

COMMERCIALISATION OF CF₃I FOR FIRE-EXTINGUISHING SYSTEMS IN NORMALLY UNMANNED AREAS

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OVERVIEW

Orion Safety Industries was introduced to CF₃I (trifluoroiodomethane) by Pacific Scientific, Inc., in 1996. The first attempt to commercialise CF₃I (triodide) as a fire extinguishing agent was made by Pacific Scientific for aircraft engine nacelle and ground vehicle engine bay fire suppression systems. These were ideal applications for this product, but there were serious obstacles to overcome.

CF₃I is by far the most efficient and environmentally friendly halogenated fire-extinguishing agent currently available. CF₃I is the only predominantly chemically active gaseous extinguishing agent currently available. This characteristic means that CF₃I has a number of important advantages over other agents:

- Lower extinguishing concentrations
- Lower levels of decomposition products
- Lower weight requirements
- Smaller space requirements

These particular characteristics make CF₃I an ideal halon replacement agent for aerospace, military, and commercial applications. CF₃I can be the best option for replacing either Halon 1211 or Halon 1301 in existing systems.

Environmentally CF₃I is in a class of its own. The atmospheric half-life is in the order of one day, meaning that over 99% of CF₃I breaks down within one week. Since it takes some years for a ground level release to migrate to the stratosphere, ozone depletion and global warming are negligible. The small amount of CF₃I needed and the relatively small amount of system hardware required mean that it can challenge even inert gases in terms of total environmental impact. While CF₃I is an expensive agent, the overall system cost can make it a very economic solution. To begin with, about half as much or less CF₃I is needed to do the same job in total-flooding systems, and possibly as little as 30% for handheld applications when compared with current alternatives. It is also important to factor in the reduced hardware requirements and reduced space and weight requirements for CF₃I that can be important economic considerations. Despite all of these advantages CF₃I has been used in only a handful of applications and has been the subject of many disputes.

EARLY APPLICATIONS

Orion Safety Industries was originally introduced to CF₃I by Pacific Dynamics, the Pacific Scientific distributor in Australia, and we first evaluated it as an explosion suppression agent. It was not found to be suitable for this application. We then conducted trials for total-flooding

applications and found CF_3I to be very effective and we proceeded to commercialise the product. The first CF_3I installation was at the QANTAS jet engine test cell in Sydney and was completed in 1996 (Figure 1). The safety of all CF_3I systems has been a central concern for us from the beginning. In early 1996 a fire occurred in a General Electric engine while it was under test in the QANTAS engine test cell in Sydney. The engine was protected by a Halon 1301 system that failed to extinguish the fire.

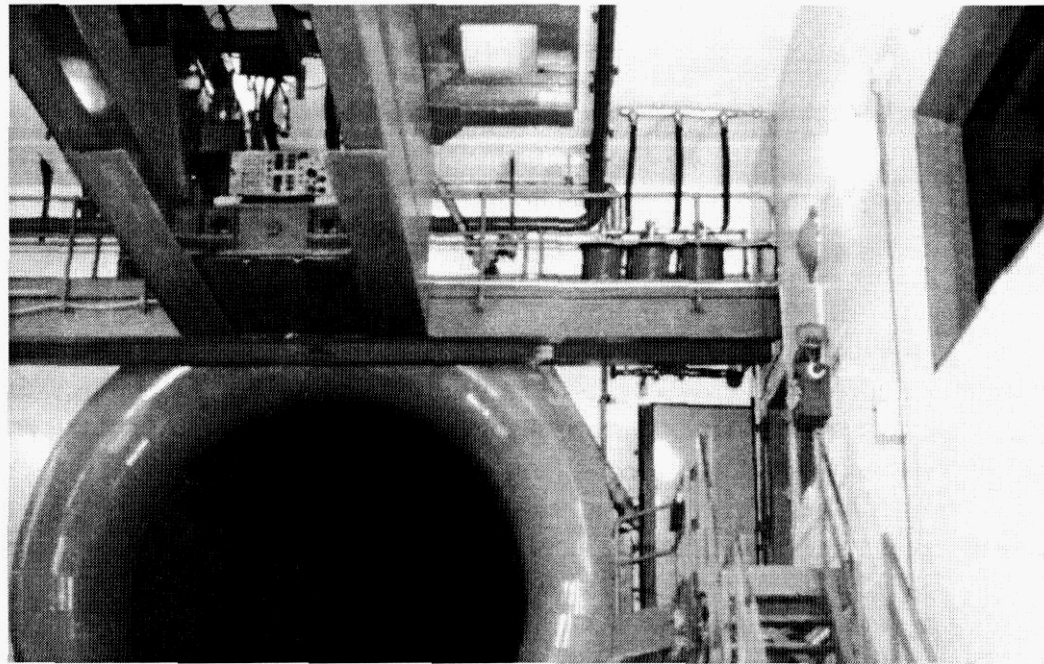


Figure 1. CF_3I system in QANTAS engine test cell, Sydney, Australia.

As a consequence of the fire, General Electric (GE) was awarded a contract to upgrade the fire protection system. GE was aware of CF_3I due to the work done by Pacific Scientific on engine nacelle applications, and this was their agent of choice for use in their engines. The main criteria for this choice were the engineering considerations of high firefighting efficiency and minimal damage expected from the agent and its decomposition products. Orion Safety was eventually awarded the contract to design and install this system. We were asked to re-use the existing Halon 1301 system where possible, to use at least an equivalent amount of agent, and to provide a three-shot system. One shot from the system was required to be available in the event of a complete power failure. The system was to be fired manually from the control room.

The initial system design was approached on the basis that the engine would be running when the fire suppression system was fired. Exactly the same criteria were used as would be for an engine in flight. The minimum design quantity required was 12 kg of CF_3I . The existing Halon 1301 cylinder had a capacity for 35 kg of CF_3I , and this was the amount eventually used with a 3.2 sec discharge time. The initial concentration would be quite high and an extinguishing concentration would be maintained for longer. When the system hydraulic design was carried out, the original agent storage location was found to be too far away from the engine and the pipe size too small to achieve a sufficiently short discharge time. Consequently, the agent storage was relocated to an unused part of the access walkway near the engine.

While this system was essentially a local application system it was being used within a manned area. A hazard assessment was carried out, and it was determined that the concentration that would be achieved in the test cell would be less than 0.3% assuming good mixing. The total volume of the engine test cell was more than 1440m³. The concentration is below the Lowest Observed Adverse Effect Level (LOAEL) for CF₃I; since good mixing was not likely to occur, the concentration in the breathing zone would be much less than this.

The Australian Standard for Total Flooding Gaseous Fire Suppression Systems AS 4214 required a lock-off valve to be fitted if the agent concentration exceeded the LOAEL. The main safety features included with this system were the following:

- (a) Visual and audible warnings to sound in the event that the system was discharged. A visible warning will be given even without power.
- (b) A system interlock preventing the electrical firing of the system when the engine is not running. Only manual (pneumatic) activation of the system could occur when the engine is not running.
- (c) 5 min emergency breathing masks are available in the test cell.
- (d) A handheld CF₃I detector was developed to provide alarms at the No Observed Adverse Effect Level (NOAEL) and LOAEL. This detector was for use in the event of a discharge to ensure that the test cell was safe to enter after the discharge.

Once the installation was complete the fire systems service contractor for the QANTAS site was asked to add it to their service contract. Their response was to declare that CF₃I was so dangerous that they could not allow their personnel to enter the building until it was removed. Three CO₂ systems, two of which were flooding manned areas, were in the same building. Fortunately, the client was well informed and they ignored the rather hysterical reaction by the service contractor. We continued to install CF₃I in engine test facilities for QANTAS, Ansett Airlines, and the Australian Airforce but other commercial sales became very difficult due to a public perception that CF₃I is extremely dangerous.

In the course of evaluating CF₃I as a drop-in replacement for Halon 1301, Orion Safety conducted a test where CF₃I was used as a direct drop in for Halon 1301. This was done on the railway generator car mentioned earlier, prior to system design being done. The 25 kgs charge of Halon 1301 in the system were replaced by 32 kgs of CF₃I to produce an equivalent design concentration and safety factor. The CF₃I was placed in the existing bottle and no other changes were made to the system. The storage bottle was pressurised to 360 psi. Three fire trays were set up in the car in the most disadvantaged locations. After a preburn of 30 sec the system was fired manually. All trays were extinguished before the end of the discharge. The system discharge time was 14 sec. Under these conditions the system was expected to take longer to discharge. This test was intended as a demonstration of the ease of changeover for Halon 1301 systems. To complete the changeover all we needed to do to make the system suitable for CF₃I was to modify the nozzles to provide a larger orifice area. A lock-off valve was installed to render the area safe while personnel are working in the car.

In 1998 the Australian Navy chose CF₃I as the agent for testing the Halon 1301 systems fitted to the new Collins class Submarines. Under Australian environmental legislation Halon 1301 can only be discharged to extinguish a fire in an emergency. Verification of the Halon 1301 system design was required. The chief concerns were with the distribution of agent within the protected spaces and the ability to hold the extinguishing concentration for 10 min. To simulate a 6%

Halon 1301 atmosphere in the space we used an equivalent weight of CF_3I to produce an atmosphere with the same density. The test would simulate leakage of agent from the space quite accurately. In doing this test we replaced the Halon 1301 in the existing storage cylinders and pressurised them to the same pressure with nitrogen (600 psi). Although the cylinder would have more nitrogen than the Halon 1301 system, this would compensate for the lower vapour pressure of CF_3I . The test was conducted in Auxiliary Machinery Space #2 which has a volume of 130 m³. This space was selected because it represented the most challenging system design. The tests showed that the space was able to retain the agent for far longer than the door fan test indicated. The system discharge time with CF_3I was 8 sec, compared with a design discharge time of 10 sec for 1301. Care was taken to evacuate the CF_3I from the machinery space after the test.

FIRE-EXTINGUISHING TEST RESULTS

Considerable data are available on the extinguishing performance of CF_3I on flammable liquids from the original development work on CF_3I . Also conducted were UL1058 fire tests in a 36 m³ test cell with 3.5 m ceiling height. Heptane and wood crib fires were extinguished. In each test 7.5 kg of CF_3I was used to achieve a 3% concentration.

An initial non-fire discharge test was conducted to check the room integrity and to measure the agent distribution vertically. A uniform distribution was achieved with a 10 sec discharge time and 60 psi nozzle pressure (360 psi cylinder storage pressure). Concentration measurements were taken at 200 mm from the floor, 1.75 m from the floor and 200 mm from the ceiling. There was no measurable concentration difference between the three sampling points at the end of the discharge or at any time during the 10 min holding time. CF_3I is expected to have vertical distribution capabilities similar to Halon 1301. The maximum nozzle height we can use will be greater than 3.6 m.

Heptane fire tests with 1 min preburn have been conducted. In all tests flame extinguishment occurred by the end of the system discharge. Wood crib fires have also been extinguished. In all tests flame extinguishment occurred within 3 sec of the end of the discharge. No reignition occurred after a 10 min holding period. UL 1058 allows up to 30 sec after the end of the discharge for flame extinguishment. The Orion Safety testing suggests that the UL1058 requirement is fairly simple to meet for this type of test.

The testing reported herein confirms the research done for specific applications. Test data presented at the 1998 Halon Options Technical Working Conference by Su et al. [1] for applications in military vehicles and by Grzyll et al. [2] for fire extinguisher applications indicate that CF_3I is the most efficient fire extinguishing agent currently available for both applications.

SAFETY CONCERNS

Based on the fire extinguishing data, CF_3I should be given a high priority for evaluation for any unmanned application and for all fire extinguisher applications. This has not generally been the case. Safety concerns have outweighed all other considerations.

There is no obvious reason for the excessive concern over the safety of CF_3I when used in unmanned areas and in fire extinguisher applications. My initial consideration of the safety

aspects of CF₃I was a simple comparison with Halon 1211. The differences are very small and CF₃I has been restricted to use in normally unmanned areas. This seemed to be a suitable precaution to take. Very few accidents occurred with Halon 1211 and a similar or better safety record for CF₃I can be expected due to stricter design controls now implemented for CF₃I. The safety of CF₃I became a major issue as soon as we installed the first system. As a result I have been researching the cardiac sensitising effects of chemicals to better understand the issues for some time.

It is often claimed that CF₃I is toxic. This description is flawed since the conventional definition of a toxic substance is based solely on the LC₅₀. The definition for a toxic gas is embodied in laws associated with transportation of goods. This is an international definition. A gas is labelled as toxic if it has an LC₅₀ of 0.5% or less. For CF₃I the LC₅₀ is greater than 13% for a 1 hr exposure making CF₃I a non toxic gas. This classification for CF₃I means that 75 kg containers can be airfreighted around the world in passenger aircraft and 150 kg containers in cargo aircraft with exactly the same restrictions as any other compressed, liquefied fire extinguishing agents. It is easier to get CF₃I into the cargo hold of an aircraft than it is to have it installed to protect the engines.

The real issue with CF₃I is not one of toxicity, but of cardiac sensitisation. There are obviously a wide variety of views on what cardiac sensitisation means in terms of safety. CF₃I has been subjected to two very comprehensive safety evaluations, first by the US Environment Protection Agency (EPA) and then by WorkSafe Australia. Both evaluations have approved CF₃I for use in normally unmanned areas and in fire extinguishers for all but domestic applications. Despite this, the fire industry and many end users have generally rejected the product on safety grounds. Obviously, the question arises as to who is right.

Certainly some organisations have made rulings that are obviously not realistic. The International Maritime Organisation (IMO) placed more emphasis on protecting people from cardiac sensitisation than toxicity, as evidenced by the fact that CO₂ systems at lethal concentrations are permitted but gaseous systems requiring concentrations in excess of the LOAEL are not! A wide range of data are available to help put cardiac sensitisation in perspective.

CARDIAC SENSITISATION

There are five areas where we can acquire data on consequences of human exposure risk to cardiac sensitising chemicals. Considerable data are available for all five areas.

1. Historic use of Halon 1211 and Halon 2402
2. Sniffing of solvents (intentional inhalation)
3. Medical chemicals
4. Industrial accidents
5. Current research

Halon 1211 Safety History

CF₃I is a more potent cardiac sensitiser than Halon 1211, but not seriously so. It is considerably less potent in this respect than Halon 2402, which was approved by the International Maritime

Organisation (and actually installed on some ships) and was also used in engine nacelle systems for some classes of aircraft. A comparison of these products with CF₃I is seen in (Figure 2).

Halon 2402 is being used at levels in the order of 20 times the LOAEL (Figure 2). Halon 1211 was also used at more than 5 times the NOAEL and CF₃I at 9 times the LOAEL. CF₃I is used at somewhat higher levels (in terms of the relative LOAELs and design concentrations) than Halon 1211, but not seriously so, and well below that of Halon 2402. Obviously, considerable history is available on the use of Halon 1211 that can be used to assess the risk associated with CF₃I.

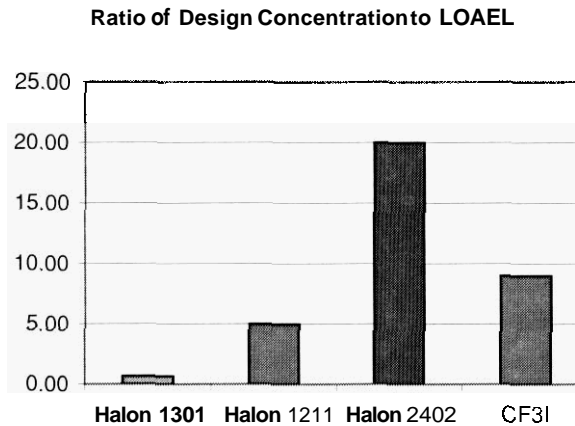


Figure 2. LOAEL comparison for halons and CF₃I.

Halon 1211 was used extensively in portable extinguishers and local application systems, and was also used in total-flooding systems in manned areas until the cardiac sensitising nature of this product was identified. For example, in Australia one class of warship, the Fremantle class patrol boats (16 ships), were fitted with Halon 1211 systems in control rooms and machinery spaces. Over the life of this class of ship, one can expect that 60-90 non-fire discharges (based on Australian Navy accidental discharge estimates) will occur, resulting in human exposure to 5% or more of Halon 1211 with no fatalities. This situation will have been repeated in many applications where Halon 1211 was installed in manned areas prior to the identification of its cardiac sensitising properties. There **are** also likely to be some exposures from accidental discharge of fire extinguishers in confined spaces (such as commercial, military and domestic vehicles). Despite these human exposures the safety record of Halon 1211 is very good.

Intentional Inhalation

Intentional inhalation (aerosol sniffing) has been practiced for more than 100 years. It has become more common with the more widespread availability of cardiac sensitising chemicals. While intentional inhalation is responsible for some hundreds of deaths each year, the mortality rate is very low. Many tens of thousands of exposures occur per year.

Medical Applications

Three chemicals with medical applications are also potent cardiac sensitizers: CFC-11, chloroform, and halothane.

CFC-11 was used in medical inhalers and has a LOAEL of about 1%.

Chloroform has a LOAEL of approximately 1% and was used as an anaesthetic. It was phased out many years ago due to toxic side effects. Chloroform was used as an anaesthetic at concentrations up to 5%, or 5 times the LOAEL when medical technology was very primitive. The mortality rate from chloroform use is reported as 1 in 3500. Cardiac sensitization is not the major cause of these fatalities: liver damage, overdosing, and respiratory failure were the major causes of death.

Halothane has a LOAEL of approximately 1.5% and is in use as an anaesthetic though its use is declining. It is used as an anaesthetic at concentrations up to 4% or nearly three times the LOAEL. Some research data indicates that halothane can trigger arrhythmias at concentrations as low as 0.5% [3]. The mortality rate for halothane use is reported as 1 in 10,000 due to a problem known as "halothane hepatitis." Cardiac mortality is reported as 1 in 50,000. Again, cardiac sensitization is not the major cause of deaths and the mortality rate is very low.

Vanik and Davis [4] reported a detailed investigation of the cardiac effects of halothane during surgery on 3967 patients. The average length of surgery is around 2 hours [5]. While arrhythmias were recorded in 17% of cases, many of these would not have been noticed without cardiac monitoring and were not potentially life threatening. Serious (potentially life threatening) cardiac arrhythmias occurred in only 0.7% of cases. Vanik and Davis reported that these arrhythmias have triggering events during the surgery. In many cases, while under the anaesthetic, the patients still experience pain from the surgery. Triggering events include the induction, initial incision, and intubation. Serious cardiac arrhythmias are not very common even in a relatively stressful surgical situation. It is important to note that they require a triggering event.

Industrial Accidents

Industrial accidents represent a very similar situation to a fire related exposure to a fire extinguishing gas in terms of stress. These exposures tend to be short but at fairly high concentrations. Table 1 lists some cardiac sensitizing chemicals where accident data are available [6].

A report on exposures to trichloroethane, trichloroethylene, and perchloroethylene by McCarthy and Jones [7] details experiences with industrial accidents in the United Kingdom. LOAEL data are available for two of these chemicals. They are very similar to CF₃I in terms of cardiac sensitization.

TABLE 1. LOAEL DATA FOR SOME INDUSTRIAL CHEMICALS.

Chemical	LOAEL
Trichloroethylene	0.5% (estimated)
Trichloroethane	0.5% (estimated)
Methylene Chloride	2.1%

Of 384 reported exposures as a result of industrial accidents from 1961 to 1980, 46% of the victims were rendered unconscious and 27 people died. Despite the high stress and high exposure concentration, only 1 of these 17 deaths appears to be due to cardiac effects. Respiratory failure due to acute narcosis was the main cause of death. Severe cardiac incidents occurred in 0.8% of cases (3 people), which is the same rate as for surgery. Fatal cases (1 person) represented 0.26% of people exposed.

A similar report by Bakinson and Jones [8] on xylene, toluene, styrene, and methylene chloride (less potent cardiac sensitisers) accidents from 1961 to 1980 reported 129 victims and 41% of whom were rendered unconscious; 4 deaths were reported and all were attributed to acute narcosis. One non-fatal cardiac event was recorded.

Stahl et al. [9] reported in detail on six deaths from the US Navy that occurred from using paint stripper and cleaning solvents containing trichloroethane. Exposures occurred in a relatively low stress manner during normal working conditions and lasted for several hours. Detailed forensic examination was made in these cases. High lactic acid levels in the brain and other symptoms indicated oxygen deprivation due to acute narcosis was the cause of death. Although it is a small sample, it does demonstrate that cardiac effects have a low probability even with cardiac sensitisers similar to CF_3I . One victim appeared to be intentionally inhaling the vapours.

Quite clearly, cardiac sensitisation is not a major cause of fatalities when people are exposed to high concentrations of cardiac sensitising chemicals.

Current Research

The work of Vinegar and Jepson [10] presented at HOTWC-98 tends to support the idea that the real cardiac sensitising levels are considerably higher than indicated by the current NOAEL and LOAEL figures derived from dog testing. These tests further indicate that prolonged elevated epinephrine levels are also necessary. The agent alone is unlikely to be harmful.

Conclusions

The data on industrial accidents reveal a relatively low level of fatalities after exposure to high concentrations of cardiac sensitising chemicals. The incidence of serious cardiac arrhythmias during surgery where a cardiac sensitising anaesthetic is used is the same as for serious industrial accidents (0.8%).

The history of Halon 1211 where a large number of human exposures can be assumed to have occurred is also consistent with the industrial and medical data. The majority of these exposures would have occurred in relatively low stress situations such as accidental system discharges.

Current animal research also confirm that death due to acute narcosis is the end result from exposure to extremely high concentration of cardiac sensitisers. In the absence of a triggering event, animals die from acute toxic effects.

By contrast with carbon dioxide, CF_3I is a relatively safe fire extinguishing agent. Where carbon dioxide is fatal for 100% of exposures lasting about 5 min CF_3I , on the other hand, can be expected to be fatal in less than 1% of cases. If one were to compare the outcomes described by

Skaggs [11] for carbon dioxide system exposures that resulted in 140 deaths, the probable outcome if these systems had used CF₃I would be a reduction in the number of fatalities from 140 to no more than 1.

In summary, cardiac sensitisation can result in fatalities in a small percentage of exposures. This risk cannot be ignored; however, it can be managed. The strategy adopted by the EPA and other work safely organisations to restrict the application of cardiac sensitisers to use in normally unmanned areas is designed to reduce the probability of exposure and thereby reduce the overall risk to acceptable levels.

In Australia an additional safety feature is added that effectively eliminates the exposure risk. A lock-off valve is fitted to systems that use cardiac sensitising agents (and for carbon dioxide systems). This valve physically isolates the system while personnel are in the protected area. One other means of reducing the exposure risk is to add an odourant to the CF₃I, a useful precaution where people may not be aware that the system has discharged.

There is no evidence that cardiac sensitisation represents the extreme risk that some people in the fire industry claim. The industrial exposure data reported above conflict with the unsubstantiated claims by Ball et al. [12] that CF₃I has problems with manufacture, distribution, filling, and handling. It **also** shows that the reaction of the service company at the QANTAS engine test facility was merely an attempt to frighten the customer with no basis in reality.

DECOMPOSITION PRODUCTS

The application of CF₃I is within the range of previous experience with Halon 2402 and Halon 1211. The cardiac sensitising level for CF₃I is about half that of Halon 1211 and four times that of Halon 2402. Past experience is a good guide to how safe this product can be. In addition, more stringent controls have been imposed on the use of CF₃I than were imposed on Halon 1211 use.

This situation contrasts with the position on decomposition products from halocarbon fire extinguishing agents. Many new agents generate 6 to 10 times the decomposition products of Halon 1301 and Halon 1211, a result that is well outside the range of experience for decomposition product exposures. In this instance no additional controls have been imposed. Figure 3, based on test data generated by NASA [13], illustrates this problem.

Quite clearly, the LC₅₀ for HF exposure (15 min) can be exceeded by a large margin when large fires are extinguished in confined spaces. In these applications the risk associated with decomposition products can be far more important than the cardiac sensitisation risk. More attention needs to be given to this hazard as it is one with which we have very little experience. This problem is exacerbated by the lower safety factors used in system design.

HF Production Vv Fire Size 1.2M³ Room (NASA Tests)

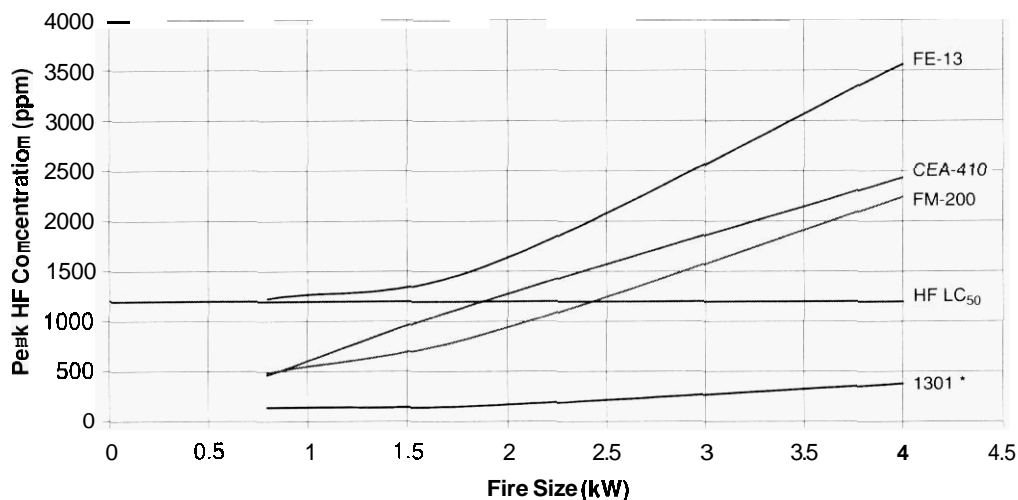


Figure 3. HF production for a range of agents and fire sizes.

FUTURE FOR CF₃I

Following from the initial system at QANTAS, systems have been installed in the jet engine test facilities for the two airlines in Australia (QANTAS and Ansett) as well as the Australian Airforce. Since then CF₃I systems have been installed in railway diesel generating cars, standby diesel generating plants, and telecommunications switch rooms. Very recently CF₃I was specified for seven transformer and switch rooms for the State Rail Authority in Australia. (In this case CF₃I represented the lowest overall system cost.) The key differences were the superior flow properties of CF₃I and the smaller space occupied by the systems. CF₃I will find application in specialised applications where the advantages of smaller, lighter systems, better flow properties, and other benefits can overcome the higher agent cost. CF₃I can be a very competitive halon replacement in existing systems. Provided that the existing halon system is correctly designed and installed, the existing pipework can almost always be re-used. This type of changeover can also result in minimal interruption to work in a facility.

While we do not envisage that CF₃I has the mass market application of 1,1,1,2,3,3 heptafluoropropane (FM-200), it is a very effective agent that can be used safely if restricted to fire-extinguisher applications or total-flooding of normally unmanned areas. Additional safety precautions can also be taken where appropriate.

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