

# **RESULTS OF HALON 1301 AND HFC-125 CONCENTRATION TESTS ON A LARGE COMMERCIAL AIRCRAFT ENGINE INSTALLATION**

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## **SUMMARY**

Back to back concentration tests of Halon 1301 and HFC-125 were conducted February 12<sup>th</sup> and 15<sup>th</sup>, 1995, on a Boeing 777 airplane equipped with Pratt & Whitney PW4084 engines. The fire zone airflow rate was approximately 10<sup>lbm/sec</sup> and the volume was approximately 200 ft<sup>3</sup>. Halon 1301 bottles were filled to 18.0 and 22.0 lbm and were discharged at ambient temperature and with bottles cooled to -65°F. HFC-125 bottle weights were chosen to match the liquid volume of the Halon 1301 bottles, and were discharged at ambient temperature and at -47°F to match the Jakob number and vapor pressure of Halon 1301. Concentration measurements were made at 12 probe locations distributed throughout the fire zone. Four Halon 1301 and four HFC-125 bottles were discharged yielding 48 direct concentration measurement comparisons. Results show that the concentration traces are in very good agreement and that HFC-125 is a viable Halon 1301 concentration test simulant at both ambient and cold temperatures.

## **BACKGROUND**

Ozone depletion caused by Halon 1301 breakdown in the upper atmosphere has led to manufacturing and discharge restrictions. Significant research and development progress is being made towards qualifying a replacement agent. However, the work is directed towards a late 1990's completion. In the interim, a need exists to minimize environmental impacts by conducting airplane tests with a Halon 1301 test substitute.

The United States Navy sponsored research to determine a Halon 1301 simulant for future military aircraft fire extinguishing tests (References 1 through 4). Contracted thermodynamic analyses and laboratory tests at the National Institute of Standards and Technology (NIST) demonstrated HFC-125 is the best Halon 1301 simulant at ambient temperatures. Contracted laboratory tests and full scale testing on an F/A-18D military aircraft by Walter Kidde Aerospace confirmed the NIST recommendation. Since Boeing engine fire extinguishing systems are currently certified using Halon 1301 at both ambient temperature and with a bottle cooled to -65°F, additional development work to match the cold case condition was required.

## **SIMULANT**

The goal of this effort is to determine criteria which, when applied to HFC-125 concentration measurements, correspond to the pass / fail criteria for Halon 1301. To do

this, an accurate simulant must be able to match the behavior of Halon 1301 as the liquid flashes to vapor. Two key parameters of this process are the vapor pressure and the Jakob number (Reference 5). These values and other properties of Halon 1301 and HFC-125 are given in Table 1.

Property	Halon 1301	HFC-125
Chemical Formula	CF <sub>3</sub> Br	CHF <sub>2</sub> CF <sub>3</sub>
Molecular Weight	148.9	120.0
Atmospheric Boiling Point, °C	-57.80	-48.14
Freezing Point, °C	-168.0	-103.1
Critical Temperature, °C	67.00	66.25
Critical Pressure, psia	575.23	526.60
Critical Density, lbm/ft <sup>3</sup>	46.50	35.70
Liquid Density, lbm/ft <sup>3</sup>	97.83 @ 21.0°C	74.27 @ 25.0°C
Vapor Density @ 1 atm 21°C, lbm/ft <sup>3</sup>	0.391	0.3157
Liquid Viscosity @ 21°C, N-sec/meter <sup>2</sup>	0.00016	0.000137
Vapor Viscosity @ 21°C, N-sec/meter <sup>2</sup>	0.000016	0.0000133
Liquid Specific Heat, BTU/lbm-°F @ 26.7°C	0.206	0.327
Vapor Specific Heat, BTU/lbm-°F @ 26.7°C	0.181	0.193
Enthalpy of Vaporization, BTU/lbm at boiling point	51.10	70.71
Vapor Pressure, psia	213.26 @ 70°F 17.7 @ -65°F	180.40 @ 70°F 17.7 @ -47°F
Jakob #	0.51 @ 68°F 0.02 @ -65°F	0.52 @ 68°F 0.02 @ -47°F

As shown above, the Jakob number and vapor pressures show good agreement at ambient temperatures. At cold temperatures, the vapor pressure and Jakob number of Halon 1301 at -65°F are exactly matched with HFC-125 at -47°F. This was the temperature chosen for the HFC-125 cold bottle discharges.

Another key parameter developed during the United States Navy sponsored investigations was the matching of liquid volumes of agent rather than the agent weight (Reference 3). This maintains equal volumes of nitrogen pressurization gas within the bottle and correspondingly similar pressures at the discharge nozzles. HFC-125 fill weights were obtained by multiplying the Halon 1301 agent weight by the density ratio (0.77).

### **BOEING AIRCRAFT TEST**

Boeing 777 engine fire extinguishing bottles are located approximately 80 feet from the discharge nozzles. In the case of an engine fire, a pyrotechnic squib is used to open a discharge port which allows the release of agent under pressure into a 0.75 inch diameter distribution system. The agent is delivered to the fire zone(s) through discharge nozzles in

less than 10 seconds. Fire zone airflow rates at the test condition were approximately 10  $\text{lbm}/\text{sec}$  into a volume of approximately 200  $\text{ft}^3$ . The spherical fire extinguishing bottles have an internal volume of 800  $\text{in}^3$  and are pressurized to 825 psig at 70°F. For cold discharges, the bottles are kept in a chiller for a sufficient period of time to ensure agent temperature stabilization at -65°F.

Agent concentration measurements were made with a Halonyzer II (serial number 3) gas analyzer purchased from Pacific Scientific, HTL/Kin – Tech Division. The unit was calibrated for Halon 1301 for all tests. Calibration to HFC-125, or to any other simulant, is not mandatory since it is the comparison of trace readings which forms the basis of this simulant study, not the absolute values. The Halon 1301 traces are true indicators of volumetric concentrations. The HFC-125 traces are not true indicators of HFC-125 volumetric concentrations since the equipment is calibrated for Halon 1301. Analyzer accuracy, operating principles, and linearity for small concentrations were carefully considered in deriving the test approach and data analysis methodology.

Boeing fire extinguishing tests are conducted to demonstrate that extinguishing agent will be distributed throughout the fire zone(s) in sufficient quantities to extinguish a fire. Standard certification criteria require that all probes detect at least 6.0% volumetric concentration of Halon 1301 simultaneously for at least 0.5 seconds. This must be demonstrated with bottles at both ambient temperature and at -65°F.

### **TEST PROCEDURE**

A test condition consists of running the engine, installing a bottle (transferred from a chiller for cold discharges), discharging the bottle, and measuring the agent concentrations as a function of time. Sampling probes were placed in 12 locations throughout the fire zone. A total of eight bottle discharges were made during this investigation: four Halon 1301 and four HFC-125. Ambient and cold bottle discharges were made at two different system discharge nozzle and bottle agent weight configurations. Table 2 summarizes the bottle configurations for all eight tests.

Test #	Halonyzer Run #	Agent	Weight (lbm)	Bottle Temperature
1	173	Halon 1301	18.0	Ambient
2	174	HFC-125	13.9	Ambient
3	175	Halon 1301	18.0	-65°F
4	176	HFC-125	13.9	-47°F
5	191	Halon 1301	22.0	Ambient
6	193	HFC-125	16.9	Ambient
7	190	Halon 1301	22.0	-65°F
8	192	HFC-125	16.9	-47°F

Table 2. Test summary

The eight bottle firings of 12 probes each yields a total of 96 individual concentration traces. This gives 48 directly comparable traces between Halon 1301 and HFC–125 (24 at ambient temperature and 24 at cold temperature). The 12 probes represent a wide range of airflows, temperatures, clutter geometries, and distances from the fire extinguishing discharge nozzles. In this sense, each bottle discharge results in 12 separate concentration tests. Tests 1 through 4 were conducted on 12 February, 1995. The four bottles were discharged back to back with the engine running continuously. Tests 5 through 8 were conducted on 15 February 1995 also during a continuous engine run but with a different discharge nozzle and bottle configuration.

### **DATA ANALYSIS**

The 12 concentration traces for Tests 1 and 2 are shown in Figure 1. This figure compares ambient temperature bottle discharges of 18.0 lbm Halon 1301 and 13.9 lbm HFC–125. The traces for Tests 3 and 4 are shown in Figure 2 comparing cold bottle discharges of 18.0 lbm Halon 1301 and 13.9 lbm HFC–125. The data show that each HFC–125 trace has a peak reading higher than the corresponding trace for Halon 1301, and that generally each HFC–125 trace rises and falls faster than the Halon 1301. Traces for Tests 5 through 8 are shown in Figures 3 and 4.

Figure 5 shows a typical trace comparison between Test 1 and Test 2 (probe #1). The curves show excellent agreement in shape and overall characteristics. Key parameters illustrated in the figure are peak concentrations and the time above the 6.0% volumetric concentration requirement for Halon 1301. Figure 5 also shows the equation used to determine the HFC–125 equivalency concentration. A tabulation of the 12 equivalency concentrations for Tests 7 and 8 is shown in Table 3 as an example. Similar tables were generated for the other three test comparisons.

The average HFC–125 equivalency concentration for the 24 ambient temperature trace comparisons is 7.1%. Similarly, the average HFC–125 equivalency concentration for the 24 cold temperature trace comparisons is 7.3%. Choosing a criterion of 7.3% for HFC–125 as an equivalent to 6.0% Halon 1301 gives the best data match for the cold bottle discharges and is slightly conservative for the ambient temperature bottle discharges.

Time above the 6.0% criterion for Halon 1301 as shown in Figure 5 was calculated for all 48 concentration traces. Values for Test 7 are included in Table 3 as an example. Time above the corresponding criterion of 7.3% for the 48 HFC–125 traces was also calculated. Values for Test 8 are included in Table 3. Figure 6 shows both the HFC–125 equivalency concentration and equivalency time for a typical concentration trace comparison (probe #9, Tests 3 and 4). Results for Tests 7 and 8 are also shown in Table 3.

Averages of the equivalency times show that 0.5 seconds above 6.0% for Halon 1301 corresponds to **0.4** seconds above 7.3% for HFC–125. This is true for both the ambient and cold temperature comparisons. Concentration and time equivalency summaries for the four discharge comparisons are shown in Table 4.

Probe Number	Test 7 Halon 1301 Peak Reading (%)	Test 8 HFC-125 Peak Reading (%)	HFC-125 Equivalency Concentration (%)	Test 7: Time Above 6.0% (sec)	Test 8: Time Above 7.3% (sec)	HFC-125 Equivalency Time (sec)
1	13.5	15.0	6.7	7.8	5.3	0.3
2	10.4	14.1	8.1	6.0	4.7	0.4
3	7.0	8.2	7.0	2.3	2.6	0.6
4	9.3	10.9	7.0	5.5	4.5	0.4
5	9.0	11.8	7.9	6.9	5.9	0.4
6	7.0	7.5	6.4	3.8	2.2	0.3
7	8.4	8.5	6.1	4.6	2.8	0.3
8	7.1	8.9	7.5	4.1	3.7	0.5
9	11.3	13.7	7.3	5.3	5.6	0.5
10	9.6	11.2	7.0	5.1	4.4	0.4
11	7.8	10.6	8.2	4.9	4.2	0.4
12	8.4	11.3	8.1	5.4	4.7	0.4
Average			7.3			0.4

Table 3. Cold temperature bottle comparison – Tests 7 and 8

Bottle Temperature	Test # Comparison	HFC-125 Equivalency Concentration (%)	HFC-125 Equivalency Time (sec)
Ambient	1 vs 2	7.0	0.4
Ambient	5 vs 6	7.1	0.4
Cold	3 vs 4	7.3	0.4
Cold	7 vs 8	7.3	0.4

A criteria of 6.0% volumetric concentration for 0.5 seconds was applied to each of the 48 Halon 1301 traces. Of these, 43 met the requirements. The same approach was used for the HFC-125 traces based on the modified criteria of 7.3% indicated volumetric concentration for 0.4 seconds. For the 43 Halon 1301 traces which met the standard criteria, all 43 corresponding HFC-125 traces met the modified criteria. For the 5 Halon 1301 traces which did not meet the standard criteria, the 5 corresponding HFC-125 traces also did not meet the modified criteria.

Each of the four Halon 1301 bottle discharges (Tests 1, 3, 5, and 7) was compared to the certification criteria of all 12 probes above 6.0% volumetric concentration for at least 0.5 seconds simultaneously. Tests 1 and 3 did not satisfy these criteria, Tests 5 and 7 did. Similarly, the four corresponding HFC-125 bottle discharges (Tests 2, 4, 6, and 8) were compared against the modified criteria of all 12 probes above 7.3% indicated volumetric

concentration for at least 0.4 seconds simultaneously. Tests 2 and 4 did not satisfy the modified criteria, Tests 6 and 8 did.

## **CONCLUSIONS**

Concentration trace comparisons between Halon 1301 and HFC–125 show very good agreement at both ambient and cold temperatures. This supports the concepts of matching agent liquid volumes to maintain nitrogen volumes, and of matching the Jakob numbers and vapor pressures to accurately simulate the flashing process.

The data show that for a Halonyzer II gas analyzer calibrated for Halon 1301, the best HFC–125 match to Halon 1301 certification requirements of 6.0% volumetric concentration for 0.5 seconds is 7.3% indicated volumetric concentration for 0.4 seconds.

For Halon 1301 discharges which satisfied the standard certification criteria, the corresponding HFC–125 discharge also satisfied the modified criteria. For Halon 1301 discharges which did not satisfy the standard certification criteria, the corresponding HFC–125 discharge also did not satisfy the modified criteria.

Finally, these results suggest that an effective method exists to minimize Halon 1301 testing on air transport engines. The Boeing company has initiated discussions with the Federal Aviation Agency to adopt the test criteria proposed in this paper and suggests these proposals form the basis for a new industry test method and standard.

## **ACKNOWLEDGEMENTS**

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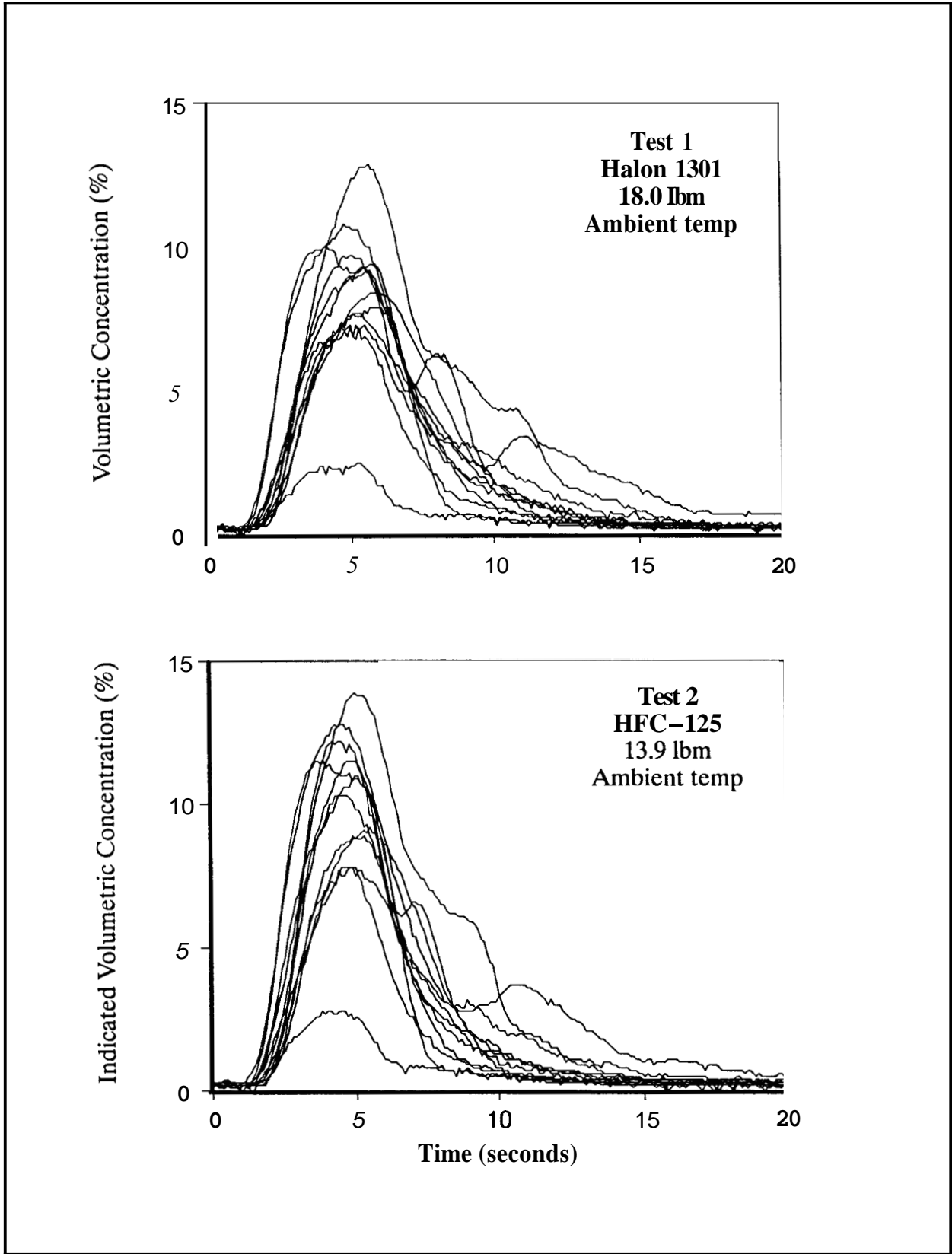


Figure 1.

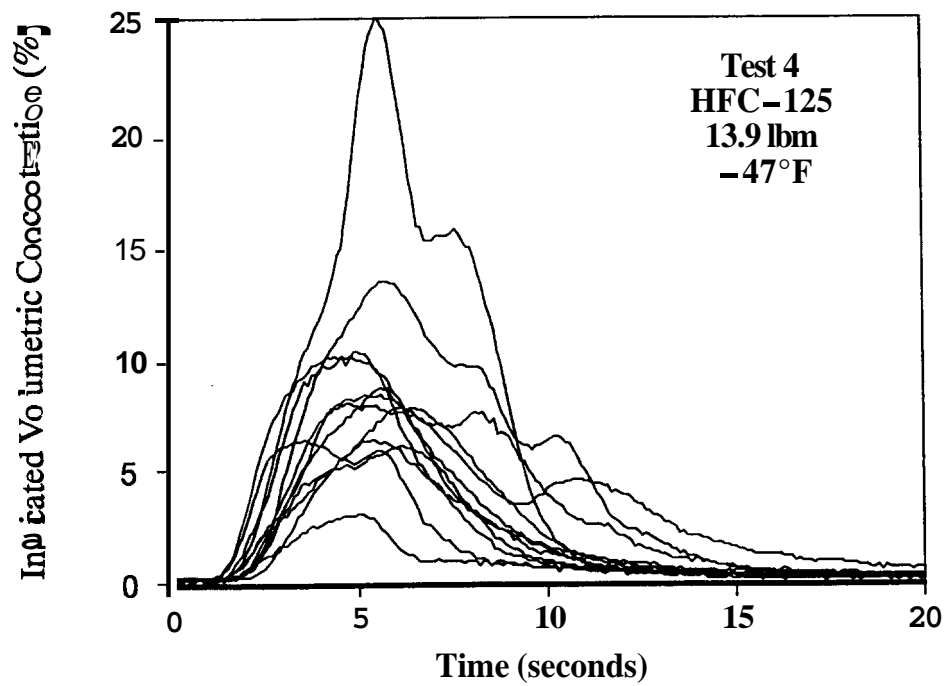
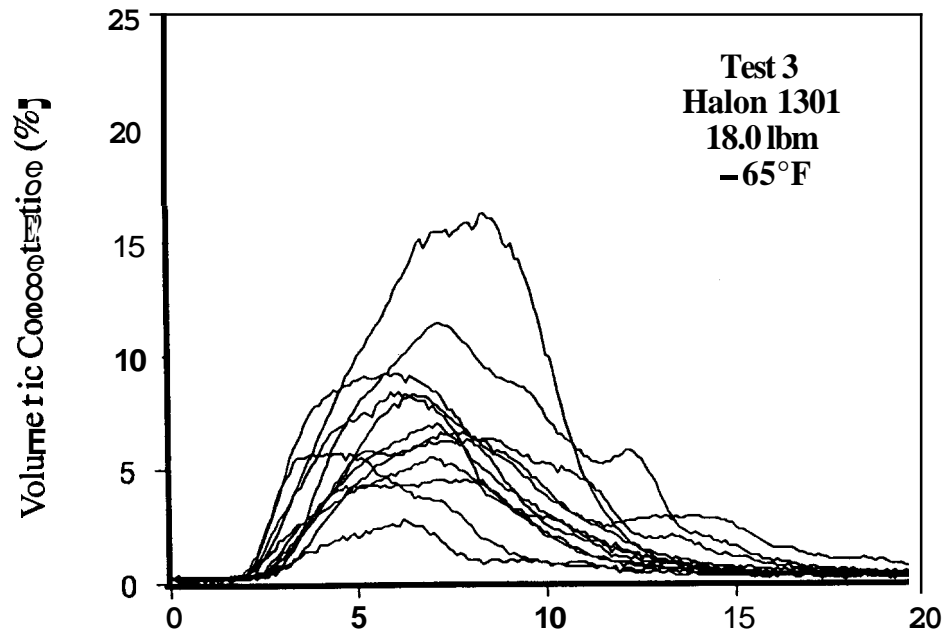


Figure 2.



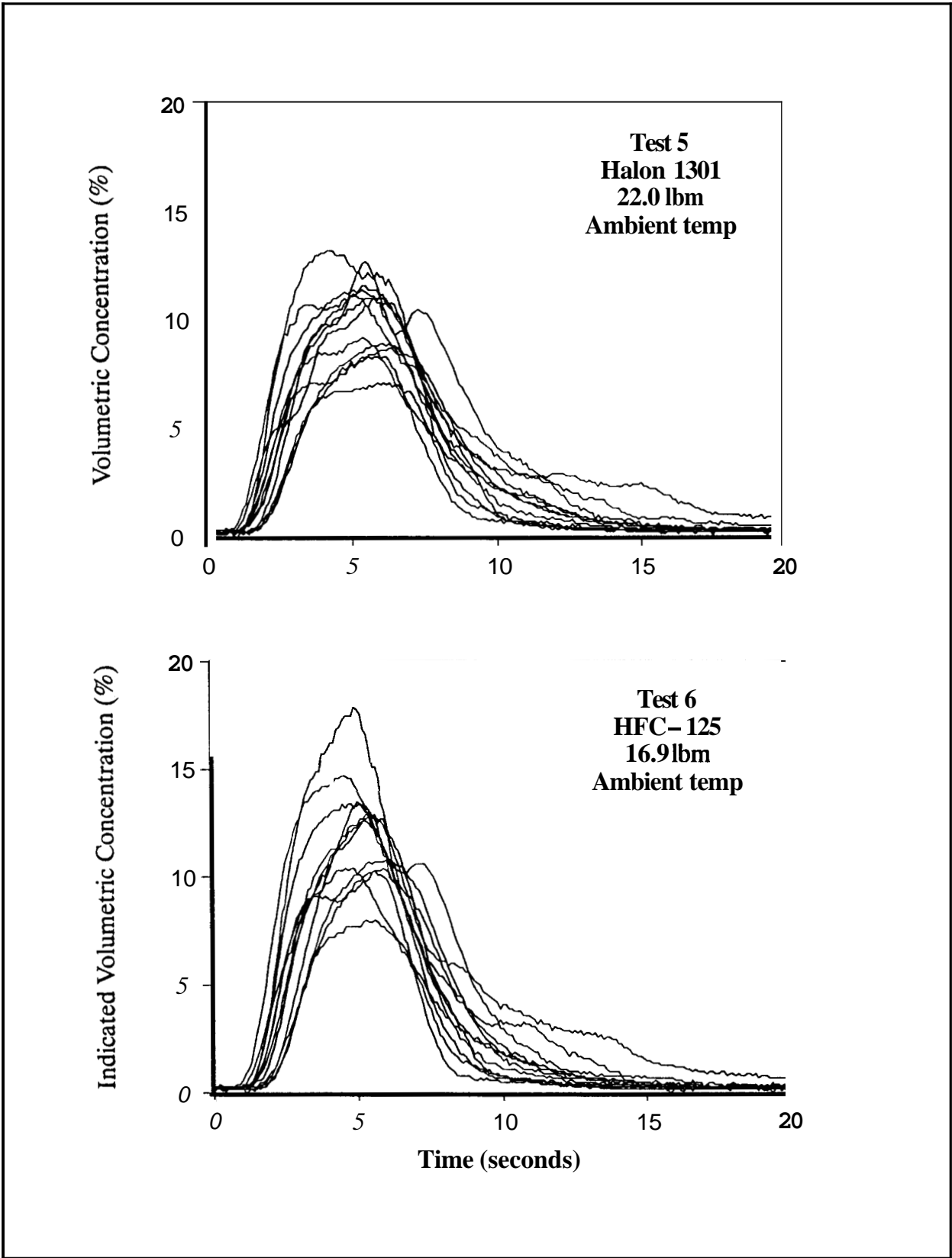
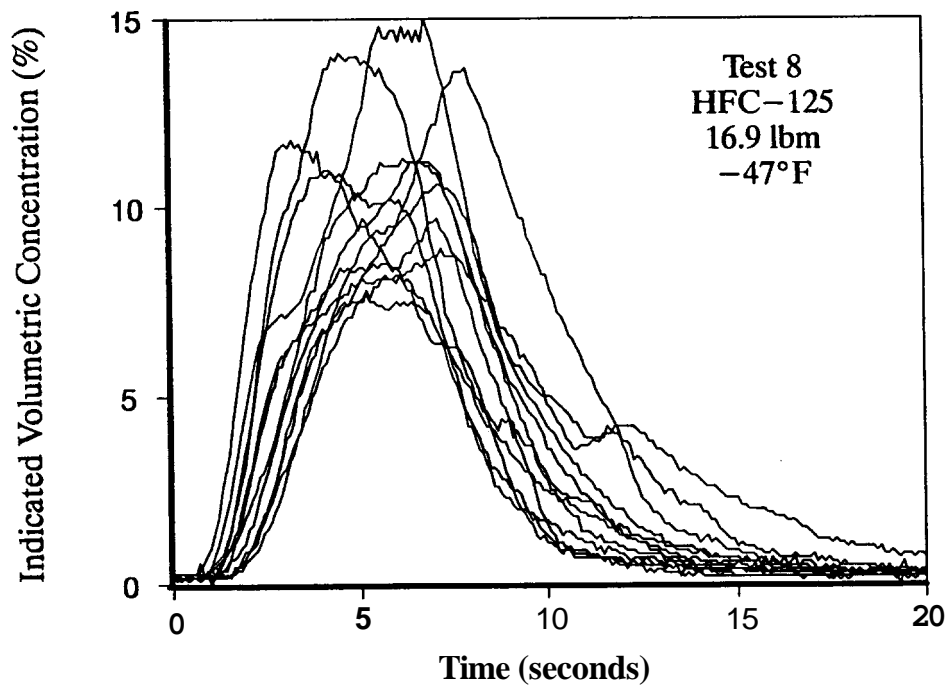
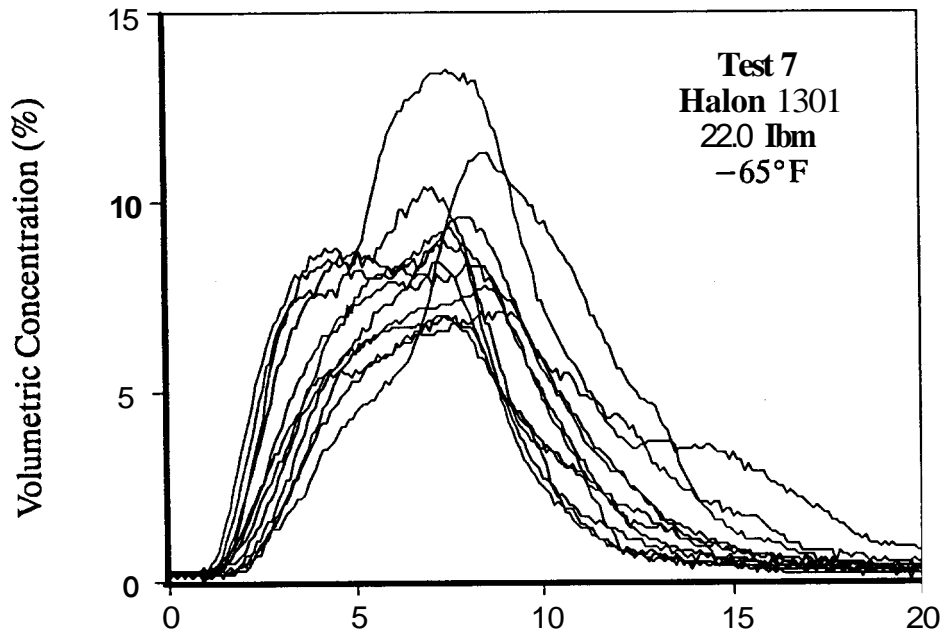
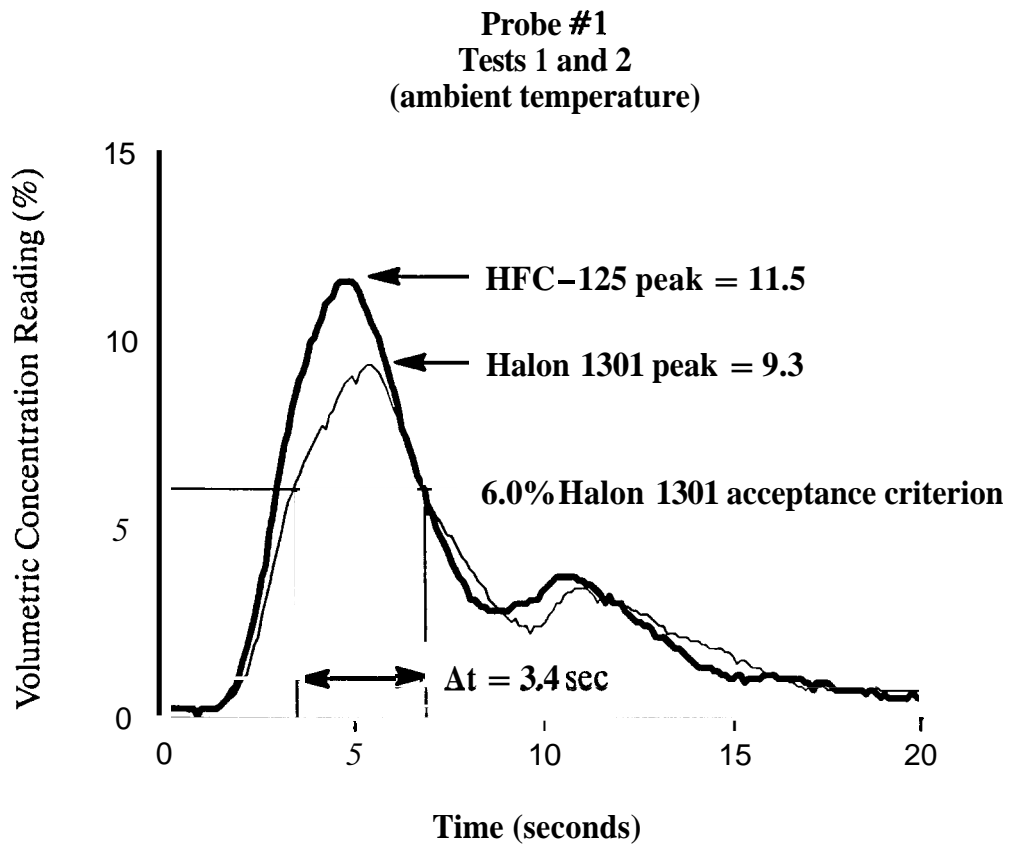


Figure 3.

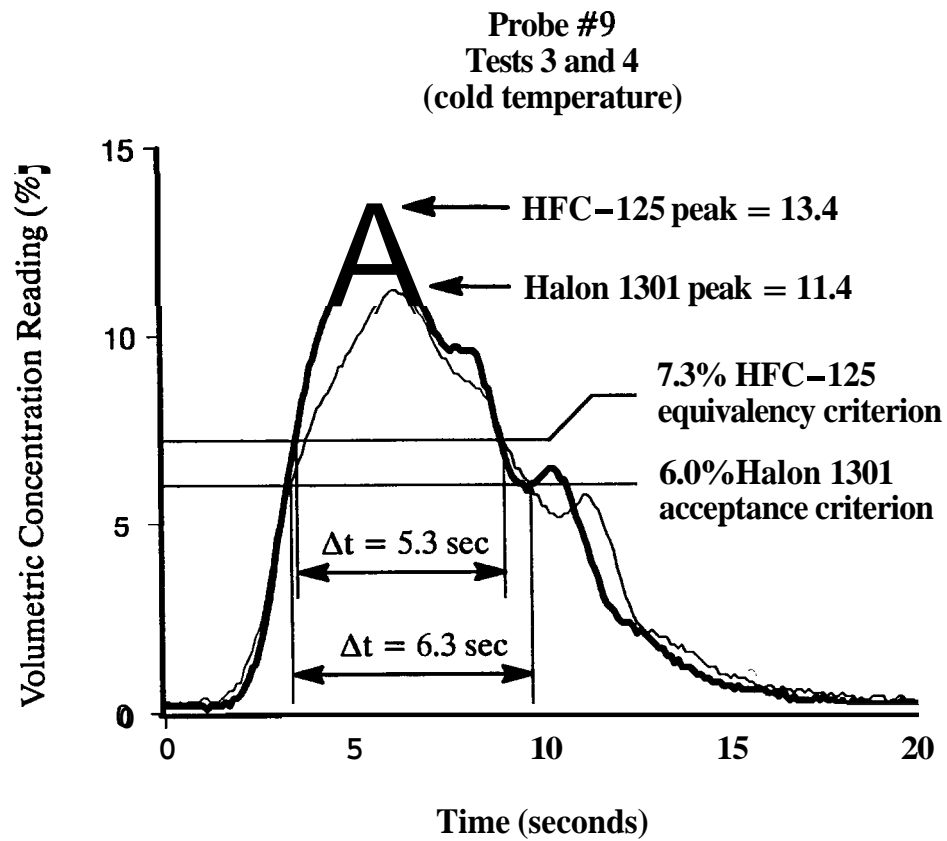


**Figure 4.**



$$\text{HFC-125 equivalency concentration} = \frac{11.5}{9.3} \times 6.0 = 7.4\% \text{ (rounded)}$$

**Figure 5.**



$$\text{HFC-125 equivalency concentration} = \frac{13.4}{11.4} \times 6.0 = 7.1\% \text{ (rounded)}$$

$$\text{HFC-125 equivalency time} = \frac{5.3}{6.3} \times 0.5 = 0.4 \text{ sec (rounded)}$$

**Figure 6.**