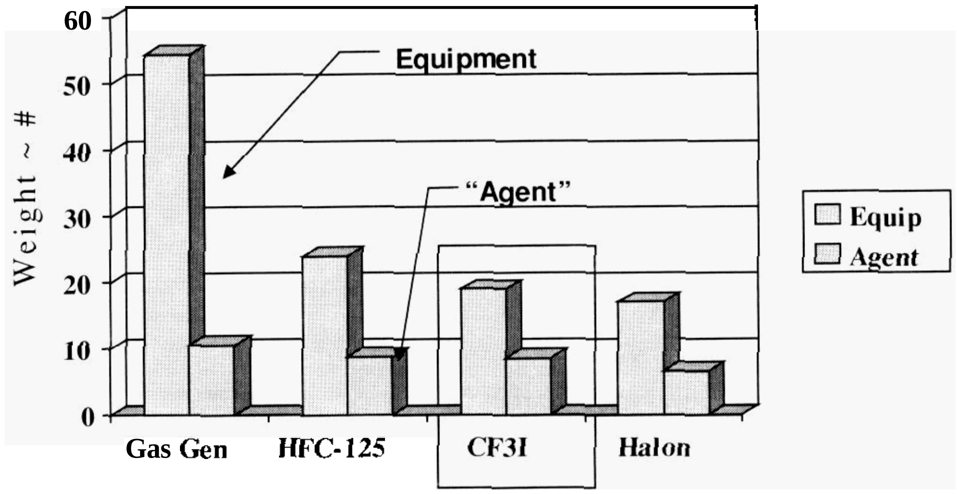
If one were tu assume that the "agent" NOAEL/LOAEL or quantity of agent were to result in a concentration level or assessment level to he unacceptable, there may he design and/or procedural charges that could protect the crew. Several forms of safety interlocks. which would only he active if the aircraft were on the ground and/or the engine nacelle doors were open, could potentially be provided. These include the following:

1. Pre-Discharge audible and/or visible alarm for a few seconds prior to discharge
2. "Door-Open'"switch to interrupt the discharge electrical signal.
3. "Remove Before Flight" pin to interrupt discharge signal.

Note: Bottles are normally discharged by applying electrical power to a pyrotechnic squib.

CURRENT ASSESSMENT OF ALTERNATIVE TECHNOLOGIES

Each year we estimate the impact of various fire protection technologies for representative F/A (fighter/attack) engine nacelles based on the latest available information. From year to year some technologies show increased or decreased impact based on new performance data and/or newly recognized issues that need to be addressed. New technologies are sometimes added and/or others dropped. The 1999 assessment is presented in Figure 6 with "Agent" and equipment weight shown as the figure of merit. CF_3I is still the lowest weight nonhalon alternative, followed by HFC-125.



Leading HALON 1301 Alternatives

Figure 6. Representative F/A Engine Bay Protection Penalties – 1999.

LOW TEMPERATURE PERFORMANCE

Since the boiling point of CF_3I (-09 "F) is much higher than Halon 1301 (-72 °F) or HFC-125 (-56 "**F),** there is concern with its low temperature performance. It **may** be necessary to extinguish a fire at low temperatures, during engine start after overnight storage in winter, for example. Some fire extinguishing bottles are stored in unheated bays with an outside air temperature that can reach –70 "F in flight. The limited work addressing this issue indicates that equivalent performance in the -40 "F to -20 °F range may require an increase in the CF_3I quantity of up to 10%. Additional work is required to determine the minimum temperature required for fire extinguishing in specific applications, and to gather more performance data on CF_3I at those temperatures, however, if the 10% value holds, CF_3I could still be very attractive, especially for retrofit applications.

CURRENT STRATEGY

The current Boeing strategy for fighter/attack and some other military applications is as follows:

1. To pursue HFC-125 development as our primary near-term approach based on the success of the F/A-18 E/F program
2. To continue work on CF_3I as a secondary mid-term approach until the toxicity. cardiac sensitization, and low temperature performance issues have been resolved since CF_3I is likely to be a less difficult and less expensive retrofit
3. To continue to monitor advances in technology that may provide stronger candidate(s) for far-term applications and to introduce those technologies into our program at the appropriate time

The authors' goal is, at any point in time, to be able to deploy the appropriate nonhalon technology that best meets the needs of our customers at the time deployment is required. We will continue to use halon as required by our customers until the requirements change.

CONCLUSION

The Boeing Company, both military and commercial, fully support continued research into CF_3I as a potential fire extinguishing candidate for normally non-occupied aircraft applications. Low temperature performance and cardiac sensitization issues require further study. It may be possible to use CF_3I safely for some fire protection applications in non-occupied spaces provided the "Agent" and its systcm are properly assessed. the appropriate design and operational changes implemented, and its use and restrictions well understood.

REFERENCES

1. Mark Kay, Scott Hammann, Glenn Harper, "An Experimental Evaluation of CF_3I Gas Dispersion," *Proceedings*, Halon Options Technical Working Conference, Albuquerque, NM. pp. 375-387, 1997.
2. A. Vinegar and G. W. Jepson. "PBPK Modeling of CF_3I Release from **F-15** Engine Nacelles." *Proceedings*, Halon Oplions Technical Working Conference, Albuquerque, NM, pp. 162-168, 1997.