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Full-Scale Evaluation of Gaseous Fire Suppressants

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ABSTRACT

Full-scale fire-suppression tests were conducted using HFC-227ea and HCFC Blend A in a mock-up of a 121 m^3 compartment of the Department of National Defence Canada's Halifax Class ships. The fire suppression effectiveness of the agents was assessed in total-flooding mode for that space using simulated electronic-cabinet fires, wood-crib fires and liquid-pool fires. Both agents were effective in extinguishing the test fires at design concentrations of 7.6% for HFC-227ea and 12% for HCFC Blend A.

INTRODUCTION

The production of halons has ceased in developed countries as a result of an international consensus, the Montreal Protocol, to regulate the use of ozone-depleting substances. The National Fire Laboratory (NFL) of the National Research Council of Canada has been assisting the Canadian Department of National Defence (DND) in selecting effective replacements for ozone-depleting Halon 1301 for fire protection applications.

Two replacement agents, HFC-227ea (1,1,1,2,3,3,3-heptafluoropropane: C_3HF_7) and HCFC Blend A, were evaluated using full-scale fire-suppression tests. HCFC Blend A is a mixture of HCFC-22 (chlorodifluoromethane: $CHClF_2$), HCFC-124 (2-chloro-1,1,1,2-tetrafluoroethane: C_2HClF_4), HCFC-123 (2,2-dichloro-1,1,1-trifluoroethane: $C_2HCl_2F_3$) and d-limonene ($C_{10}H_{16}$). Table 1 gives general information about these two agents [1]. In this paper, the results of the full-scale tests with the two agents are discussed.

Table 1. General Information on HFC-227ea and HCFC Blend A

Halocarbon	CB (%)	MW (g/mol)	T_b (°C)	$P_{v,25°C}$ (kPa)	ODP (CFC-11=1)	HGWP (CFC-11=1)	GWP_{100yr} (CO_2=1)	ALT (yr)	NOAEL (%)	LOAEL (%)	LC_{50} (%)
HFC-227ea	5.8-6.6	170.0	-16.4	458	<<.001	0.45	2050	31	9.0	10.5	80
HCFC Blend A	9.9-11.6	92.9	-38.3	948	0.02-0.05	0.02-0.34	90-1600	2-16	10.0	>10.0	64*
HCFC-22	11.6	86.47	-40.8	1050	0.05	0.34	1600	16	2.5	5.0	35*
HCFC-124	6.4-8.2	136.5	-12	386	0.022	0.10	440	7	1.0	2.5	36
HCFC-123	7.1-7.8	152.9	+27.1	97	0.02	0.02	90	2	1.0	2.0	3.2

Note:
HCFC Blend A consists of 82% HCFC-22, 9.5% HCFC-124, 4.75% HCFC-123 and 3.75% d-limonene by weight.

Legend:

ALT	atmospheric lifetime in years
CB	heptane cup-burner value
GWP_{100yr}	global warming potential relative to carbon dioxide (CO_2) over 100-year time horizon
HGWP	halocarbon global warming potential relative to CFC-11 (CCl_3F)
LC_{50}	the lethal concentration that kills 50% of tested animals for 4-hour inhalation (* 15-minute inhalation)
LOAEL	lowest observed adverse effect level
MW	molecular weight in g/mol
NOAEL	no observed adverse effect level
ODP	ozone depletion potential relative to CFC-11 (CCl_3F)
$P_{v,25°C}$	vapour pressure in kPa at 25°C
T_b	normal boiling point in °C at a pressure of 101.325 kPa

EXPERIMENTATION

Test Facility

The full-scale tests were conducted in a mock-up of a 121 m^3 compartment of the DND Halifax Class ships. Figures 1 and 2 show the test room constructed inside the NFL's Burn Hall. The equivalent leakage area of the room was 0.014 m^2 for a 50 Pa pressure difference.

Three thermocouple trees were used to measure the temperatures in the room. They were located near the southwest corner, the centre and the northwest corner of the room. Each thermocouple tree, 2.8 m high, contained six thermocouples. Nine pressure taps were installed on the west wall at three elevations (0.29, 1.47 and 2.67 m above the floor). The sound level in the room was monitored using a broad-band sound meter.

A piping system was designed for each agent. Each discharge system was instrumented with pressure transducers and thermocouples. Figure 1 shows the HCFC Blend A piping system designed to deliver a 12% agent concentration. This discharge system had two nozzles, each producing a 360°, horizontal spray. Two Ginge-Kerr* (GK) cylinders, currently used on the DND ships, were used in all of the HCFC Blend A tests, except one test in which two SES CO_2 cylinders were used. During discharge, the mass loss rate of the agent in the cylinders was measured using a weigh scale and timer. Figure 2 shows the HFC-227ea piping system with cylindrical nozzles. This two-nozzle discharge system was designed to deliver a 7.6% HFC-227ea concentration using a Chemetron cylinder.

A Fourier Transform Infrared (FTIR) spectrometer was used to measure the concentration of agents and combustion by-products during the tests. An FTIR gas-sampling port was mounted on each of the three thermocouple trees. The heights of the sampling ports above the floor were: 1) 1.5 m in the southwest corner, 2) 0.6 m near the centre and 3) 2.8 m in the northwest corner (see Figures 1 and 2). A CO_2/CO analyzer and an O_2 analyzer were used to measure CO_2, CO and O_2 concentrations. These were connected to two tygon sampling ports located near the middle of the west wall and at the ceiling near the west wall (see Figures 1 and 2).

Fire Scenarios

Test fires included a 400 kW round-pan (RP, 0.7 m diameter) fire, 50 kW square-pan (SP, 0.3 m x 0.3 m) fires, simulated fires in electronic cabinets (EC), wood-crib (WC)

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*Certain commercial products are identified in this paper in order to adequately specify the experimental procedure. In no case does such identification imply recommendations or endorsement by the National Research Council Canada, nor does it imply that the product or material identified is the best available for the purpose.

fires and tell-tale (TT) fires. Heptane was used as the fuel for the TT, SP and RP fires. Different combinations of these test fires were used to create four test scenarios as shown in Table 2.

Table 2. Fire Scenarios Used in the Full-Scale Fire Tests

Fire Scenario (Total Heat Release)	Test Fires	Fire Locations in Room	Comments
1 (200 kW)	7 TTs SP-1 SP-2 SP-3	throughout the room southeast corner, floor northwest corner, floor southwest corner, mid-height	TTs: 50 kW SPs: 50 mm from walls
2 (600 kW)	7 TTs SP-1 SP-2 SP-3 RP	throughout the room northeast corner, floor northwest corner, floor southwest corner, mid-height southeast corner, floor	TTs: 50 kW SPs: 50 mm from walls
3 (400 kW)	EC-1 EC-2 EC-3 EC-4 WC	1 m from southeast corner on top of EC-1 near north wall east wall near door southwest corner, floor	5% grill openings 5% grill openings 2% grill openings 10% grill openings 6-layer pine sticks
4 (400 kW)	EC-1 EC-2 EC-3 EC-4 shielded RP	1 m from southeast corner on top of EC-1 near north wall east wall near door southeast corner, floor	5% grill openings 5% grill openings 2% grill openings 10% grill openings shielded in a metal box

The mock-up cabinets (EC-1, EC-2 and EC-3) were 0.81 m by 0.81 m and 1 m high. EC-1 and EC-2 had a 5% opening area in the sides and EC-3 had a 2% opening area. A tell-tale fire was placed in the centre of each mock-up cabinet.

EC-4 was an electronic switching-gear cabinet with grill openings. A cable bundle and a tell-tale fire were placed in the upper part and lower part of EC-4, respectively. The wood crib was 0.6 m by 0.6 m and 0.24 m high and was made of 40 mm by 40 mm pine sticks in 6 layers. A metal box, made of perforated sheet steel with 33% openings on the sides and 6% openings on the top surface, was used to cover the RP in Fire Scenario 4.

The test fires were allowed a pre-burn of at least 30 s while the compartment door was kept open to prevent oxygen depletion. Thermocouples were placed above each test fire. These thermocouples were used to monitor fire extinguishment.

Quantity of Agents Used

The fire tests were conducted at a design concentration of 12% for HCFC Blend A and at design concentrations of 7.6 and 8.8% for HFC-227ea. Table 3 shows the agent mass of HFC-227ea and HCFC Blend A used in the tests. After the pre-burn period, the agent was discharged into the room.

Table 3. Agent Mass Used in the 121 m^3 Test Compartment

Design Concentration (%)	Agent	Mass (kg)	Liquefied Volume* (dm^3)
12	HCFC Blend A	64	53.3
7.6	HFC-227ea	72	51.6
8.8	HFC-227ea	85	60.9

* at 25°C

RESULTS

The discharge times for the agents were determined using the pressure transducers and thermocouples installed in the piping system, the broad-band sound meter and the weigh scale. Discharge times were 11 s for tests designed for the 7.6% HFC-227ea concentration, and 14 s for the 8.8% HFC-227ea concentration. Discharge times for HCFC Blend A tests were 7 s, except one test which required 13 s because the agent flow was restricted by a narrow dip tube in the CO_2 cylinders.

HFC-227ea at concentrations of 7.6 and 8.8% and HCFC Blend A at a concentration of 12%, were effective in extinguishing all the test fires. Fire extinguishment times were measured using the thermocouples placed above the fuel surface. Most test fires were extinguished before the completion of the discharge, as shown in Table 4. The in-cabinet fires and the wood-crib fire, however, required more time to be extinguished than the open pan fires.

Table 4 also shows 5 min averaged concentrations of hydrogen fluoride (HF) generated during fire suppression. The HF concentration increased with increasing fire size, and the higher agent concentration resulted in lower HF production. The test compartment was built inside the NFL's Burn Hall and, therefore, was essentially

independent of ambient wind conditions. The compartment was air-tight and the measured air change rate in the test room was very low. This affected the decay rate of HF and the averaged HF concentrations.

The results of HF production for HFC-227ea tests were consistent with published data with adjustments for the ratio of fire size to room volume [2, 3]. For the HCFC Blend A tests, the HF concentrations in Fire Scenarios 1 and 3 were similar to that for the HFC-227ea tests. Hydrogen chloride (HCl) was also produced during the HCFC Blend A tests.

Table 4. Extinguishment Results in the 121 m^3 Test Compartment

Fire Scenario (Total Heat Release)	Test Fires	12% HCFC Blend A ext. time (s)	HF (ppm)	7.6% HFC-227ea ext. time (s)	HF (ppm)
1 (200 kW)	7 TTs	2-15	1,500	2-12	1,200
	SP-1	11		8	
	SP-2	10		8	
	SP-3	4		14	
2 (600 kW)	7 TTs	1-7	10,000	2-12 (2-10*)	6,300 (4,600*)
	SP-1	4		4 (8*)	
	SP-2	5		4 (12*)	
	SP-3	2		6 (12*)	
	RP	6		3 (5*)	
3 (400 kW)	EC-1	11	1,500	24	1,800
	EC-2	14		23	
	EC-3	15		25	
	EC-4	8, 6		undetermined	
	WC	30		15	
4 (400 kW)	EC-1	12	7,000	no test	no test
	EC-2	25			
	EC-3	30			
	EC-4	22, 8			
	shielded RP	8			

* at a design concentration of 8.8% HFC-227ea

CONCLUSIONS

HCFC Blend A, at a design concentration of 12%, gave effective total-flooding fire-extinguishing performance for the test scenarios investigated. Published data has

already shown, however, that the total-flooding performance of HCFC Blend A at a concentration of 8.6% was unsatisfactory because this concentration was below the lowest heptane cup-burner value of 9.9% for this agent [4, 5]. The extinguishment results for HFC-227ea were consistent with that from other research laboratories [5-7]. The quantities of acid gases generated during fire suppression can be related to agent concentration, agent discharge time, fire type and size as well as extinguishment time. The results of HF production were also in accordance with published data [2, 3].

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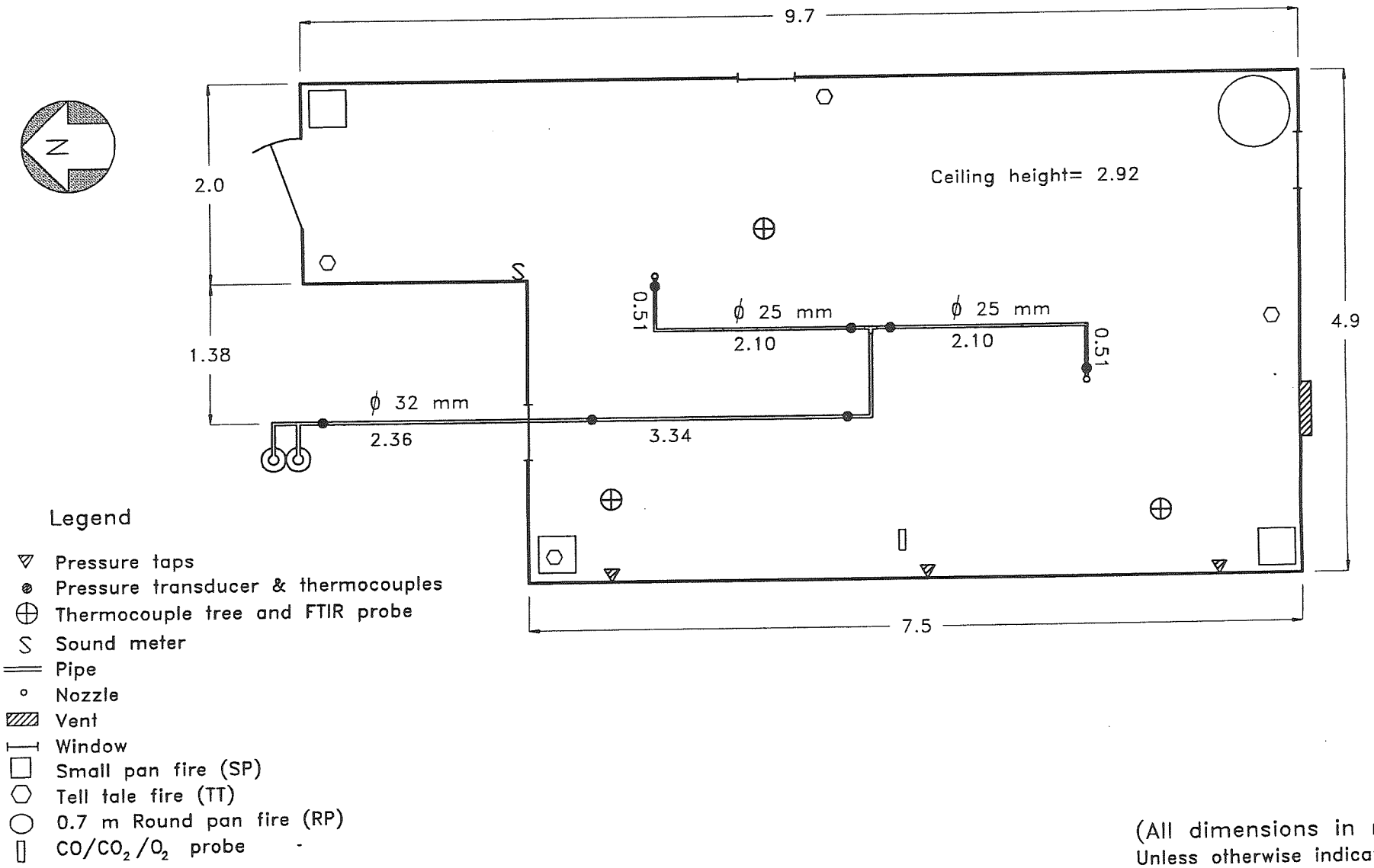

Figure 1. Plan view of test room, instrumentation and piping system for HCFC Blend A

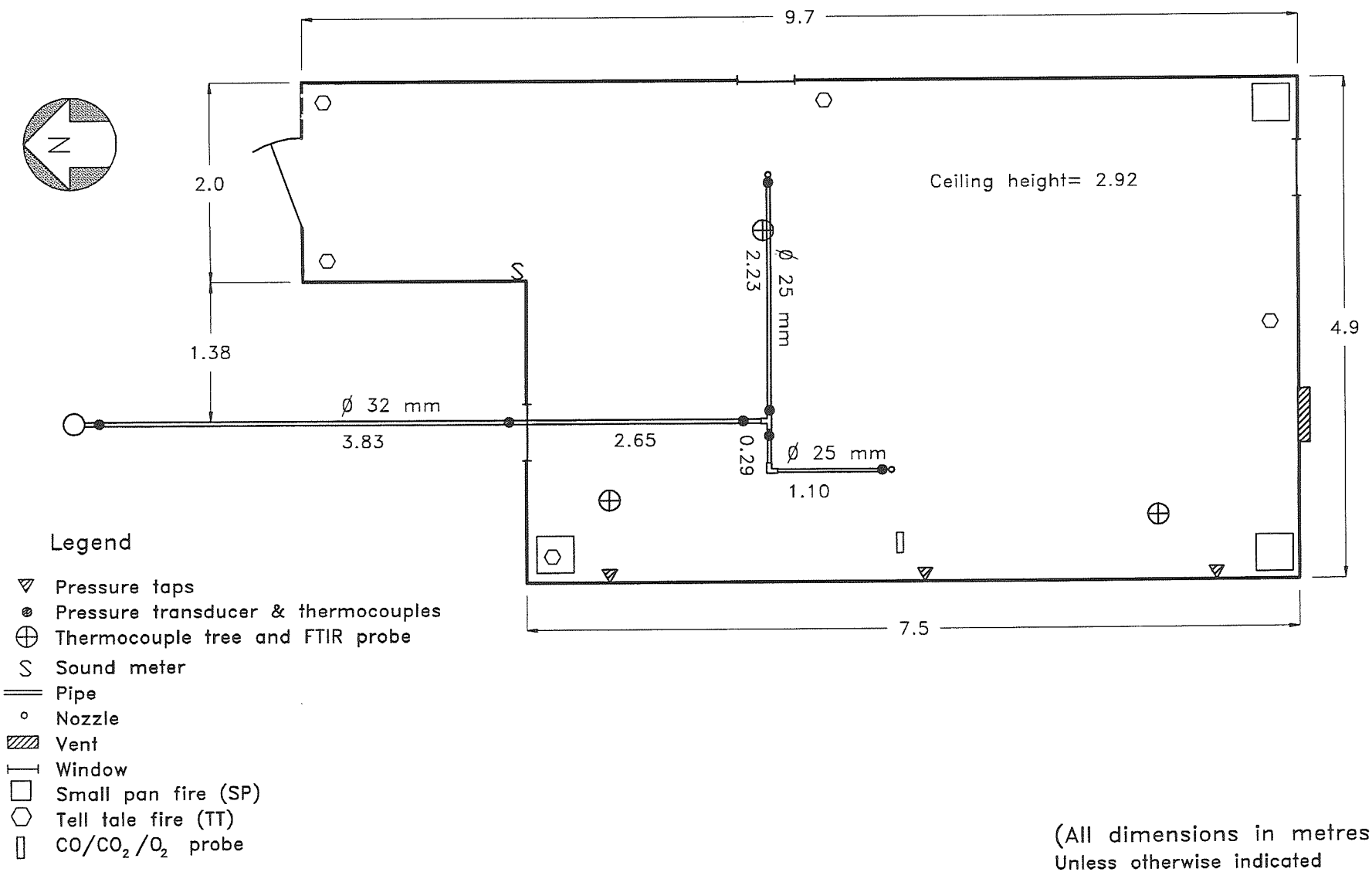

Figure 2. Plan view of test room, instrumentation and piping system for HFC-227ea