FINAL FIREFIGHTER EXPOSURE RESULTS: A COMPARISON OF HALON 1211, HCFC123 AND PFH

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OBJECTIVES

The U.S. Air Force Halon Replacement Program is' concerned about the exposure of personnel to chemical compounds during fire-training exercises as well as during actual flightline fires. The Air Force also is interested in understanding the environmental fate and effects of chemical compounds resulting from the combustion of halocarbon firefighting agents and jet fuel during these training exercises or fires. The purpose *of* this study was to assess the hazards associated with the inhalation of these compounds and to evaluate the fate and effects of the halocarbon/jet fuel combustion products.

BACKGROUND

Fire-training exercises are conducted routinely for Air Force personnel at several locations throughout the United States. In a typical training exercise, a controlled fire is ignited and firefighter personnel are directed to extinguish the blaze, using safe and effective techniques. Jet fuel (JP-4) is typically combusted in a circular test pit or cement dike to create the exercise scenario. During these exercises, firefighters can be exposed to the airborne vapors, aerosols, and gases from both the jet fuel and the extinguishing agent, and the combustion products of each.

TEST DESIGN

The test matrix was set up as follows:

- One test burn of a fuel fire without using a firefighting agent
- Two test burns with agent Halon 1211
- Three test burns with agent HCFC 123
- Three test burns with agent perfluorohexane (PFH)
- One test with each agent was run with only the FTIR and Draeger tubes to further characterize the acid gas emissions.

SUMMARY OF SAMPLING METHODS

Analyte(s)	Sampling method	Analysis method
Volatile organic compounds	Tenax®/charcoal adsorption	GC/MS (Modified EPA Method T02 and 8260)
	Summa@ passivated canister	GC/MS (Modified EPA Method T014 and 8260)
Semivolatile organics compounds	Polyurethane foam (PUF) absorption	GC/MS (Modified EPA Method T04 and 8270)
Polychlorinated dioxins and furans	PUF	MRI Modified Method GC/MS 8290
Total particulate mass and bound organic carbon	Filtration	Gravimetric and GC/MS
Volatile toxic gases	Continuous monitor	Portable Fourier transform infrared analyzer
	Draeger tube w/personnel sampler pump	Length-of-stain tube
Fire extinguishing agents	Canister, vertical profile	Gas chromatography

RECOMMENDATIONS

In order to minimize the risks to firefighters and other exposed individuals, the following items of caution should be considered:

1. Because all known halocarbon extinguishing agents will produce mixtures of toxic acid gases whenever they are applied to a flame or high temperature source, their use must be carefully evaluated in any situation where the resulting plume may expose unprotected persons.

2. Halocarbon-based agents should not be used by untrained personnel.

3. Discharging halocarbon-based extinguishers in such a manner that the resulting plume may envelop unprotected personnel, especially if such persons have no easy exit available, is to be avoided.

4. Because acid-gas concentrations are highest in the plume, adjacent to it, and downwind from it during the extinguishing agent application and for a few minutes afterwards, these toxic-hazard areas should be avoided by personnel who do not have breathing protection.

5. When using halocarbon-based extinguishing agents, personnel should note wind direction prior to use and attack the fire from the upwind direction, where the least chance of exposure to the plume gases will occur.

6. Firefighters should be informed that the acid gas plume from the application of PFH to a fire is much less visible but just as toxic as Halon 1211. Plume visibility using HCFC 123 is intermediate between the other two agents.

7. Whenever possible, personnel who may be exposed to the extinguisher/smoke plume should wear a pressure-demand supplied-air respirator.

8. Because all three agents tested are much denser than air and concentrate near ground level, asphyxiation from the neat agents is possible near ground level, especially in low-lying areas.

CONCLUSIONS

1. The FTIR identified an unexpected toxic compound, carbonyl fluoride, which poses the greatest threat to site personnel when they use any of the three agents.

2. Average total acid gas concentration, as measured by FTIR at the close-in (regular angle) downwind location, showed that IDLH values were exceeded by factors of 7.4 (Halon 1211), 8.1 (HCFC 123), and 9.1 (PFH). Long-angle total acid gas concentrations (single FTIR reading only) showed that IDLH values were exceeded by factors of 3.2, 5.6, and 3.8 (1211, 123, and PFH, respectively). Instantaneous concentrations measured in the plume exceeded the IDLH for COF_2, 10 times and the combined IDLH for the total acid gases 20 times.

3. When using Halon 1211 to extinguish a fire, the four acid gases formed (HCl, HBr, HF, COF_2) presented the greatest hazard. Results of modeling indicate that all four gases are near or above their respective IDLH limits at breathing height in the downwind plume at distances of up to 30 meters from the fire. Conservative modeling calculations show that the combined toxicity of all four gases may still be hazardous up to 80 meters downwind.

4. When the two replacement agents, HCFC 123 and perfluorohexane, are used, the respective elimination of HBr and HCI offgases is offset by increases in HF and COF_2 concentrations. Use caution in evaluating acid gas expcsures based on total acid indicator tubes. Simple acid gas detectors such as Draeger tubes give a weak response to carbonyl fluoride and HF, which dominate the toxic emissions from PFH. The apparent reading in a PFH smoke plume may be 3 to 4 times lower than a Halon 1211 smoke plume of equivalent toxicity.

5. The FTIR successfully recorded the rapid concentration changes that occur in the plume as firefighting proceeds. During use of all three agents, acid gases, CO, and unburned JP-4 vapor concentrations rise very quickly when agent application begins and then decay over a period of 1 to 5 minutes after agent application ceases.

6. CO, benzene, toluene, JP-4, and the halocarbons were also present at significant levels, but none exceeded the IDLH limits.

7. CO and unburned hydrocarbons increase in concentration as combustion temperature drops when agents are applied to a fire.

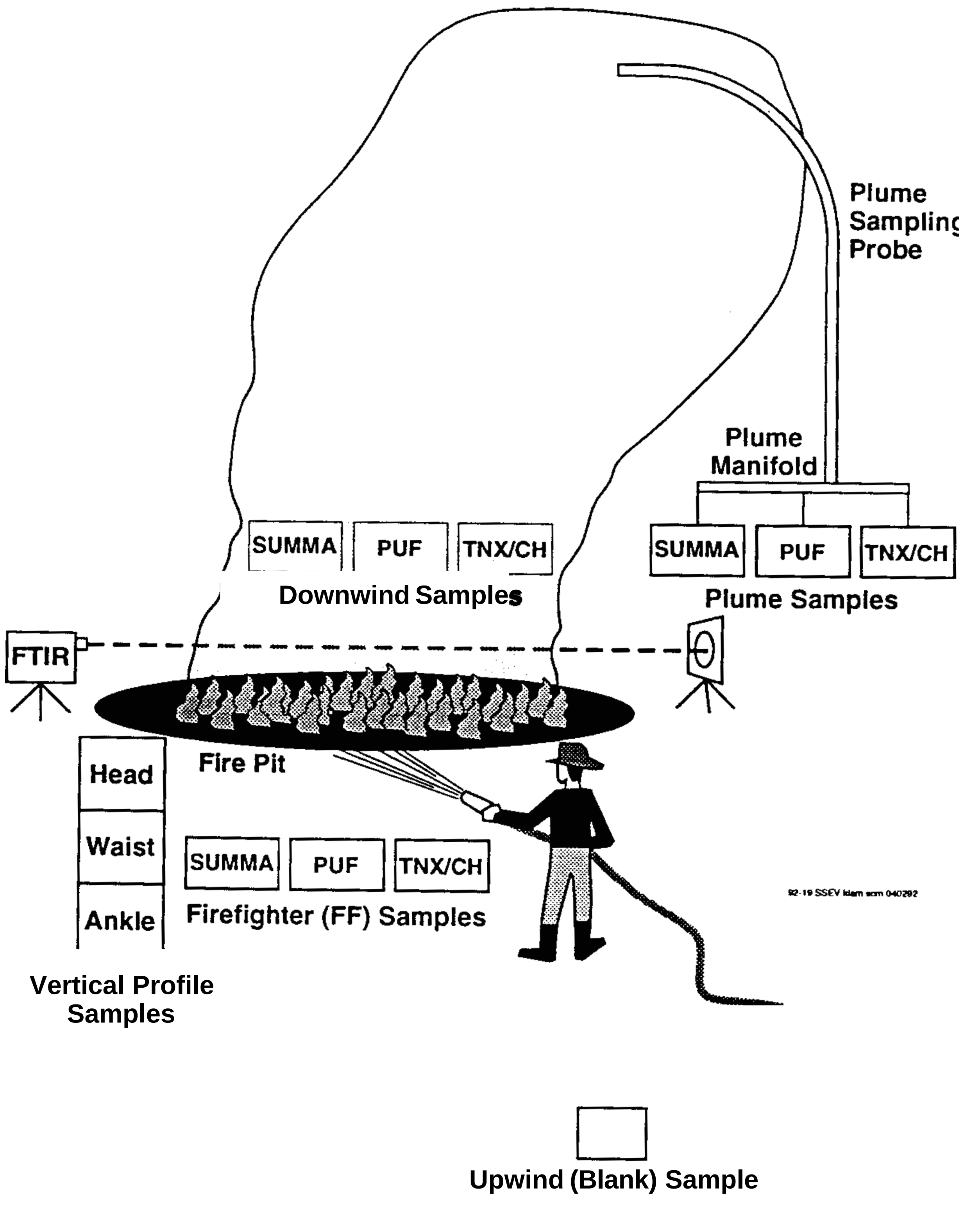
8. All three agents showed concentrations up to 100 times greater at ankle height compared to breathing zone height, especially when used to fight a pool fire. Therefore, the agents may reach IDLH limits near ground level.

9. Several polynuclear aromatic hydrocarbons associated with the jet fuel were detected, but not at significant concentrations.

10. Nearly all dioxins were below detection limits. A few furans were detected at low concentrations.

11. Community exposures to dioxins and furans and benzene indicate less than 1×10^{-7} cancer risk.

12. All this work was done prior to the USAF project which optimized the fire hose nozzles for the alternative agents HCFC-123 and PFH. Fire extinguishment times and agent quantities have both been reduced in recent USAF tests, which would in turn reduce the combustion by-products. Halon 1211 tests used the optimized Halon 1211 nozzle used by the USAF.


Plume
Sampling
Probe
Plume
Manifold
SUMMA
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Downwind Samples
SUMMA
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TNX/CH
Plume Samples
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Fire Pit
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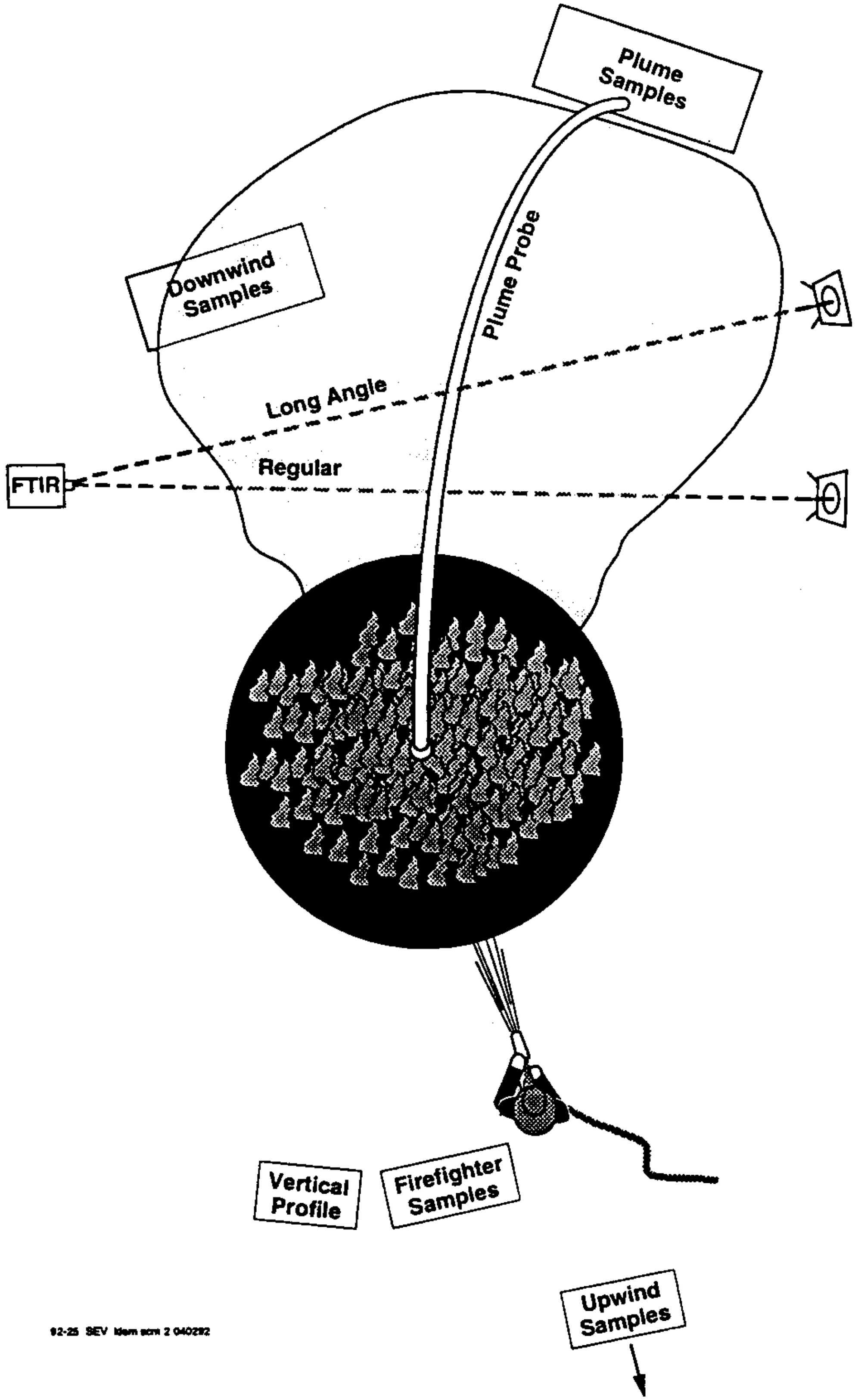
Waist
Ankle
SUMMA
PUF
TNX/CH
Firefighter (FF) Samples
Vertical Profile
Samples
Upwind (Blank) Sample


Plume Samples
Downwind Samples
Plume Probe
Long Angle
Regular
FTIR
Vertical Profile
Firefighter Samples
Upwind Samples

FTIR DATA BY AGENT

(Concentrations, ppm [v/v])

Run Number		1 (R)	2 (R)	3 (L)	4 (R)	5 (R)	7 (R)	8 (R)	9 (L)	10 (L)
		JP-4	Halon 1211	Halon 1211	HCFC 123	HCFC 123	PFH	PFH	PFH	HCFC 123
HCl	Fire		[illegible]	0.0	0.0	0.0				0.0
	Agent		[illegible]	[illegible]	120	[illegible]40				110
	Out[a]		[illegible]	0.79	1.1	17				16
HF	Fire		0.0	0.0	0.0	[illegible]	0.0	0.0	1.0	0.0
	Agent		44	[illegible]	[illegible]	120	65	120	43	69
	Out[a]		2.5	[illegible]	1.0	15	11	7.9	10	16
HBr	Fire		0.0	0.0						
	Agent		[illegible]	[illegible]						
	Out[a]		0.0	0.62						
COF_2	Fire		0.0	0.0	0.0	0.58	0.0	0.0	0.0	0.0
	Agent		35	19	26	72	87	95	35	33
	Out[a]		0.76	0.55	0.0	2.2	9.6	5.6	5.4	4.5

[a] Fire was not extinguished in Runs 1,2, and 4.   L = Long-angle path (just slightly downwind of plume).   R = Regular-angle path (directly through the plume).

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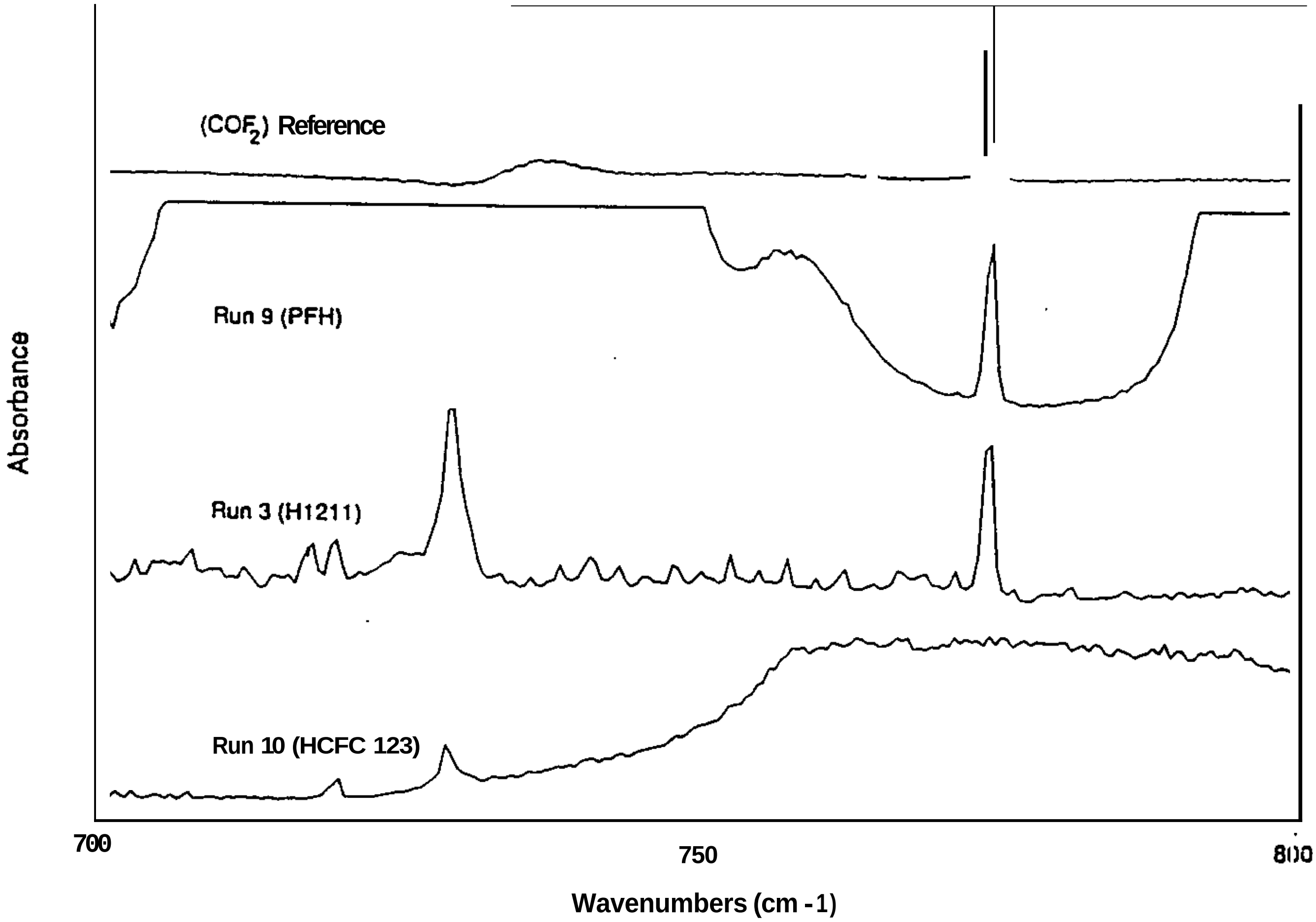
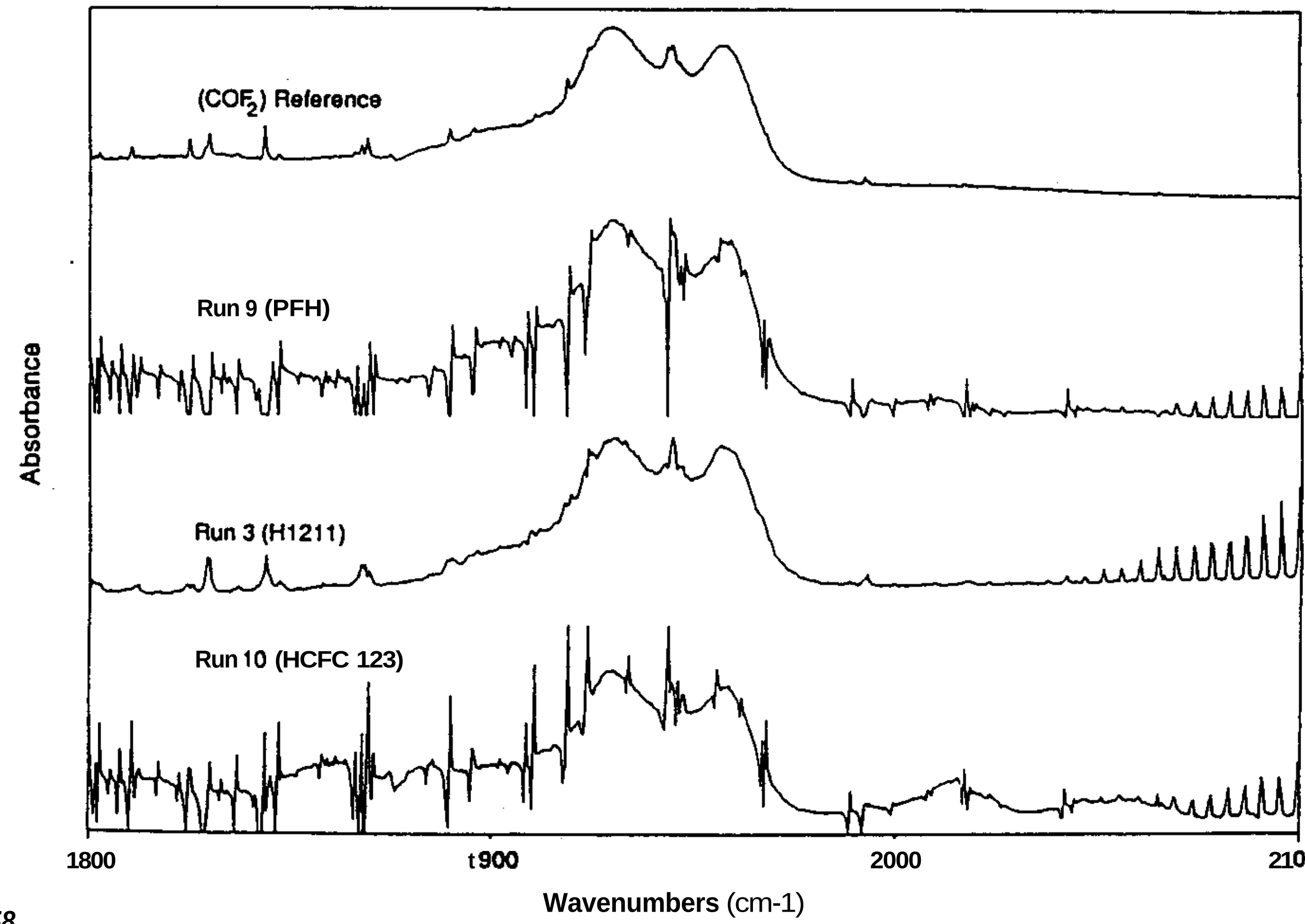


Comparison of carbonyl fluoride reference and field spectra at 774 cm^{-1}



Comparison of carbonyl fluoride reference and field spectra at 1900 to 1950 cm^{-1}.