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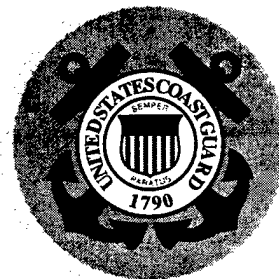
1082 Shennecossett Road, Groton, CT 06340-6096

Report No. CG-D-02-99

An Evaluation of the International Maritime Organization's Gaseous Agents Test Protocol with Halocarbon Agents and an Inert Gas, 180° Nozzles, and Low Temperature Conditioned Cylinders



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16. Abstract (MAXIMUM 200 WORDS) This report provides an evaluation of four gaseous halon alternatives (CEA-308, NAF-SIII, FM-200, and Inergen) in full-scale machinery space applications. The primary objective of this investigation was to evaluate the IMO's test protocol for gaseous halon alternative fire extinguishing systems for use with an "inert" gaseous agent (Inergen), with discharge systems containing 180° (Sidewall) nozzles, and with agent discharge cylinders conditioned to low temperatures. The evaluation focused on whether the protocol requires modification to properly evaluate these systems.					
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (WEIGHT)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³

TEMPERATURE (EXACT)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

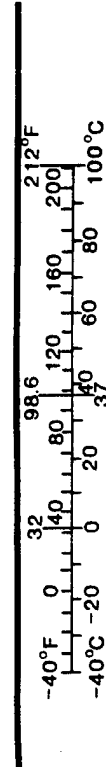
*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	ac
MASS (WEIGHT)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³

TEMPERATURE (EXACT)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

Four total flooding gaseous halon alternatives (CEA-308, NAF-SIII, FM-200, and Inergen) were evaluated in full-scale machinery space applications. The primary objective of this investigation was to evaluate the International Maritime Organization's (IMO) test protocol for gaseous halon alternative fire extinguishing systems for use with an "inert" gaseous agent (Inergen), with discharge systems containing 180° (Sidewall) nozzles, and with agent discharge cylinders conditioned to low temperatures. The evaluation focused on whether the protocol requires modification to properly evaluate these systems.

The Montreal Protocol, an International Treaty, established production bans on Halon fire suppression agents. The ban was based on Halon's contribution to the destruction of the earth's stratospheric ozone layer. For most of the industrial world, this production ban became effective in 1994. Halon fire suppressant agents, particularly Halon 1301, had become a common fixed fire protection choice on marine vessels. With this production ban came an important need to find acceptable alternatives for these fire suppression applications. Several alternative gaseous agents have been proposed to replace Halon 1301. The IMO drafted a test protocol for these replacements. The U.S. Coast Guard, as part of its regulatory duties, needed to evaluate the effectiveness of the test protocol across a variety of agents and configurations.

The tests were conducted in a simulated machinery space aboard the test vessel, STATE OF MAINE, at the U.S. Coast Guard Fire and Safety Test Detachment located at Little Sand Island in Mobile, AL. The agents/systems were evaluated against five fire scenarios. Two of the five scenarios consisted of small heptane pan fires (telltales) located in the corners of the space to evaluate the mixing characteristics of the system. The remaining three scenarios were large fires consisting of combinations of pan and spray fires produced using either heptane or diesel fuel. One test included a small wood crib. To meet the protocol requirements, the systems were required to extinguish all of the test fires within 30 seconds of the end of agent discharge, and limit the mass loss of the wood crib to 60% of its original weight.

The results of these tests suggest that the protocol provides a reasonable basis for evaluating both halocarbon and inert gas extinguishing agents. The lack of a definition in the protocol for the end of agent discharge required clarification from the U.S. Coast Guard in order to judge the performance of the inert gas extinguishing agent (Inergen). It was recommended that the protocol be revised to include a uniform definition of discharge time based on 95% of the agent having been delivered to the protected space. This definition should serve for both the measurement of discharge time and to designate the end of agent discharge.

The addition of a new nozzle design/type or new nozzle spacing was fairly evaluated by the protocol using a single telltale fire test. Additional large fire tests should not be required. However, it was recommended that two additional telltales be added to the center of the space (one on the engine mockup and one in the bilge under the engine mockup). This would further validate the mixing of the agent throughout the compartment.

The effects of the low temperature discharge cylinders varied from system-to-system, and were observed to be related to a number of system parameters (i.e., fill density and percent of agent in pipe). Due to the lack of a general understanding of how these various design parameters affect the discharge characteristics of the system, a systematic study was recommended to bound the problem. Provisions (although not yet defined) should be added to the test protocol for evaluating systems that have agent storage cylinders located in unconditioned spaces.

Based on the U.S. Coast Guard's interpretation of the IMO requirements, five agent/hardware combinations successfully completed the test protocol. These agent/hardware combinations include; Inergen with Ansul hardware, CEA-308 with TEPG hardware, and FM-200 with Hygood hardware, Kidde-Fenwal hardware, and Chemetron hardware.

These results demonstrate that IMO's test protocol, with the proposed recommendations, can effectively evaluate a variety of agents and configurations. The protocol can evaluate different gases, different piping layouts, as well as systems where the agent storage cylinders are at low temperatures.

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1.0 INTRODUCTION

The International Maritime Organization's (IMO) Maritime Safety Committee (MSC) on fire protection (FP), has developed a test protocol for evaluating the extinguishing effectiveness and critical design parameters of fixed gaseous halon alternative fire extinguishing systems [1]. The test protocol was developed to establish the extinguishing effectiveness of a gaseous halon alternative and to assure that the distribution system can achieve an extinguishing concentration of agent at all points in the space being protected.

In a previous investigation, three halocarbon agents (North American Fire Guardian Technology, Inc.'s (NAFGT) NAF-SIII, 3M Corporation's CEA-410, and Great Lakes Chemical Corporation's FM-200), one gas/powder mix (Powsus Corporation's Envirogel), and Halon 1301 for baseline comparisons were evaluated against the draft test protocol [2]. Based on these results, the protocol was revised and published as final. During that initial investigation, the agents were evaluated using discharge systems that contained 360° nozzles and cylinders stored at ambient temperatures. More recently, interest has arisen pertaining to the use of 180° nozzles and agent cylinders stored in unconditioned spaces. In addition, no inert gas agents had been tested against the protocol.

Sidewall nozzles (nozzles with 180° discharge patterns) are commonly used in machinery spaces and can provide an added degree of design flexibility. Once the system has successfully completed the IMO test protocol for a given set of hardware (nozzles), the addition of new nozzles only requires an evaluation against the telltale fire test (Fire Scenario 1). This approach assumes that a new nozzle design would only affect the ability to distribute the agent throughout the space, which is the primary objective of the telltale fire test.

Agent cylinders can be stored in areas that are either open to the weather or in unconditioned spaces. There is a concern that a low cylinder temperature and resulting lower cylinder pressure would affect the distribution/mixing characteristics of the system. This evaluation assessed the impact of low temperature cylinders on the system performance and determined whether additional tests should be included in the protocol.

The test protocol was also evaluated using the inert gaseous agent, Inergen. The inert gaseous agents are allowed longer discharge times similar to carbon dioxide (CO₂) systems (120 seconds for the inerts versus 10 seconds for the halocarbon agents) because they do not decompose in the presence of fire. The longer discharge times alleviate many of the problems associated with the higher extinguishing concentrations and the gaseous discharge of these agents (i.e., enclosure overpressurization, larger pipes, and nozzles). There is a concern that these longer discharge times may allow the reduction in oxygen concentration in the compartment caused by the fire to aid in the extinguishment process. The inert gas portion of this investigation focused primarily on agent discharge times, fire extinguishment times, and the affect of oxygen depletion on the extinguishment of the fires.

This report addresses the tests conducted in accordance with the approved test plan [3].

2.0 OBJECTIVES

The objective of this test program was to further evaluate the IMO gaseous agent test protocol for use with systems containing 180° nozzles, low temperature agent cylinders, and inert gas extinguishing agents. Based on this evaluation, modifications to the test protocol may be recommended.

3.0 TECHNICAL CONSIDERATIONS

Once a system has successfully completed the IMO test protocol for a given extinguishing agent and set of distribution hardware (nozzles), the addition of a new nozzle design or installation only requires an evaluation against the telltale fire test. The rationale for this approach is that the new nozzle design should only affect the distribution/mixing characteristics of the system, which is the primary objective of the telltale fire test. Consequently, during the 180° nozzle evaluation, the focus was not only to identify the mixing characteristics of the nozzles but

also to determine whether additional tests (i.e., large fire tests) should be required to evaluate new system designs and components.

There is a concern that low temperature cylinders and the resulting lower cylinder pressure may affect the distribution/mixing characteristics of the system. Since a low temperature cylinder test is currently not required by the IMO, the parameters of the test are not defined in Reference 1. The specific parameters that should be addressed are; cylinder fill density, cylinder temperature, and the percent agent in pipe. Performance criteria for discharge time and extinguishment times also need to be defined. Other standards [4] evaluate these systems using the maximum fill density and the lowest anticipated exposure temperature. These standards require fire extinguishment within 60 seconds of the end of agent discharge. Due to the lack of specific IMO performance requirements, the results of these tests will require interpretation.

There are some additional concerns with the IMO protocol applied to evaluating inert gas extinguishing agents. These concerns are the lack of definitions of discharge time and the end of agent discharge. IMO requires that inert gas extinguishing systems be designed to discharge the agent in two minutes or less. This discharge time is based on 85% of the mass of the agent being delivered to the space. The discharge time requirement for the halocarbon agents is based on 95% of the mass of the agent being delivered to the space. Typically, liquid agent runout as noted by the inflection points on the nozzle pressure plots has been used to define the end of agent discharge for the halocarbon agents. The inconsistency in discharge time definitions only becomes an issue if the definition is used as the starting point of the extinguishment time interval. The 95% definition has been used in the past to evaluate the halocarbon agents, but has not been an issue since the end of agent discharge by any definition usually occurs within seconds of liquid agent runout. The end of agent discharge for the inert gases, however, can vary by as much as 60 seconds, depending on the definition. Due to the lack of a definition for the end of agent discharge, the extinguishment times were measured and recorded from system activation and the agent discharge times were given for 85, 95, and 99.5% of the agent delivered to the space. The actual extinguishment time can be determined by subtracting the discharge time from the recorded extinguishment time based on the preferred discharge time definition.

4.0 CRADA PARTICIPANTS

To meet the test objectives, the project was structured to allow the participation of agent and equipment manufacturers through Cooperative Research and Development Agreements (CRADAs). Through these CRADAs, the Coast Guard provided the test facility (Fire & Safety Test Detachment, Mobile, AL), test compartment, all fuels, instrumentation, test personnel, and the final report. The CRADA participants provided the extinguishing agent, distribution system design with design calculations, all system hardware, and were responsible for installing the system. CRADAs were established with the following companies:

- Ansul Inc. using Inergen and Ansul hardware;
- Ansul Inc. Marine Division using North American Fire Guardian Technology, Inc.'s (NAFGT) agent NAF-SIII;
- Minnesota Mining and Manufacturing, 3M, using CEA-308 and distribution hardware provided by Tyco Electronic Product Group (TEPG);
- Factory Mutual Research Corporation using Great Lakes Chemical Corporation's agent FM-200 and distribution hardware provided by Hygood Ltd. and Sea-Fire;
- Kidde-Fenwal Inc. using Great Lakes Chemical Corporation's agent FM-200 and Kidde-Fenwal hardware; and
- Chemetron, Inc. using Great Lakes Chemical Corporation's agent FM-200 and Chemetron hardware.

4.1 Extinguishing Agents

Four agents (three halocarbons and one inert gas) were included in this evaluation. These agents include heptafluoropropane C_3HF_7 (FM-200), perfluoropropane C_3F_8 (CEA-308), a hydrochlorofluorocarbon blend (NAF-SIII, HCFC Blend A), and a blend of nitrogen, argon, and carbon dioxide (Inergen). FM-200 is manufactured by Great Lakes Chemical Corporation, CEA-308 by 3M, NAF-SIII by North American Fire Guardian Technologies, and Inergen by Ansul Inc. The physical/chemical characteristics of Halon 1301, for reference purposes, and the four agents

are listed in Table 1 [4-7]. Also included in Table 1 are the agents' cup burner extinguishment concentrations for n-heptane.

Table 1. Extinguishing Agents Chemical and Physical Properties [5-8]

Trade Name	Halon 1301	CEA-308	FM-200	NAF-SIII*	Inergen**
Chemical Formula	CF ₃ Br	C ₃ F ₈	C ₃ HF ₇	82% CHClF ₂ (R-22), 9.5% C ₂ HClF ₄ (R-124), 4.75% C ₂ HCl ₂ F ₃ (R-123), and 3.75% (Isopropenyl-1- Methyl Cyclohexene)	52% N ₂ , 40% Ar, and 8% CO ₂
Molecular Weight	149	188	170	93 (Avg)	34 (Avg)
Normal Boiling Point, °C	-57.8	-36.7	-16.4	-38	-196
Vapor Pressure, MPa at 21 °C	1.47	0.782	0.405	0.853	NA
Critical Temperature, °C	67	71.9	101.7	125	122.4
Critical Pressure, Mpa	3.97	2.68	2.91	6.65	4.33
Vapor Density, kg/m ³ At 21 °C and 0.101 Mpa	6.26	7.87	7.26	3.85	1.43
Liquid Density, kg/m ³ at 21 °C	1567	1315	1403	1219	NA
Agent Cylinder Pressure, MPa at 21 °C	2.58	2.58	2.58	2.58	14.8
n-heptane Cup Burner Extinguishment Concentration, % Volume Extinguishment	3.5	6.5	6.7	9.9	29.1
Telltale Test Concentration % Volume		6.5	6.7 ¹ , 7.2 ²	10	31.5
Large Fires Test Concentration % Volume		8.5, 9.0	8.7		37.5

Note: * Composition by Weight, Average Properties Given
 ** Composition by Volume, Average Properties Given
 ¹ Concentration used by FMRC/Sea-Fire
 ² Concentration used by Kidde-Fenwal and Chemetron

All fire tests were conducted using the CRADA participant's recommended design concentration with the exception of the telltale fire tests. The telltale fires were conducted using the agents' minimum extinguishing concentration, which typically was the cup burner extinguishing concentration for n-heptane or diesel fuel. The maximum allowable concentration for use in the telltale fire tests is 83.3% of the CRADA participants recommended design concentration [1].

5.0 TEST COMPARTMENT

The tests were conducted in a simulated machinery space aboard the test vessel, STATE OF MAINE, at the U.S. Coast Guard Fire and Safety Test Detachment located at Little Sand Island in Mobile, AL. The machinery space was located on the fourth deck of the Number 6 cargo hold. The compartment was constructed to meet the dimensional requirements of the IMO test protocol. The compartment volume was approximately 500 m^3 with nominal dimensions of $10 \text{ m} \times 10 \text{ m} \times 5 \text{ m}$ as shown in Figure 1. The diesel engine mockup described in the test protocol was located on the fourth deck in the center of the compartment as shown in Figure 2. Air to support combustion was provided naturally through two 2 m^2 vent openings located on the fourth deck forward in the compartment. These two vents were equipped with remotely activated retractable doors. Products of combustion were exhausted from the compartment through a 6 m^2 vertical stack located in the back of the compartment (aft). The exhaust stack was equipped with a remotely activated hydraulic damper. Both the supply vents and vertical stack were open during the preburn period and closed just prior to agent discharge.

The enclosure integrity was determined prior to the previous evaluation using a door fan test [2]. The door fan tests were conducted by Brendle Inc. of Montgomery, AL. Four tests were conducted using air flow rates from 65 to $110 \text{ m}^3/\text{min}$, which produced compartment pressures ranging from 15 to 40 Pa . Based on the results of these tests, the equivalent leakage area for the compartment was determined to be approximately 0.17 m^2 .

A Harford Duracool, 8 m^3 , Model DR36788GG1MSI walk-in freezer with adjustable temperature controls was installed on the main deck of the "STATE OF MAINE" adjacent to the cylinder manifold. The agent cylinders were conditioned in the freezer for the over twelve hours prior to testing.

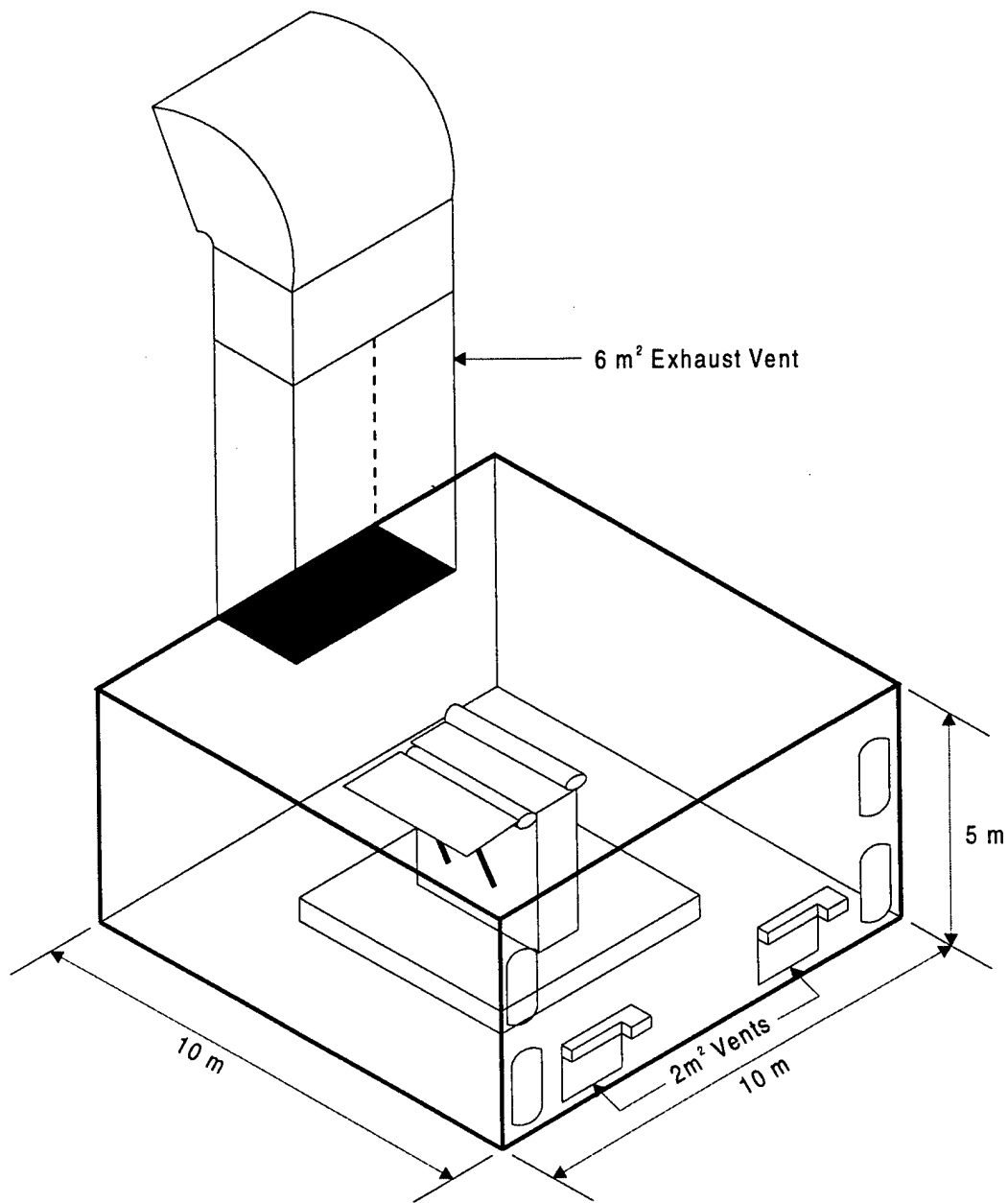


Figure 1. Machinery Space Configuration

6.0 FIRE SCENARIOS

The fire scenarios required by the IMO test protocol [1] are listed in Table 2 and are designated as Fire Scenarios 1, 2A, 2B, 3, and 4. The locations of the fires listed in Table 2 are shown in Figure 3. Per the IMO requirements, the halocarbon agents were evaluated against fire Scenarios 1, 2A, 3, and 4; and the inert gas was evaluated against Fire Scenarios 1, 2B, 3, and 4. The inert gas(s) are evaluated against a smaller spray fire combination (Fire Scenario 2B) to reduce the effects of oxygen depletion.

Table 2. Fire Scenarios

Fire Scenario	Nominal Total Heat Release Rate	Components	Nominal Heat Release Rates	Location (Figure 3)
1	~24 kW	82 cm ² heptane pan fires (telltale)	~3 kW/ea	Corners (TT)
2A	7.95 MW	Low pressure heptane spray fire	5.8 MW	Top of mockup (S1)
		High pressure diesel spray fire	1.8 MW	Top of mockup (S2)
		0.25 m ² heptane pan fire	0.35 MW	Under mockup (P1)
2B	0.49 MW	0.10 m ² heptane pan fire	0.14 MW	Side of mockup (P2)
		0.25 m ² heptane pan fire	0.35 MW	Under mockup (P1)
3	4.40 MW	Low pressure/flow heptane spray fire	1.10 MW	Side of mockup (S3)
		Wood crib	0.30 MW	Deck level (C1)
		2.0 m ² diesel pan fire	3.00 MW	Bilge Plate (P3)
4	6.00 MW	4.0 m ² diesel pan fire	6.00 MW	Bilge (P4)
* 5	~24 kW	82 cm ² heptane pan fires (telltale)	~3 kW/ea	Corners (TT)

* A low temperature conditioned cylinder test is not currently included in the IMO test protocol.

Fire Scenario 5 was conducted to evaluate the effects that low temperature cylinders have on the mixing characteristics of the systems. Fire Scenario 5 was a repeat of Fire Scenario 1 with the agent cylinders conditioned to a lower temperature. The cylinder temperature used during these tests was selected by the CRADA participants.

The telltale cups were constructed of 10 cm long sections of 10 cm diameter schedule 40 steel pipe. The cups had an internal diameter of 10.23 cm and a wall thickness of 0.60 cm. The cups were filled with a 2.5 cm deep layer of water and a 5 cm deep layer of heptane, resulting in a 2.5 cm freeboard.

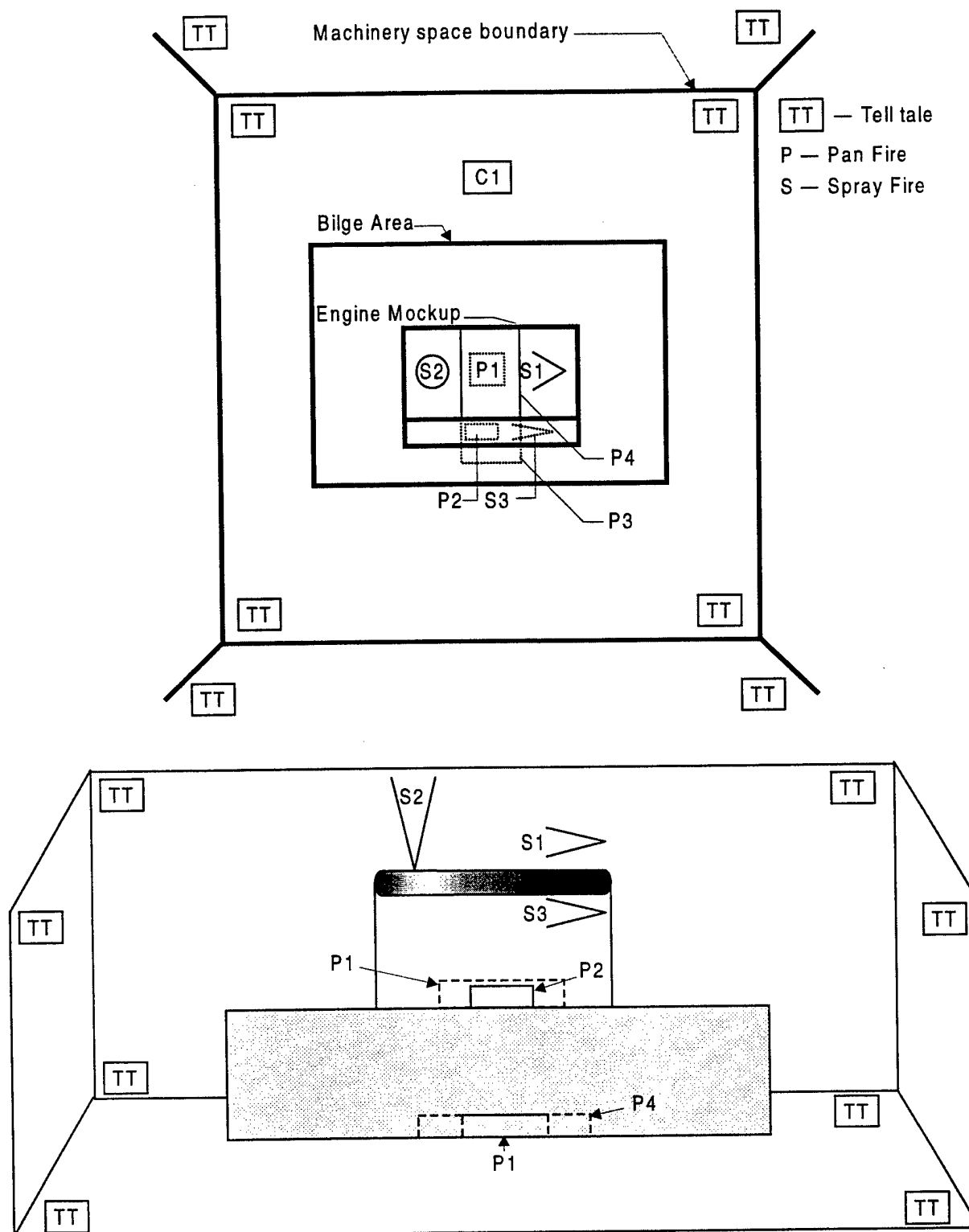


Figure 3. Fire Locations

The fuel pans used during these tests were square in shape and constructed of 3.2 mm steel plate with welded joints. The pans were 22.9 cm in depth with side dimensions of 31.6 cm, 50 cm, 144 cm, and 200 cm for the 0.2 m², 0.25 m², 2 m², and 4 m² pans, respectively. These pans were filled with a 2.5 cm deep layer of water and a 5 cm deep layer of either heptane or diesel fuel. Heptane was added to the 2 m² and 4 m² diesel pans to initiate the fire (1.9 L and 3.8 L, respectively).

The wood crib was constructed of 4 layers of 6 members each. Each member was trade size 5 x 5 x 45 cm (actual 3.8 x 3.8 x 45 cm) fir with a moisture content between 9% and 13%. The wood crib was placed on an angle iron frame 0.3 m above the deck. The crib was ignited using a 0.25 m² pan that was fueled with 3.8 L of heptane. The wood crib was weighed both before and after each test.

The spray fire parameters are given in Table 3. The low pressure heptane spray fires were produced using a pressurized fuel tank and a pipe network constructed of 1.2 cm stainless steel tubing. The fuel flow was controlled by both a manual quarter turn ball valve and a remotely actuated solenoid valve. The fuel tank was pressurized with nitrogen from a regulated cylinder. The high pressure diesel spray was produced using a positive displacement pump and a pipe network constructed of 1.2 cm stainless steel tubing. The fuel flow was controlled by both a manual quarter turn ball valve and a remotely actuated solenoid valve.

Table 3. Spray Fire Parameters

Fire Type	Low Pressure	Low Pressure, Low Flow	High Pressure
Spray nozzle	Wide spray angle (120-125) full cone type	Wide spray angle (80) full cone type	Standard angle (at 6 bar) full cone type
Nozzle make and model	Bete Fog Nozzle P-120	Bete Fog Nozzle P-48	Spraying Systems LN-8
Fuel flow	0.16 ± 0.01 kg/s	0.03 ± 0.005 kg/s	0.050 ± 0.002 kg/s
Fuel temperature	20 ± 5 °C	20 ± 5 °C	20 ± 5 °C
Nominal heat release rate	5.8 ± 0.6 MW	1.1 ± 0.1 MW	1.8 ± 0.2 MW

The fires were ignited to achieve the following preburn times prior to agent discharge (wood cribs 360 seconds, pan fires 120 seconds, and spray fires 15 seconds).

The IMO protocol requires that all Class B fires must be extinguished within 30 seconds of the end of agent discharge. In addition to the extinguishment time requirement, the mass loss of the wood crib in Fire Scenario 3 cannot exceed 60% of its original weight. This implies that the wood crib must be extinguished during the test. The test protocol should be revised to state the extinguishment time requirement.

7.0 AGENT DISTRIBUTION SYSTEMS

Each CRADA participant was responsible for the design and installation of their respective distribution system. Each CRADA participant was required to submit both a system design and flow/discharge time calculations to the Coast Guard prior to system testing. Systems were designed in accordance with the IMO protocol. The halocarbon agent systems were designed for a maximum discharge time of 10 seconds (95% of the mass of agent delivered to the enclosure). The inert gas system (Inergen) was designed for a maximum discharge time of 120 seconds (85% of the agent delivered to the enclosure).

Each CRADA participant utilized multiple distribution system configurations during the course of this evaluation. The additional configurations were used to either employ the 180° nozzles, to increase the nozzle coverage area, or to adjust for the difference in agent quantity between the telltale and larger fire scenarios. Due to the number and variation of these systems, the specific layouts and design parameters will be discussed later with the results for each CRADA participant.

All fire tests were conducted using the manufacturers' recommended design concentration with the exception of the telltale fire tests. The telltale fires were conducted using the agents' minimum extinguishing concentration, which typically was the cup burner

extinguishing concentration for n-heptane or diesel fuel. These concentrations are listed in Table 1.

8.0 INSTRUMENTATION

The U.S. Coast Guard's data acquisition system was used to collect all of the data during this evaluation with the exception of the extinguishing agent and HF concentrations. These measurements were made using an FTIR (Fourier Transform Infrared Spectrometer) which has a dedicated data acquisition system. The U.S. Coast Guard's data acquisition system was used to collect data at two rates; one set sampled at a rate of 10 Hertz, and the other set at 1 Hertz. The 1 Hertz data set consisted of the machinery space and fire instrumentation and the 10 Hertz data set consisted of the agent discharge system, and compartment pressure instrumentation.

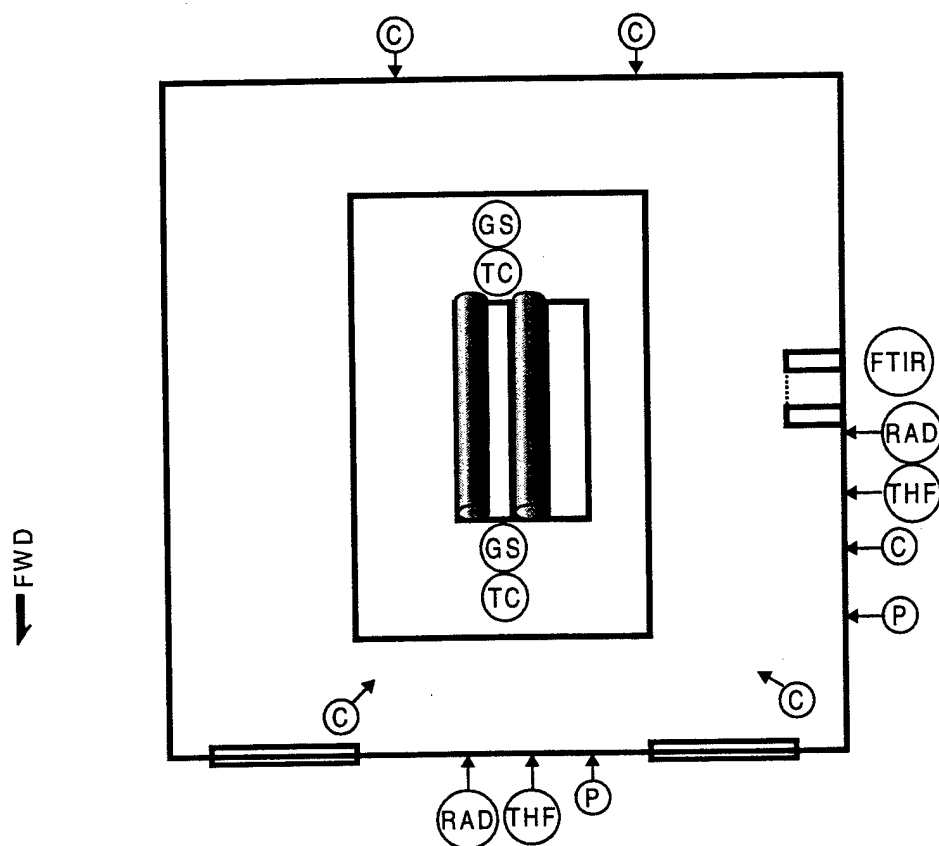
The instrumentation scheme is shown in Figure 4 and a complete list of instrumentation is found in Appendix B.

8.1 Machinery Space and Fire Monitoring Instrumentation (1 Hertz Data Set)

The machinery space was instrumented to measure air temperatures, fire/flame temperature (to note extinguishment time), radiant and total heat flux, fuel nozzle pressure, and O₂, CO₂, and CO gas concentrations. A more detailed description of the instrumentation scheme is listed as follows.

8.1.1 Temperature Measurements

Two thermocouple trees were installed in the compartment. Each tree consisted of eight thermocouples positioned at the following heights above the lower deck (1.0, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 4.9 m). Inconel sheathed type K thermocouples (0.32 cm diameter) (Omega Model KMQIN-125G-600) were used for this application.



- (GS) Gas Sampling CO, CO₂, O₂ (1.0, 2.5, 4.0 m)
- (TC) Thermocouples (1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0 m)
- (RAD) Radiometers (2.0, 4.0 m)
- (THF) Calorimeters (2.0, 4.0 m)
- (P) Pressure Measurements (1.5 m)
- (FTIR) FITR Measurements (1.5 m)
- (C) Video Cameras

Figure 4. Instrumentation

8.1.2 Gas Concentration Measurements

Carbon monoxide, carbon dioxide, and oxygen concentrations were sampled at two locations and three elevations in the compartment. These measurements were recorded at the center line of the space both forward and aft of the engine mockup as shown in Figure 4. Measurements were taken 1.0, 2.5, and 4.0 m above the lower deck. MSA Lira 3000 Analyzers with a full-scale range of 10% by volume were used to measure the carbon monoxide concentration. MSA Lira 303 Analyzers with a full-scale range of 25% by volume were used to monitor the carbon dioxide concentration. Rosemont 755 Analyzers were used to monitor the oxygen concentration with full-scale range of 25% by volume. These analyzers are pressure sensitive, so that concentration measurements above ambient can be recorded during agent discharge.

The gas samples were pulled through 0.95 cm stainless steel tubing and a Drierite packed filter using a vacuum sampling pump at a flowrate of 1 L/min, resulting in a 10 second transport delay.

8.1.3 Heat Flux Measurements

Both radiant and total heat flux measurements were recorded at four locations in the compartment. These transducers were installed on the forward and port bulkheads 2.0 m and 4.0 m above the lower deck as shown in Figure 4. These instruments were water cooled Schmidt Boelter transducers manufactured by Medtherm Co. (Medtherm 64 Series Transducers) and had a full-scale range of 0-100 kW/m². The radiometers were equipped with 150 sapphire windows.

8.1.4 Fire Temperature

To aid in the extinguishment time determination, one thermocouple was placed in the flame region 5 cm above telltale cups, 20 cm above the larger pan fires, and 45 cm downstream of the spray fire nozzles. Inconel sheathed, Type K thermocouples (0.32 cm diameter) (Omega Model - KMQIN-125G-600) were used for the large fires and 0.16 cm diameter (Omega Model - KMQIN-062G-600) thermocouples were used for the telltale cups.

8.1.5 Fuel Pressure

The fuel nozzle pressure for these spray fires was monitored approximately six meters upstream of the nozzles where the fuel lines entered the test chamber. The two low pressure spray fires were monitored using a Setra Model 205-2 pressure transducer with a full-scale range of 1.7 MPa. The high pressure spray fire was monitored using a Setra Model 205-2 pressure transducer with a full-scale range of 20.7 MPa.

8.2 Discharge System Instrumentation (10 Hertz Data Set)

The discharge system was instrumented to provide system pressures, fluid temperatures, and pipe wall surface temperatures during the discharge of the agent. The compartment pressure was also included in this set of data. A more detailed description of these instruments is listed as follows.

8.2.1 Pressure Measurements

System pressures were measured at five locations: two discharge nozzles, before each tee, and on the cylinder discharge manifold. Setra Model 205-2 pressure transducers were used for this application. These transducers have a range of 0-6.9 MPa with an accuracy of 0.01% full-scale.

8.2.2 Temperature Measurements

The cylinder temperature was measured using an inconel sheathed Type K thermocouple (Omega Model KMQIN-062-600) fastened to the side of the cylinder with glazing compound. As a result of this fastening/measurement technique, the actual agent temperature can vary by as much as a few degrees. Fluid temperatures were measured using fast-response, exposed junction, 0.16 cm diameter, inconel-sheathed, Type K thermocouple probes (Omega Model KMQIN-062E-300) inserted into the flow (center of the pipe) adjacent to the locations of the pressure measurements. The pipe wall surface temperatures were measured using 24 AWG Type K

thermocouples, welded to the pipe surface adjacent to the fluid temperature and system pressure measurement locations.

8.2.3 Cylinder Weight Measurements

During the tests conducted with Inergen, one cylinder was weighed using a load cell scale assembly. The scale assembly had a range of 0-227 kg (gross). Due to the reaction forces exerted on the load cell during discharge, the weight traces could not be used during the analysis.

8.2.4 Compartment Pressure Measurements

The compartment pressure was measured at the centerline of the forward and port bulkheads 1.0 m above the deck as shown in Figure 4. Setra Model 264 pressure transducers with a range of ± 2.48 kPa were used for this application. These instruments have an accuracy of 0.01% full-scale. Both transducers were mounted outside of the compartment with the reference taken at the transducer location.

8.3 Agent and Hydrogen Fluoride (HF) Concentration

With the exception of the tests involving Inergen and NAF-SIII, the agent and hydrogen fluoride (HF) concentrations were measured using a KVB/Analect Diamond 20 Fourier Transform Infrared Spectrometer (FTIR) configured with an open path in situ measurements inside the space. This configuration employed two flat 90° mirrors (Analect Model OBE-100), two 91 cm light pipes (Axiom Model AOT-36), two 90° parabolic mirrors with 20 cm focal lengths (Analect Model OBE-108), and two 3.8 cm diameter calcium fluoride, CaF_2 , windows. A 40 cm active path length was used during these tests. Measurements were taken every 1.2 seconds starting 5 seconds before the agent discharge until 16 seconds after discharge. After that period, measurements were taken every 30 seconds, starting 30 seconds after the agent discharge until 9 minutes after discharge. Finally, measurements were taken every 60 seconds starting 9 minutes after discharge until the end of the test.

Agent and HF concentrations were determined by comparison with spectra obtained using known concentrations. The specific agent concentrations were determined by the absorbencies at the wave numbers shown in Table 4.

Table 4. Agent and Decomposition Product Wave Numbers

Agent / Compound	Wave Number (cm ⁻¹)
FM-200 (C ₃ HF ₇)	2034
CEA-308 (C ₃ F ₈)	2040
Hydrogen Fluoride (HF)	4003, 4041, and 4077

The HF concentrations implied by the absorbencies at wave numbers 4003, 4041, and 4077 cm⁻¹ were averaged together.

The calibration spectra for use in determining the agent concentration was obtained using two glass cells, one with a path length of 5 cm and one with a 10 cm path length. These cells were evacuated and then filled with agent/air mixtures corresponding to 12.5% by volume and 25% by volume.

The HF calibration spectra was obtained using two plastic cells, one with a path length of 10 cm path and one with a 88.9 cm path length. Six mixtures of known concentrations ranging from 980 ppm HF to 9000 ppm were flowed through each cell to result in 12 spectras corresponding to concentrations ranging from 245 ppm to 20,000 ppm.

Inergen concentrations were determined using the oxygen concentration measurements and Equation 1.

$$C_{Inergen} = 100 * \left(1 - \frac{O_2}{O_{2,Init}} \right) \quad (1)$$

where $C_{Inergen}$ is the Inergen Concentration (% by volume), O_2 is the measured oxygen concentration, and $O_{2, Init}$ is the initial oxygen concentration. The Inergen concentration can also be determined by multiplying the carbon dioxide concentration by 12.5. In either case, the

determined concentration is overstated by the presence of the fire, which both consumes oxygen and generates carbon dioxide. The NAF-SIII concentration was determined using the same technique.

8.4 Video Equipment

Five video cameras were used to visually document the events of the test. Two video cameras were located one on each level inside the compartment as shown in Figure 4. The other three cameras were located outside the compartment primarily viewing the area around the diesel engine mockup. A microphone was also installed in the center of the space to provide the audio for the five video cameras.

9.0 PROCEDURES

The tests were initiated from the control room located on the second deck level forward of the test compartment. Prior to the start of the test, the pans were fueled, and the compartment ventilation condition was set. (The two 2 m² lower vents and the 6 m² stack vent were opened prior to the start of the test.) During Fire Scenario 5, the agent discharge cylinders were removed from the freezer and connected to the manifold just prior to the start of the test. The video and data acquisition systems were activated, marking the beginning of the test. One minute after the start of the data acquisition system, the fires were ignited, and the compartment was cleared of test personnel. The ignition sequence timing was driven by the compartment fires in the test scenario. Wood crib fires were ignited 360 seconds prior to agent discharge. Pan fires and the telltale cups were ignited 120 seconds prior to agent discharge. Spray fires were ignited 15 seconds prior to agent discharge. Ten seconds prior to agent discharge, the vents into the space were closed and the extinguishing system was activated. The fuel for the spray fires was secured 15 seconds after these fires were confirmed to be extinguished (either visually through the video, or by the drop in temperature measured by the fire thermocouples). The test continued for 15 minutes after discharge at which point the re-ignition test for Fire Scenario 2A was conducted.

On completion of the test, the space was ventilated to remove the remaining agent and products of combustion.

10.0 RESULTS AND DISCUSSION

10.1 Tests Conducted

A total of 39 tests were conducted during this evaluation. These 39 tests consisted of 21 telltale fire tests, and 18 large fire tests. The telltale fire tests represent a larger portion of this evaluation, in comparison to the previous evaluation, due to the greater emphasis placed upon investigating additional hardware (180° nozzles) and due to evaluating the effects of low temperature storage cylinders.

The performance requirements stated in the IMO test protocol are measured from the end of agent discharge. Due to the lack of a definition for the end of agent, the extinguishment times presented in the results section were measured from system activation. Various discharge times are also presented for each test. The 85% and 95% discharge times for Inergen were determined using the Soave-Redlich-Kwong (SRK) equation of state [9, 10] and the pressures and temperatures measured in the cylinder manifold during discharge. Details of this methodology are given in Appendix C. For the halocarbon agents, the industry standard practice defines the 95% discharge time by the inflection points on the nozzle pressure/time plots are, which indicate liquid agent runout. The 99.5% discharge times for all agents were defined as the time when the nozzle pressure dropped below 35 kPa. The use of these values for any approvals or listings is subject to the interpretation of the approving administration.

Due to variations in test set-ups and test objectives, the results of these tests will be discussed on a CRADA participant basis in the following sections. A complete set of data is found in Appendix D for each test.

10.1.1 Inergen Extinguishing Agent, Ansul CRADA, Ansul Hardware

The eight Inergen tests included five telltale and three large fire tests as shown in Table 5. The complete set of fire scenarios was conducted for a system containing a single 360° nozzle located in the center of the space using a short discharge time (nominally 60 seconds). These tests include: Fire Scenario 1 – Test #1, Fire Scenario 2B – Test #5, Fire Scenario 3 – Test #6, Fire Scenario 4 – Test #7, and Fire Scenario 5 – Test #2. Tests #3 and #8 evaluated a system with a longer discharge time (nominally 120 seconds) and Test #4 evaluated a system containing two 180° nozzles.

The system configurations evaluated during this investigation are shown in Figures 5 through 7 with the system parameters listed in Table 5. The longer pipe network used during the telltale tests was designed to reduce the minimum nozzle pressure.

The telltale fire tests were conducted with a 31.5% agent concentration. The results of these tests are shown in Table 6. The first test was conducted with the cylinders at ambient temperature and the remaining tests with low temperature conditioned cylinders. During the test conducted with the discharge cylinders at ambient temperature and a nominal 60 second discharge time (Test #1), all of the telltales were extinguished within 55 seconds of system activation. This was not the case when the test was repeated with the low temperature conditioned cylinders (Test #2). The low temperature conditioned cylinders resulted in longer extinguishment times with the extinguishment times increasing by 20 seconds on average. All of the telltales were extinguished during this test within 86 seconds of system activation. Two tests were also conducted with low temperature conditioned cylinders and a nominal 120 second discharge time (Test #3 and Test #8). During Test #3, all of the telltale fires were extinguished within 177 seconds of system activation. During Test #8, all the telltale fires were extinguished within 106 seconds of system activation. The remaining test consisted of low temperature conditioned cylinders and two 180° nozzles (Test #4). During this test all of the telltale fires were extinguished within 101 seconds of system activation.

Table 5. Ansul Inergen Test Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder		Manifold Orifice Area (mm ²)	Number of Nozzles	Nozzle				
					Vol. (l)	Temp.			Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
1	1	A-1	31.5	16	85.0	Ambient	475.3	1	360°	1480.9	100	10	5
2	5	A-2	31.5	16	85.0	Conditioned	475.3	1	360°	1480.9	100	10	5
3	5	A-2	31.5	16	85.0	Conditioned	273.2	1	360°	641.0	100	10	5
4	5	A-3	31.5	16	85.0	Conditioned	606.1	2	180°	791.3	50	10	5
5	2B	A-4	37.5	19	85.0	Ambient	791.3	1	360°	1288.4	100	10	5
6	3	A-4	37.5	19	85.0	Ambient	791.3	1	360°	1288.4	100	10	5
7	4	A-4	37.5	19	85.0	Ambient	791.3	1	360°	1288.4	100	10	5
8	5	A-5	31.5	16	85.0	Conditioned	300.7	1	360°	714.8	100	10	5

Table 6. Ansul Inergen Telltale Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration *			Avg. Nozzle Pressure	Dis. Time (sec)			Telltale Fire Extinguishment Time (sec)							
							60 sec (%)	300 sec (%)	600 sec (%)		85%	95%	99.5%	High				Low			
														Forward		Aft		Forward		AFT	
														Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd
1	1	A-1	1	360°	16	31.5	32.4	32.0	30.7	1462	41	73	87	47	5	45	28	51	55	11	5
2	5	A-1	1	360°	2	31.5	33.1	32.6	31.2	1413	42	74	87	48	51	19	42	72	54	64	86
3	5	A-2	1	360°	-15	31.5	31.3	31.0	30.0	1902	75	128	163	71	45	46	76	177	151	121	124
4	5	A-3	2	180°	-10	31.5	32.6	31.8	30.5	1623	36	63	78	71	17	101	46	57	18	12	41
8	5	A-5	1	360°	-4	31.5	35.5	34.8	33.0	1966	69	115	145	47	58	37	42	64	91	106	133

* Based on measured Oxygen Concentration

System A-4

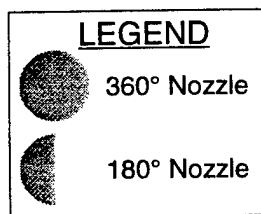
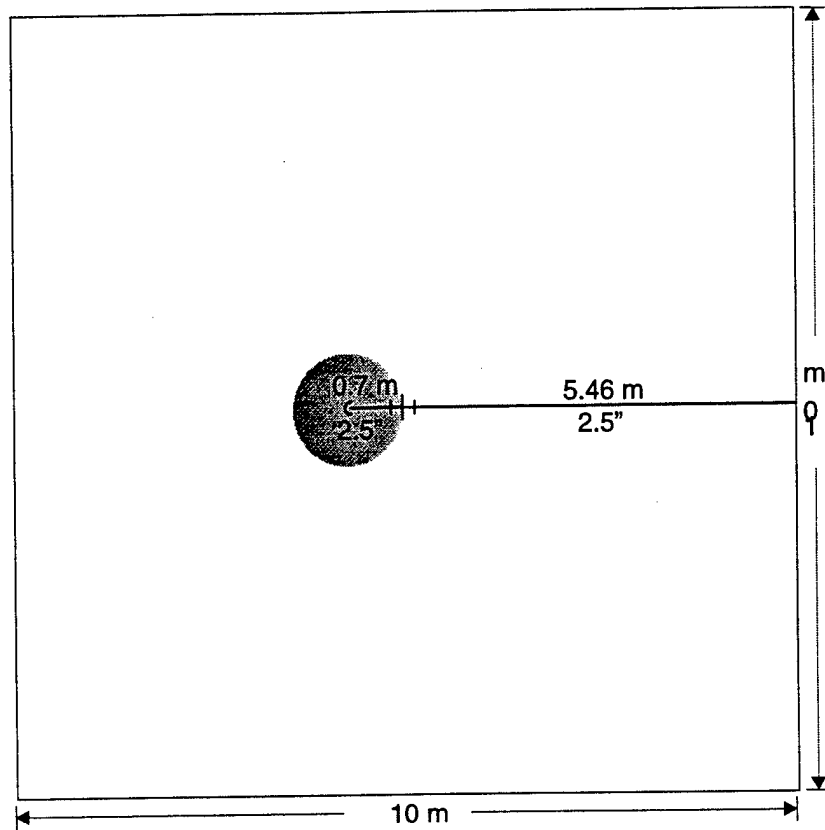


Figure 5. Ansul Inergen Telltale Fire Discharge System with 360° Nozzles (Short)

Systems A-1, A-2 and A-5

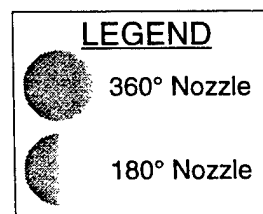
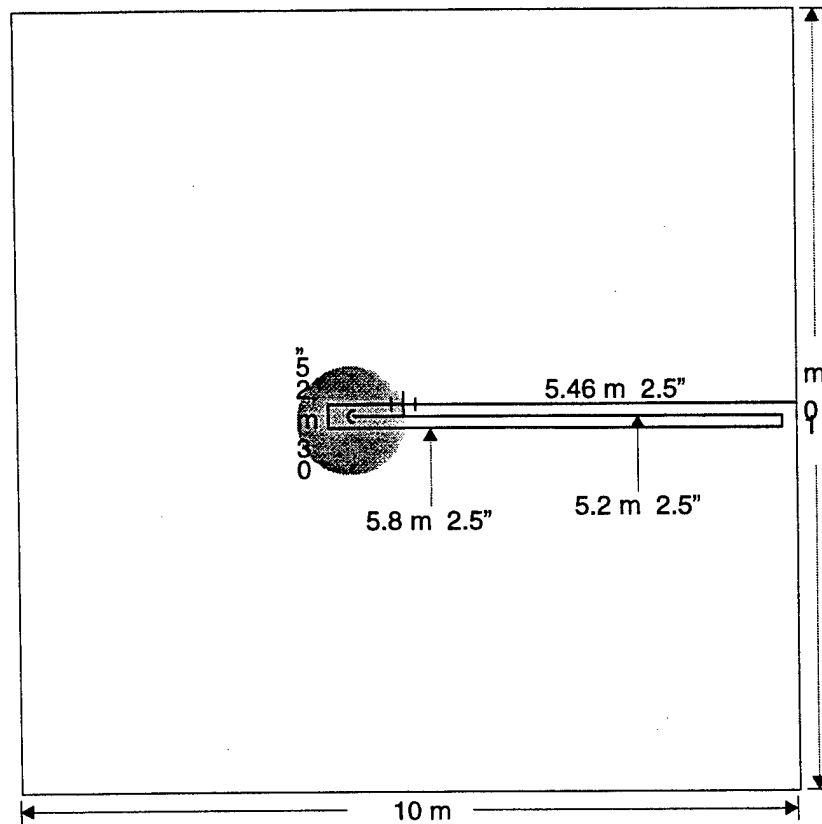


Figure 6. Ansul Inergen Telltale Fire Discharge System with 360° Nozzles (Long)

System A-3

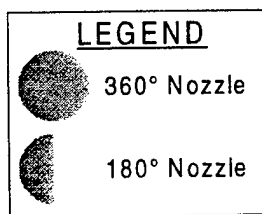
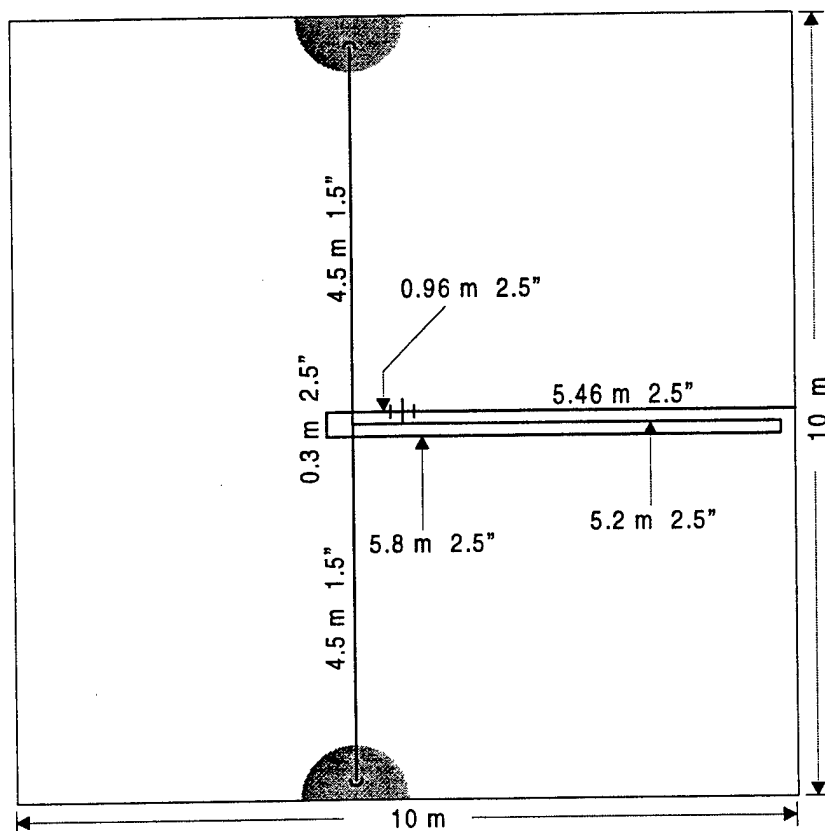


Figure 7. Ansul Inergen Telltale Fire Discharge System with 180° Nozzles

The large fire tests were conducted with a 37.5% agent concentration, which is 20% above the concentration used during the telltale fire tests. The results of these tests are shown in Table 7.

As shown in Table 7, Fire Scenarios 3 and 4 were extinguished early into the agent discharge suggesting that these fires were extinguished due to localized effects rather than a uniform homogeneous extinguishment concentration achieved throughout the space. The extinguishment times for Fire Scenario 2B were similar to the telltale extinguishment times. As expected, the smaller pan fire combination (Scenario 2B) added to the IMO test protocol after the initial investigation [2] proved to be the most challenging. The 0.25 m² heptane pan fire in Scenario 2B was extinguished 42 seconds after system activation while the smaller fire (0.1 m² heptane pan fire) was not extinguished until 74 seconds after system activation.

The machinery space was instrumented to measure the increase and/or decrease in compartment pressure resulting from the discharge of the agent. Due to the configuration of the exhaust stack damper/flapper and to problems associated with instrumentation, the compartment pressures recorded during these tests were not representative of an actual machinery space application. The concern associated with increases and/or decreases in compartment pressure still exists and should be considered when installing an inert gas system in a relatively air-tight machinery space.

10.1.2 NAF-SIII Extinguishing Agent, Ansul CRADA, North American Fire Guardian Technologies Hardware

Two tests were conducted under the Ansul CRADA using North American Fire Guardian's hardware and agent. During the previous investigation [2], a system containing two 360° nozzles successfully completed the IMO evaluation using ambient temperature cylinders. The objectives of these tests were to re-evaluate the system with cylinders conditioned to low temperatures. The discharge system used during these tests is shown in Figure 8 and was identical to one evaluated previously. The parameters for the system are given in Table 8.

Table 7. Ansul Inergen Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Design Conc. (%)	Agent Concentration *			Dis. Time (sec)			Fire 1		Fire 2		Fire 3		
						60 sec (%)	300 sec (%)	600 sec (%)	85%	95%	100%	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Mass Lost
5	2B	A-4	1	360°	37.5	41.1	40.7	39.4	34	59	76	0.25 m ² heptane	42	0.1 m ² heptane	74			
6	3	A-4	1	360°	37.5	58.5	56.3	53.4	34	59	77	2 m ² Diesel	7	1.1 MW Heptane Spray	9	Wood Crib	18	39.5%
7	4	A-4	1	360°	37.5	58.9	57.9	55.9	34	59	78	4 m ² Diesel	16					

* Based on measured Oxygen Concentration

Table 8. Ansul NAF-SIII Test Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder			Number of Nozzles	Nozzle				
					Fill Density (kg/m ³)	Vol. (l)	Temp.		Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
9	5	N-1	10	1	883	243	Conditioned	2	360°	1641.6	50	5	5
10	5	N-1	10	1	883	243	Conditioned	2	360°	1641.6	50	5	5

System N-1

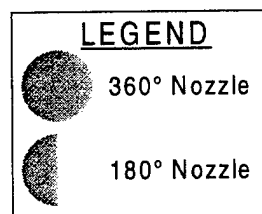
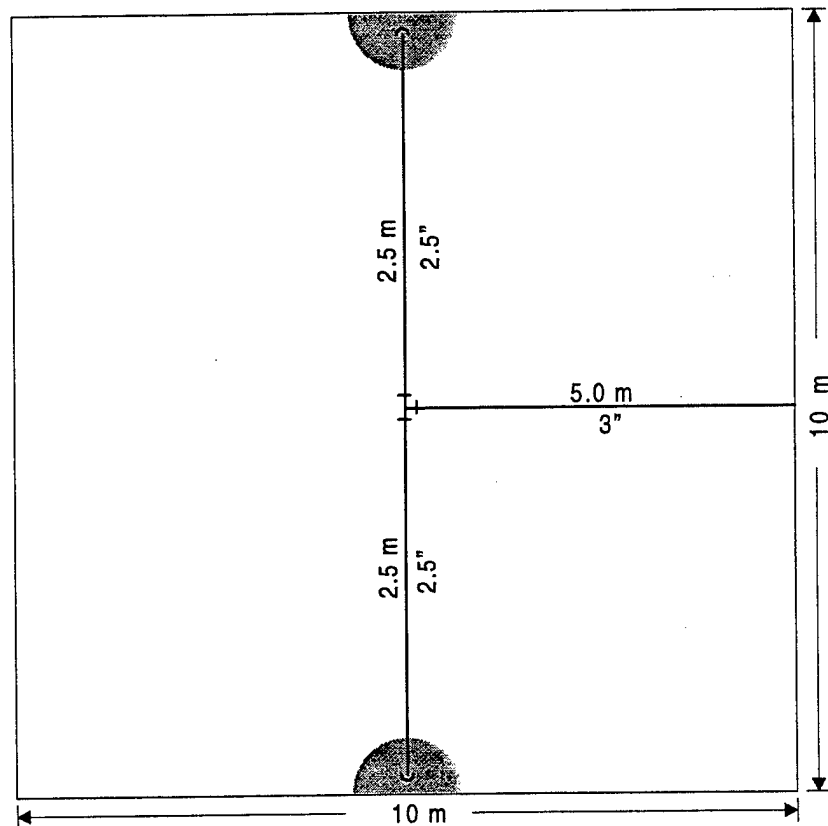


Figure 8. Ansul NAF-SIII Telltale Fire Discharge System

The tests were conducted with a 10% agent concentration. The results of these tests are shown in Table 9. The agent concentrations shown in this table were based on the oxygen concentrations measured in the space. As shown in this table, one telltale fire was not extinguished in each of the two tests. In the first test, with the cylinders conditioned to -20°C, the Low-Aft-Port telltale fire was not extinguished. In the second test, with the cylinders conditioned to 0°C, the High-Forward-Port telltale was not extinguished. The remaining telltale fires were all extinguished within 40 seconds of system activation in both tests.

The low cylinder temperature significantly affected the discharge characteristics of the system. The agent mixing characteristics of the system is primarily a function of the nozzle pressure during discharge. The lower cylinder temperature reduced the average nozzle pressures from 900 kPa as measured during the previous investigation to 300 kPa measured during these tests. Since low temperature cylinders are not currently included in the IMO test protocol, these tests were conducted to provide information on the effects low temperature condition cylinders have on the discharge characteristics of the system.

10.1.3 CEA-308 Extinguishing Agent, 3M CRADA, Tyco Electronic Product Group Hardware

The eight SEA-308 tests included two telltale and six large fire tests as shown in Table 10. The complete set of five fire tests was conducted for a system containing four 360° nozzles installed with a nominal 5.0 m nozzle spacing and an 8.5% design concentration. These tests include: Fire Scenario 1 – Test #11, Fire Scenario 2A – Test #20, Fire Scenario 3 – Test #16, Fire Scenario 4 – Tests #15 and #17 (Test #15 was repeated due to hardware problems which resulted in a longer discharge time), and Fire Scenario 5 – Test #12. The large fire tests were also repeated with a 9.0% design concentration in an attempt to reduce the production of decomposition products (Tests #13, #18, and #19).

Three discharge system configurations were included in this evaluation. These systems are illustrated in Figures 9 and 10 with the system parameters listed in Table 10.

Table 9. Ansul NAF-SIII Telltale Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration *			Avg. Nozzle Pressure	Dis. Time (sec)		Telltale Fire Extinguishment Time (sec)							
							60 sec (%)	300 sec (%)	600 sec (%)		95%	99.5%	High				Low			
													Forward		Aft		Forward		AFT	
													Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd
9	5	N-1	2	360°	-20	10	10.1	10.7	10.7	300	14.5	17	21	21	17	17	40	30	N/E	20
10	5	N-1	2	360°	0	10	10.8	11.1	11.1	390	12.5	16	N/E	4	10	11	20	20	28	4

* Based on measured Oxygen Concentration

Table 10. 3M CEA-308 System Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder			Number of Nozzles	Nozzle				
					Fill Density (kg/m ³)	Vol. (l)	Temp.		Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
11	1	T-1	6.5	3	622	147.0	20.0	4	360°	628.0	25	5	5
12	5	T-1	6.5	3	622	147.0	2.0	4	360°	628.0	25	5	5
13	3	T-2	9	3	888	147.0	20.0	4	360°	1607.7	25	5	5
16	3	T-3	8.5	3	833	147.0	20.0	4	360°	1061.3	25	5	5
17	4	T-3	8.5	3	833	147.0	20.0	4	360°	1061.3	25	5	5
18	4	T-2	9	3	888	147.0	20.0	4	360°	1607.7	25	5	5
19	2A	T-2	9	3	888	147.0	20.0	4	360°	1607.7	25	5	5
20	2A	T-3	8.5	3	833	147.0	20.0	4	360°	1061.3	25	5	5

System T-1

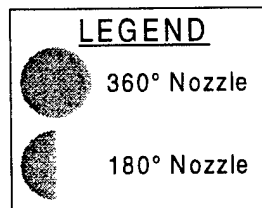
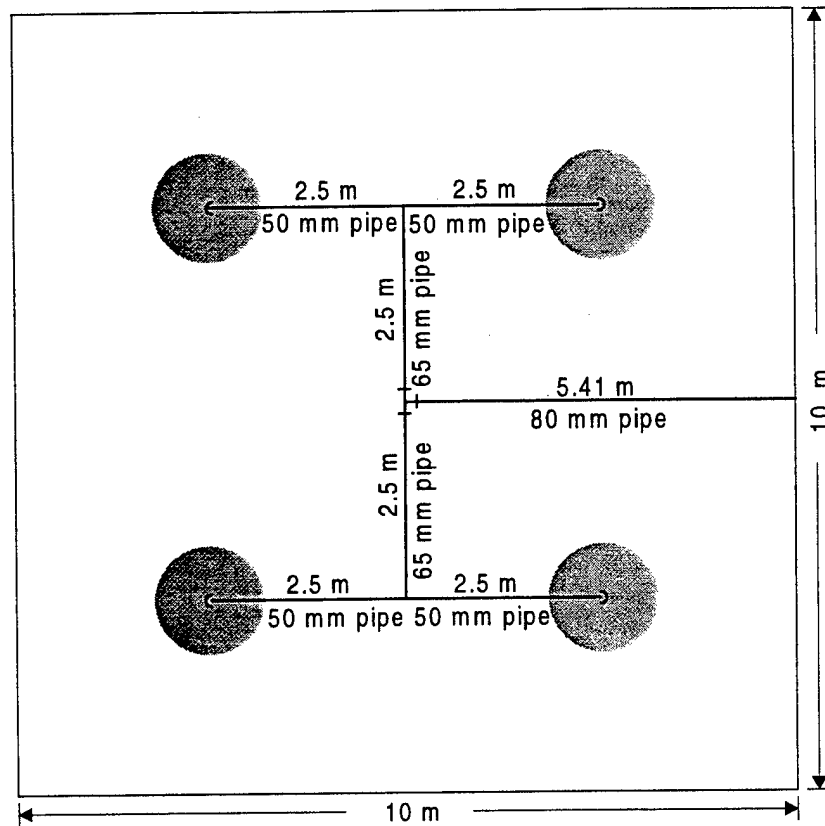


Figure 9. 3M CEA-308 Telltale Fire Discharge System

System T-2 and T-3

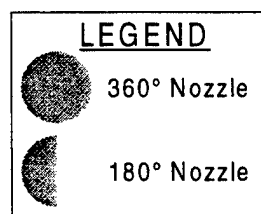
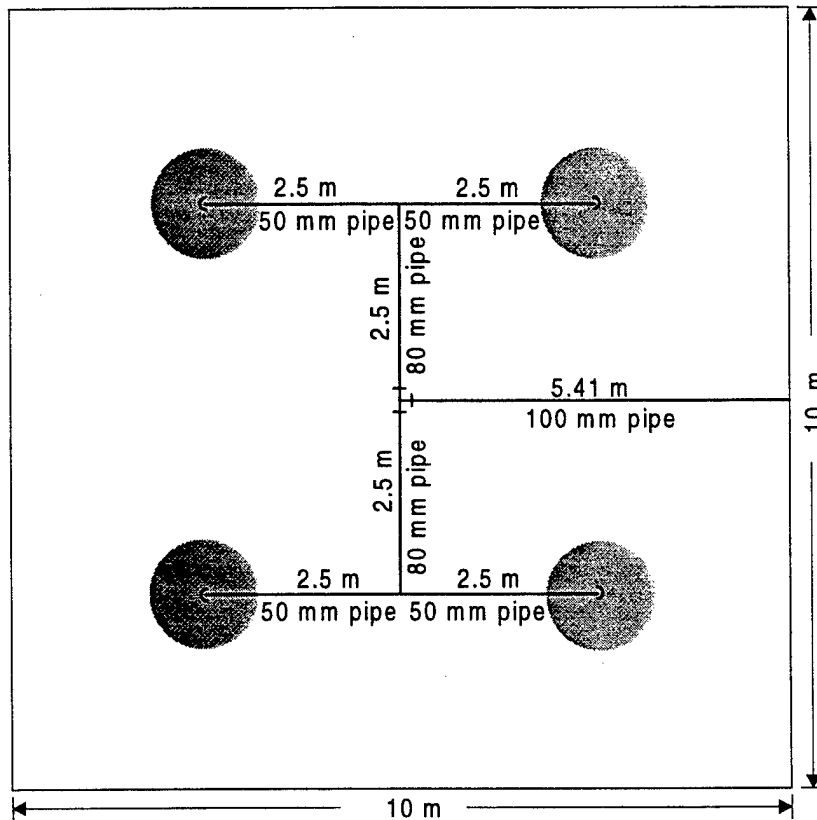


Figure 10. 3M CEA-308 Large Fire Scenario Discharge System

The telltale fire tests were conducted with a 6.5% agent concentration. The results of these tests are shown in Table 11. As shown in this table, all of the telltale fires were extinguished within 30 seconds of system activation. The decrease in cylinder temperature from 20°C to 2°C had little effect on the telltale fire extinguishment times.

The three large fire scenarios were conducted using two design concentrations, 8.5 % and 9.0 % by volume. These concentrations are nominally 30% and 40% above the concentration used during the telltale fire tests. The results for these tests are given in Table 12. As shown in this table, all of the fires were extinguished within the 20 seconds of system activation. The longest extinguishment times were observed for the 4 m² diesel pan in Scenario 4 and the wood crib in Scenario 3. These fires were both extinguished approximately 20 seconds after system activation.

The HF concentrations recorded during these tests follow the same trends found throughout the literature [2]. The average HF concentrations observed 300 seconds after extinguishment ranged from approximately 2500 to 4000 ppm for the 8.5% design concentration and 1600 to 3000 ppm for the 9.0% concentration. The use of the higher agent concentration reduced the amount of HF produced by an average of 30%.

10.1.4 FM-200 Extinguishing Agent, Factory Mutual Research Corporation CRADA, Sea-Fire and Hygood Hardware

Six tests were conducted under the Factory Mutual Research Corporation CRADA. These tests included three telltale and three large fire tests as shown in Table 13. The complete set of fire scenarios was conducted for a system containing four 360° nozzles installed with a nominal 5.0 m nozzle spacing. These tests include: Fire Scenario 1 – Test #21, Fire Scenario 2A – Test #24, Fire Scenario 3 – Test #23, Fire Scenario 4 – Test #25, and Fire Scenario 5 – Test #22. The system was then re-evaluated to include 180° nozzles in Test #26.

Three discharge system configurations were included in this evaluation. The discharge systems are illustrated in Figures 11 and 12 with the system parameters listed in Table 13.

Table 11. 3M CEA-308 Telltale Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration			Avg. Nozzle Pressure	Dis. Time (sec)		Telltale Fire Extinguishment Time (sec)							
							60 sec (%)	300 sec (%)	600 sec (%)		95%	99.5%	High				Low			
													Forward		Aft		Forward		AFT	
													Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd
11	1	T-1	4	360°	20	6.5	6.1	6.2	6.0	900.0	10	15	7	5	5	3	16	24	26	10
12	5	T-1	4	360°	2	6.5	6.2	6.2	6.0	700.0	10	15	10	7	5	6	23	20	30	18

Table 12. 3M CEA-308 Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Design Conc. (%)	Agent Concentration			Dis. Time (sec)		Fire 1		Fire 2		Fire 3			Avg. HF Concentration		
						60 sec (%)	300 sec (%)	600 sec (%)	95%	99.5%	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Mass Lost	60 sec (ppm)	300 sec (ppm)	600 sec (ppm)
20	2A	T-3	4	360°	8.5	8.7	9.1	8.7	11	14	0.25 m ² Heptane	12	5.8 MW Heptane Spray	3	1.8 MW Diesel Spray	3		4338	4158	3425
16	3	T-3	4	360°	8.5	8.5	9.1	7.9	11	14	2 m ² Diesel	5	1.1 MW Heptane Spray	15	Wood Crib	20	35.0%	2890	2509	1991
17	4	T-3	4	360°	8.5	8.8	8.7	8.5	11	14	4 m ² Diesel	16						3842	2932	2308
19	2A	T-2	4	360°	9.0	9.2	9.3	8.7	11	14	0.25 m ² Heptane	15	5.8 MW Heptane Spray	3	1.8 MW Diesel Spray	3		4120	3091	2533
13	3	T-2	4	360°	9.0	7.4	9.1	9	11	13	2 m ² Diesel	10	1.1 MW Heptane Spray	10	Wood Crib	20	40.0%	1531	1599	1353
18	4	T-2	4	360°	9.0	9.4	9.2	9.1	11	14	4 m ² Diesel	8						2338	2000	1812

Table 13. Factory Mutual Research Corporation FM-200 System Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder			Number of Nozzles	Nozzle				
					Fill Density (kg/m ³)	Vol. (l)	Temp.		Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
21	1	F-1	7.2	3	522	180.0	Ambient	4	360°	509.0	25	5	5
22	5	F-1	7.2	3	522	180.0	Conditioned	4	360°	509.0	25	5	5
23	3	F-2	8.7	3	640	180.0	Ambient	4	360°	1029.4	25	5	5
24	2A	F-2	8.7	3	640	180.0	Ambient	4	360°	1029.4	25	5	5
25	4	F-2	8.7	3	640	180.0	Ambient	4	360°	1029.4	25	5	5
26	1	F-3	7.2	3	522	180.0	Ambient	4	180°	538.8	25	5	5

System F-1 and F-2

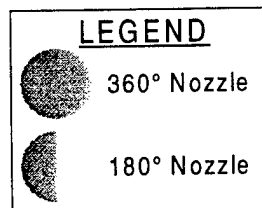
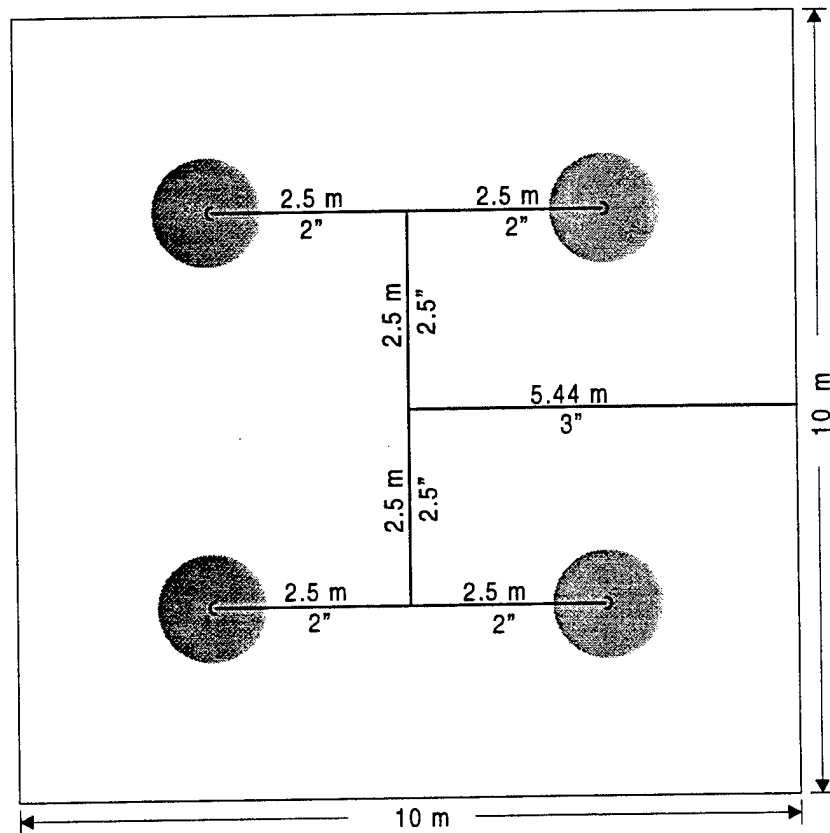


Figure 11. FMRC Sea-Fire Hygood Discharge System with 360° Nozzles

System F-3

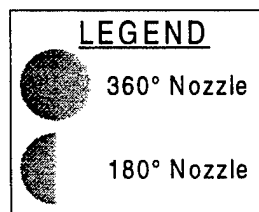
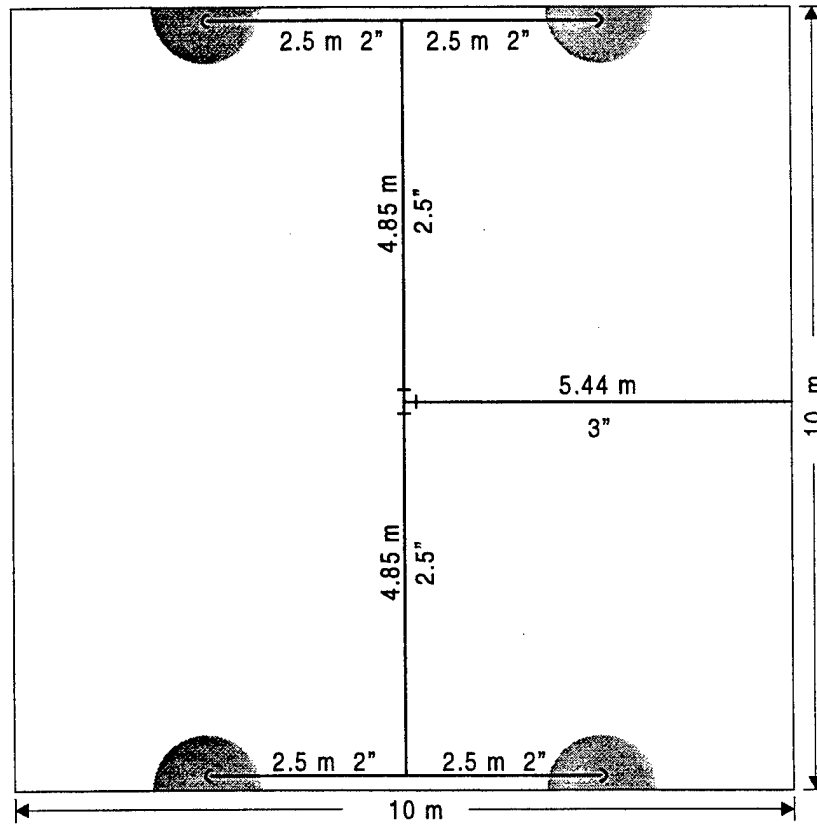


Figure 12. FMRC Sea-Fire Hygood Discharge System with 180° Nozzles

The telltale fire tests were conducted with a 7.2% agent concentration. The results of these tests are shown in Table 14. The telltales were extinguished within 25 seconds of system activation for all three tests. The cylinder temperature had little effect on the telltale fire extinguishment times for this system configuration. The extinguishment times for the 180° nozzles were similar to the 360° nozzles for the telltales located high in the space, but produced longer extinguishment times for the lower telltale fires. During the test conducted with the 180° nozzles, two additional telltales were added in the center of the compartment (one on top and one below the diesel engine mockup). During this test, the extinguishment times for the two additional telltales were similar to the telltales located in the corners of the space (i.e., within 24 seconds of system activation).

The large fire tests were conducted with an 8.7% design concentration, which is 20% higher than the concentration used during the telltale fire tests. The results of these tests are shown in Table 15. As shown in this table, all of the test fires were extinguished within 11 seconds of system activation.

The HF concentrations recorded during these tests follow the same trends found throughout the literature [2]. The average HF concentrations observed 300 seconds after extinguishment ranged from 2200 to 5000 ppm.

10.1.5 FM-200 Extinguishing Agent, Kidde-Fenwal CRADA, Kidde-Fenwal Hardware

During the previous investigation [2], a Kidde-Fenwal system containing four 360° nozzles installed with a nominal 5.0 m nozzle spacing successfully completed the IMO test protocol. During these tests, the system was re-evaluated using a variety of nozzles and configurations and with low temperature conditioned cylinders.

There were six tests conducted under the Kidde-Fenwal CRADA. All six tests were telltale fire tests with four of these tests conducted with low temperature conditioned cylinders as shown in Table 16. Test #27 re-evaluated the initial system using low temperature conditioned cylinders.

Table 14. Factory Mutual Research Corporation FM-200 Telltale Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration			Avg. Nozzle Pressure	Dis. Time (sec)		Telltale Fire Extinguishment Time (sec)								Center	
							60 sec (%)	300 sec (%)	600 sec (%)		95%	99.5%	High				Low					
													Forward		Aft		Forward		AFT			
													Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd		
																					Port	Stbd
21	1	F-1	4	360°	20	7.2	7.8	7.5	7.2	1100.0	9.25	15	18	22	2	2	12	5	2	10		
22	5	F-1	4	360°	-6	7.2	7.8	7.5	7.2	825.0	9.25	15	8	25	1	2	15	11	8	8		
26	1	F-3	4	180°	20	7.2	7.7	7.8	7.4	1100.0	9.5	15	24	12	8	8	17	21	17	16	4	14

Table 15. Factory Mutual Research Corporation FM-200 Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Design Conc. (%)	Agent Concentration			Dis. Time (sec)		Fire 1		Fire 2		Fire 3			Avg. HF Concentration		
						60 sec (%)	300 sec (%)	600 sec (%)	95%	99.5%	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Mass Lost	60 sec (ppm)	300 sec (ppm)	600 sec (ppm)
23	3	F-2	4	360°	8.7	8.9	9.2	8.8	10	15	2 m ² Diesel	8	1.1 MW Heptane Spray	8	Wood Crib	3	38.0 %	5026	4217	
24	2A	F-2	4	360°	8.7	9.2	9.4	8.9	10	15	0.25 m ² Heptane	11	5.8 MW Heptane Spray	4	1.8 MW Heptane Spray	4		2856	2332	
25	4	F-2	4	360°	8.7	9.1	9.1	8.7	10	15	4 m ² Diesel	8						2492	2237	1943

Table 16. Kidde-Fenwal FM-200 Test Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder			Number of Nozzles	Nozzle				
					Fill Density (kg/m ³)	Vol. (l)	Temp.		Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
27	5	K-1	6.7	2	923	142	Conditioned	4	360°	569.8	25	5	5
28	5	K-2	6.7	2	923	142	Conditioned	2	360°	831.8	50	5	5
29	5	K-3	6.7	2	923	142	Conditioned	2	180° *	603.7	50	10	5
30	1	K-3	6.7	2	923	142	Ambient	2	180° *	603.7	50	10	5
31	5	K-4	6.7	2	923	142	Conditioned	2	180°	831.8	50	10	5
32	1	K-4	6.7	2	923	142	Ambient	2	180°	831.8	50	10	5

* Back-to-back nozzle configuration in center of compartment.

Test #28 evaluated a system containing two 360° nozzles with twice the area coverage. Tests #29 and #30 evaluated an innovative design consisting of two back-to-back 180° nozzles and, Tests #31 and #32 evaluated these two 180° nozzles using a conventional installation (nozzles installed adjacent to compartment boundaries).

The four Kidde-Fenwal discharge system configurations included in this test series are shown in Figures 13 through 16 with the system parameters listed in Table 16.

All tests were conducted with a 6.7% agent concentration. The results of these tests are listed in Table 17. As shown in this table, all of the telltale fires were extinguished within 28 seconds of system activation with the exception of Test #29. During Test #29 (low temperature conditioned cylinders and back-to-back 180° nozzles), the high-aft-port telltale was not extinguished until 44 seconds after system activation. In comparison of the two systems utilizing 360° nozzles, the two nozzle system extinguished the telltale fires almost twice as fast as the four nozzle system (on an average 6 seconds versus 12 seconds from system activation).

Unlike the previous two CRADA participants, the lower cylinder temperature significantly affected the discharge characteristics of the Kidde-Fenwal system. This was probably the result of the higher cylinder fill densities used by Kidde-Fenwal during these tests. For the two sets of tests that were conducted using both ambient and low temperature conditioned cylinders, the average nozzle pressure was reduced by over 25%. These lower pressures resulted in longer extinguishment times for the tests conducted with 180° nozzles installed back-to-back but had little effect on the extinguishment times when the 180° nozzles were installed adjacent to the bulkhead. The effects of reduced cylinder temperatures will also be discussed in Section 9.2.2 of this report.

10.1.6 FM-200 Extinguishing Agent, Chemetron CRADA, Chemetron Hardware

Seven tests were conducted under the Chemetron CRADA. These tests included four telltale and three large fire tests as shown in Table 18. The complete set of fire scenarios was conducted for a system containing four 360° nozzles installed with a nominal 5.0 m nozzle spacing. These tests include:

System K-1

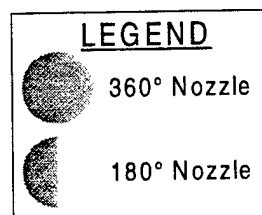
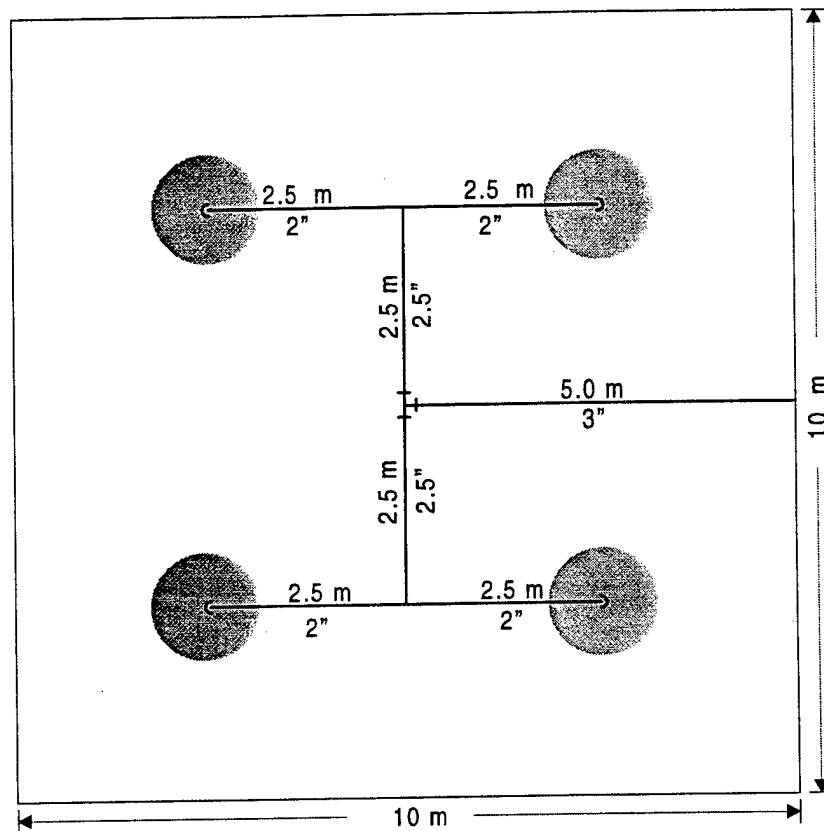


Figure 13. Kidde-Fenwal Discharge System with Four 360° Nozzles

System K-2

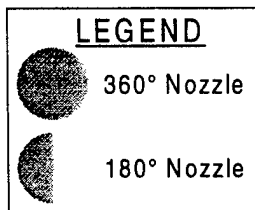
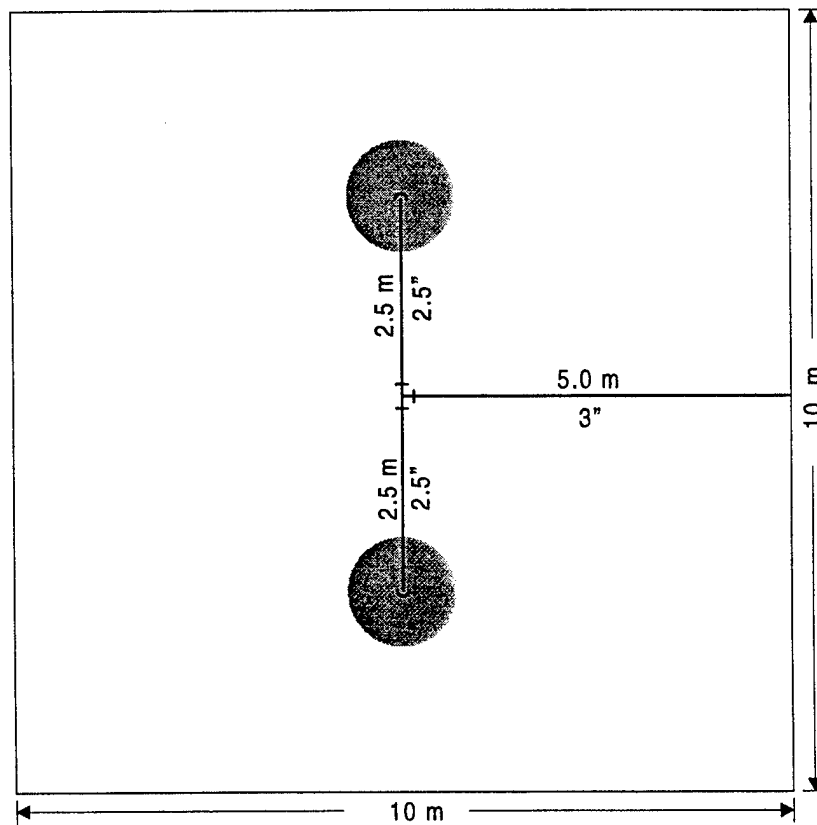


Figure 14. Kidde-Fenwal Discharge System with Two 360° Nozzles

System K-3

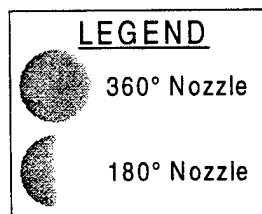
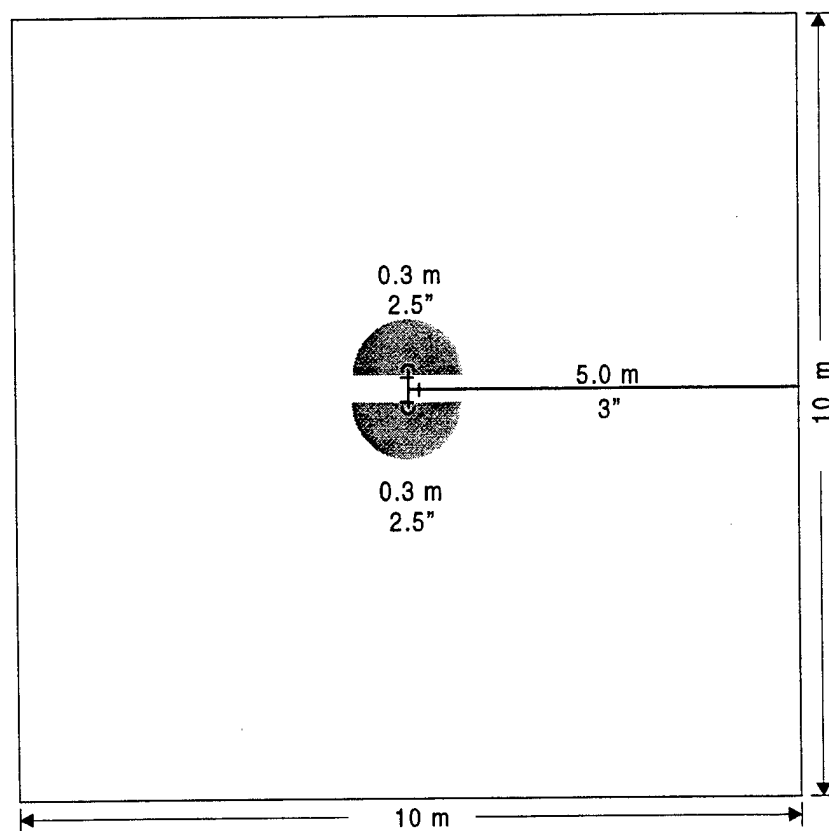


Figure 15. Kidde-Fenwal Discharge System with Back-to-Back 180° Nozzles

System K-4

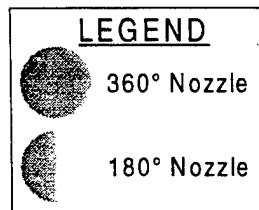
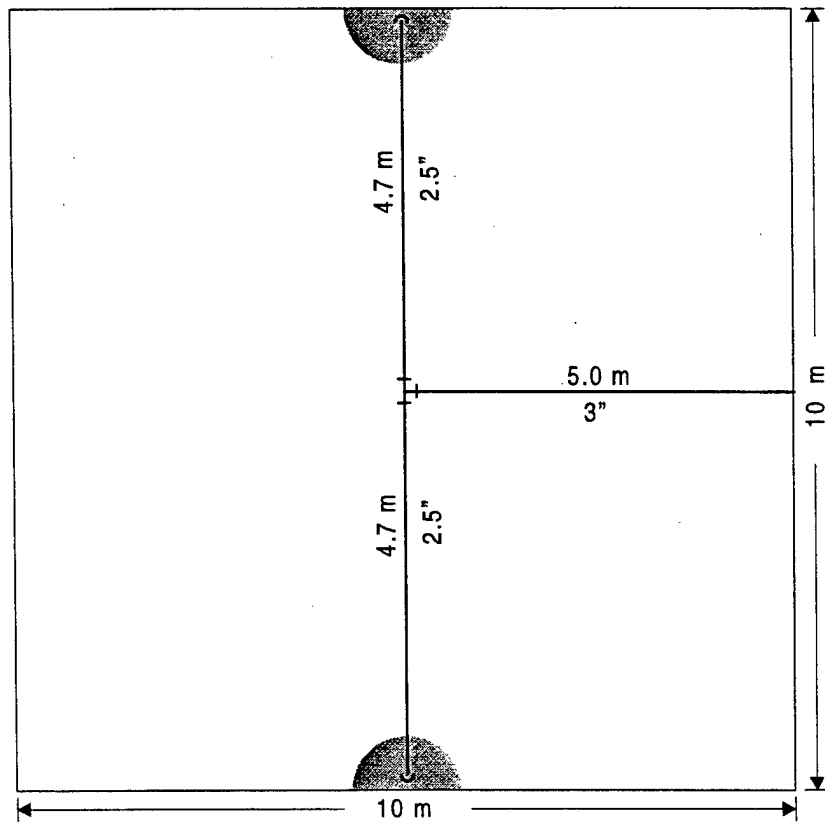


Figure 16. Kidde-Fenwal Discharge System with Bulkhead 180° Nozzles

Table 17. Kidde-Fenwal FM-200 Telltale Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration			Avg. Nozzle Pressure	Dis. Time (sec)		Telltale Fire Extinguishment Time (sec)							
							60 sec (%)	300 sec (%)	600 sec (%)		95%	99.5%	High				Low			
													Forward		Aft		Forward		AFT	
													Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd
27	5	K-1	4	360°	0	6.7	7.3	7.5	7.2	435	11.5	15	8	3	9	5	26	17	15	10
28	5	K-2	2	360°	1	6.7	6.7	7.0	6.8	475	11.5	15	8	9	6	3	13	5	4	3
29	5	K-3	2	180°	0	6.7	6.9	7.1	6.9	510	12	15	14	5	44	5	32	16	8	7
30	1	K-3	2	180°	21	6.7	7.0	7.1	6.9	700	11	15	11	8	8	8	28	11	3	6
31	5	K-4	2	180°	0	6.7	6.7	6.9	6.8	450	11.5	15	5	4	5	8	14	4	4	6
32	1	K-4	2	180°	20	6.7	6.8	7.0	6.8	625	11	14	6	5	5	3	18	5	3	5

Table 18. Chemetron FM-200 Test Parameters

Test #	Fire Scenario	System	Design Conc. (%)	Number of Cylinders	Cylinder			Number of Nozzles	Nozzle				
					Fill Density (kg/m ³)	Vol. (l)	Temp.		Type	Orifice Area (mm ²)	Coverage Area (m ²)	Spacing (m)	Height (m)
33	1	C-1	6.7	2	586	222	Ambient	4	360°	603.7	25	5	5
34	5	C-1	6.7	2	586	222	Conditioned	4	360°	603.7	25	5	5
35	2A	C-2	8.7	2	779	222	Ambient	4	360°	569.8	25	5	5
36	3	C-3	8.7	2	779	222	Ambient	4	360°	831.8	25	5	5
37	4	C-3	8.7	2	779	222	Ambient	4	360°	831.8	25	5	5
38	5	C-4	6.7	2	586	222	Conditioned	2	360°	831.8	50	5	5
39	5	C-5	6.7	2	586	222	Conditioned	2	180°	831.8	50	5	5

* Back-to-back nozzle configuration in center of compartment.

Fire Scenario 1 – Test #33, Fire Scenario 2A – Test #35, Fire Scenario 3 – Test #36, Fire Scenario 4 – Test #37, and Fire Scenario 5 – Test #34. Test #38 evaluated a system containing two 360° nozzles with greater area coverage, and Test #39 evaluated a system consisting of two 180° nozzles.

Five discharge system configurations were included in this evaluation. These systems are illustrated in Figures 17 through 19, with the corresponding parameters given in Table 18. It should be noted that during the evaluation of the 180° nozzles, the nozzles were installed adjacent to a single bulkhead as shown in Figure 19, rather than adjacent to opposing bulkheads as was done with other CRADA participants.

The telltale fire tests were conducted with a 6.7% agent concentration. The results of these tests are shown in Table 19. As shown in this table, all telltale fires were extinguished within 25 seconds of system activation. On an average, the extinguishment times were similar between system configurations. The low-forward-starboard telltale was the last fire extinguished using the four 360° nozzle system, while the high-forward-port was the last fire extinguished using either the two 360° nozzle or two 180° nozzle configurations. The low temperature conditioned cylinders had little effect on the extinguishment times for the telltale fires.

The large fire tests were conducted with a 8.7% design concentration, which is 30% higher than the concentration used during the telltale fire tests. The results of these tests are given in Table 20. After Test #35, the nozzle orifice sizes were increased in order to decrease the discharge time to below 10 seconds. Although the discharge time during Test #35 was slightly longer than that required by IMO (11.5 seconds versus 10 seconds), the test was not repeated due to the short extinguishment times observed during the test. The assumption was made that a shorter discharge time would only increase the fire suppressing capabilities of the system. During these tests, all of the fires were extinguished within 15 seconds of system activation.

The HF concentrations recorded during these tests follow the same trends found throughout the literature [2]. The average HF concentrations observed 300 seconds after extinguishment ranged from 1600 to 3400 ppm.

Systems C-1, C-2 and C-3

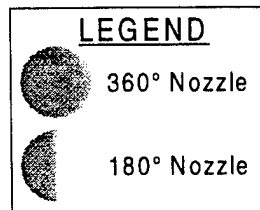
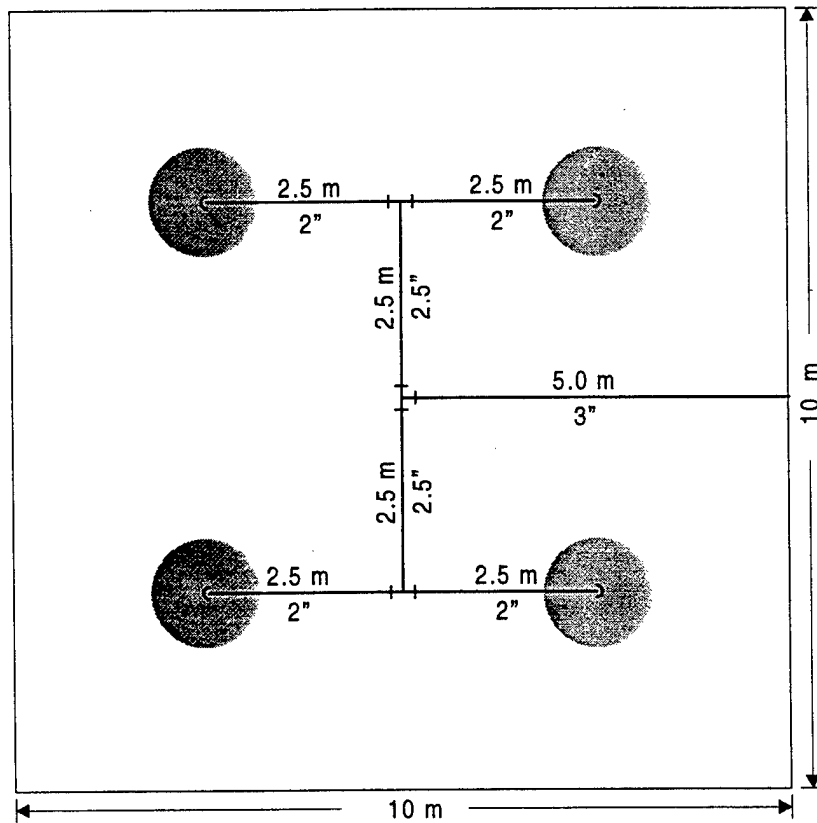


Figure 17. Chemetron Discharge System with Four 360° Nozzles

System C-4

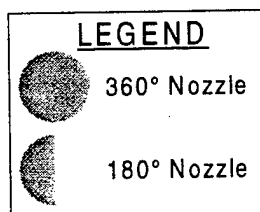
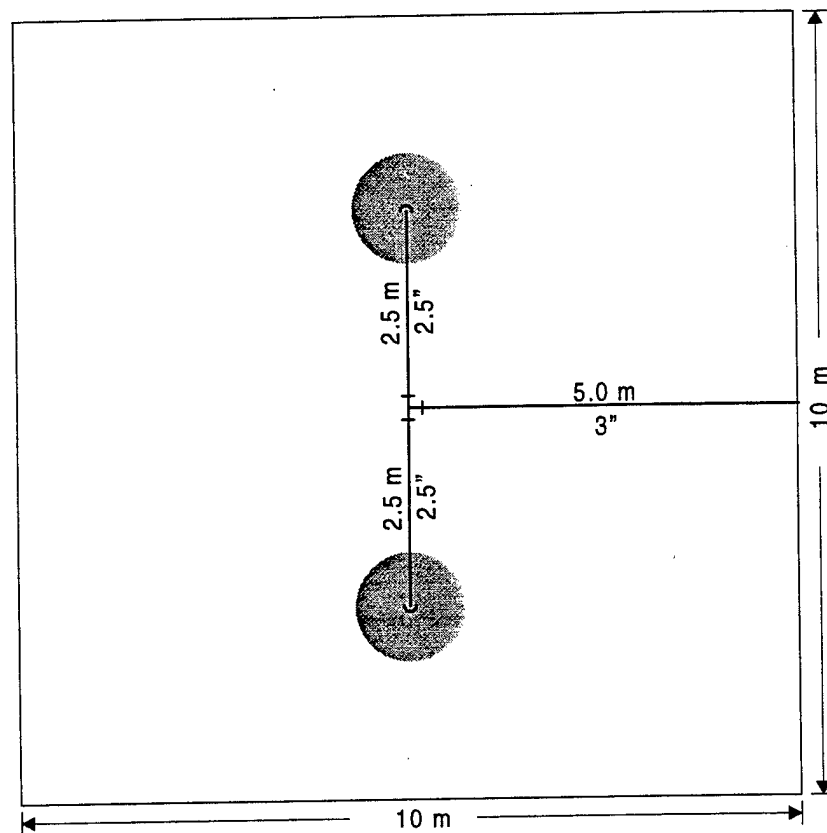


Figure 18. Chemetron Discharge System with Two 360° Nozzles

System C-5

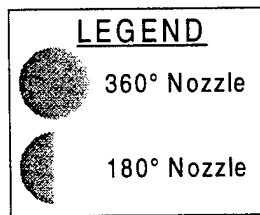
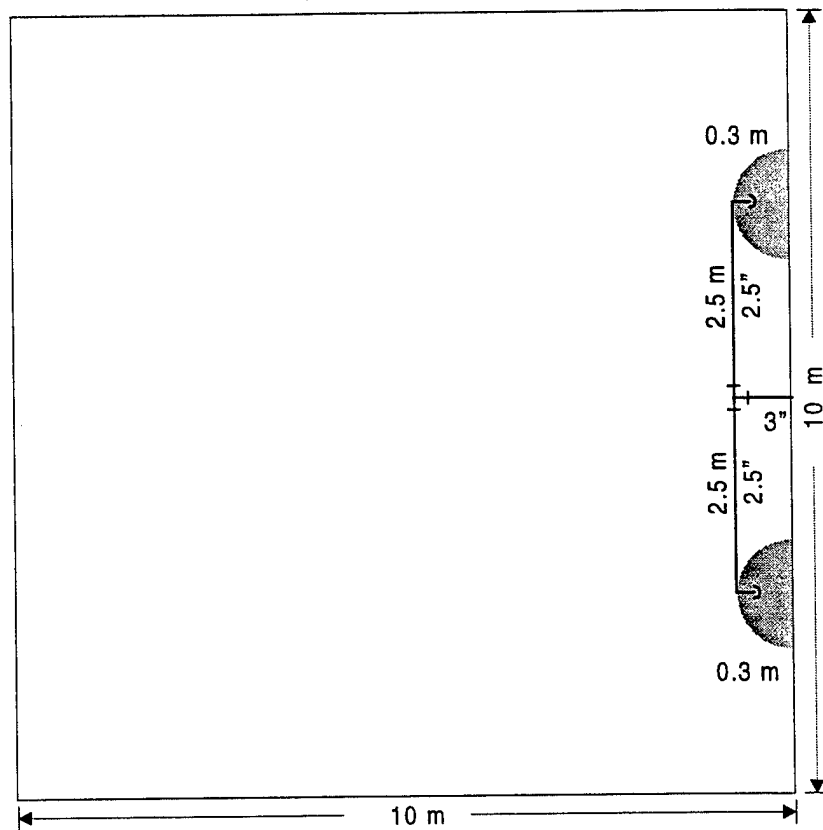


Figure 19. Chemetron Discharge System with Bulkhead 180° Nozzles

Table 19. Chemetron FM-200 Telltale Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Cylinder Temp. (C)	Design Conc. (%)	Agent Concentration			Avg. Nozzle Pressure	Dis. Time (sec)		Telltale Fire Extinguishment Time (sec)							
							60 sec (%)	300 sec (%)	600 sec (%)		95%	99.5%	High				Low			
													Forward		Aft		Forward		AFT	
													Port	Stbd	Port	Stbd	Port	Stbd	Port	Stbd
33	1	C-1	4	360°	18	6.7	7.5	7.1	6.8	975	8	14	6	5	6	8	18	19	10	9
34	5	C-1	4	360°	0	6.7	7.3	7	6.8	825	8	14	5	6	9	5	15	17	12	10
38	5	C-4	2	360°	-2	6.7	6.9	6.9	6.7	1075	9	15	22	12	8	8	11	12	11	5
39	5	C-5	2	180°	-2	6.7	7.9	7.4	7.0	1150	9	15	25	20	3	3	10	5	2	6

Table 20. Chemetron FM-200 Fire Test Results

Test #	Fire Scenario	System	Nozzles	Type	Design Conc. (%)	Agent Concentration			Dis. Time (sec)		Fire 1		Fire 2		Fire 3				Avg. HF Concentration			
						60 sec (%)	300 sec (%)	600 sec (%)	95%	99.5%	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Description	Ext. Time (sec)	Mass Lost	60 sec (ppm)	300 sec (ppm)	600 sec (ppm)		
35	2A	C-2	4	360°	8.7	8.7	9.2	8.9	11.5	16	0.25 m ² Heptane	15	5.8 MW Heptane Spray	5	1.8 MW Heptane Spray	5		3916	3429	2715		
36	3	C-3	4	360°	8.7	8.9	9.3	9.0	10	14	2 m ² Diesel	10	1.1 MW Heptane Spray	15	Wood Crib	10	41.0 %	2981	3012	2689		
37	4	C-3	4	360°	8.7	9.4	9.3	9.2	10	14	4 m ² Diesel	12						1755	1579	1459		

10.1.7 Test Summary

The systems evaluated during this investigation are summarized in Table 21. Also, included in this table are the relevant design parameters of each system.

Table 21. System Summary

CRADA Participant	Hardware	Agent	Design Conc. (%)	Number of Nozzles	Nozzle Type	Coverage Area (m ²)	Height (m)	Avg. Nozzle Pressure (kPa)
Ansul, Inc.	Ansul	Inergen	37.5	1	360°	100	5	943
Ansul, Inc.	Ansul	Inergen	37.5	2	180°	50	5	1062
Ansul, Inc.	Ansul	NAF-SIII	10	2	360°	50	5	300
3M	TEPG/3M	CEA-308	8.5	4	360°	25	5	900
FMRC	Hygood/Sea-Fire	FM-200	8.7	4	360°	25	5	1100
FMRC	Hygood/Sea-Fire	FM-200	8.7	4	180°	25	5	1100
Kidde-Fenwal	Kidde-Fenwal	FM-200	8.7	2	360°	50	5	475
Kidde-Fenwal	Kidde-Fenwal	FM-200	8.7	2	180° *	50	5	700
Kidde-Fenwal	Kidde-Fenwal	FM-200	8.7	2	180°	50	5	625
Chemetron	Chemetron	FM-200	8.7	4	360°	25	5	975
Chemetron	Chemetron	FM-200	8.7	2	360°	50	5	1075
Chemetron	Chemetron	FM-200	8.7	2	180°	50	5	1150

* Nozzles installed back-to-back.

Each of the five CRADA participants was evaluated using systems that contained 360° nozzles. Four CRADA participants (Ansul, FMRC/Sea-Fire, Kidde-Fenwal, and Chemetron) were also evaluated using systems containing 180° nozzles. All five CRADA participants were evaluated using systems that contained low temperature conditioned cylinders. The fire extinguishment capabilities of these systems were discussed in previous sections of this report. The use of this data for any approvals or listings require interpretation of the approving administration.

10.2 IMO Protocol Evaluation

This evaluation of the IMO test protocol focused on three key issues: the use of 180° nozzles, the effects of low agent cylinder temperatures, and on inert gas extinguishing agents. These issues will be discussed separately in the following sections of this report.

10.2.1 Variations in Nozzle Types

The 180° nozzles were fairly evaluated by the protocol and produced similar results to the 360° nozzles. The successful extinguishment of the two additional telltales located in the center of the space, added during one of the tests involving 180° nozzles, strengthens this test in terms of ensuring that the agent is distributed evenly throughout the space. As stated in the previous investigation [2], two additional telltales should be added in the center of the space (on top of and under the engine mockup). Based on the results of these tests, when changing nozzle types or nozzle spacings, additional large fire tests beyond the telltale test should not be required.

10.2.2 Low Temperature Conditioned Cylinders

The effects of low temperature discharge cylinders varied from system-to-system and were observed to be system parameter dependent. The discharge characteristics (i.e., discharge times and nozzle pressures) for all of the halocarbon agents were significantly affected by the low temperature conditioned cylinders. The low temperature conditioned cylinders had the greatest effect on the nozzle pressure of the system. Reducing the cylinder temperature by 25 C typically resulted in a decrease in nozzle pressure on the order of 20%. The magnitude of the reduction appears to be related to the fill density of the cylinders. The greatest impact was observed for the cylinders with the highest fill densities. The nozzle pressures for the inert gas (Inergen) were relatively unaffected by the lower cylinder temperatures.

Although the nozzle pressures were affected by the reduction in cylinder temperature, for a majority of the systems tested, the fire extinguishment times were not significantly affected. For example, the 3M, FMRC/Sea-Fire, and Chemetron system extinguishing times were largely unaffected by the change in temperature/pressure. However, other systems were significantly

affected. The North American Fire Guardian system using low temperature conditioned cylinder was unable to extinguish all eight telltale fires. Although the nozzle pressures and discharge times were unaffected by the reduction in temperature for the inert gas (Inergen.), the extinguishment times increased on average by over 20 seconds. The Kidde-Fenwal systems produced mixed results.

The variations in firefighting capabilities observed during the low temperature conditioned cylinder tests define the need for the inclusion of this test in the protocol or for a better understanding of how low temperatures effect the discharge characteristics of the system. There are at least two approaches to this problem.

The first approach is to include a low temperature conditioned cylinder test in the IMO test protocol and have the system parameters included in the test define the design parameters for the system. These design parameters include: maximum cylinder fill density, maximum percent agent in the pipe, and the minimum cylinder temperature.

Another approach is to modify the flow programs used to design these systems to allow the cylinder temperature to be input as a design parameter. Using these programs, the systems could then be designed to meet or exceed the minimum nozzle pressure defined during the telltale fire test (Fire Scenario 1) for the minimum expected cylinder temperature.

Although these two approaches form a sound basis for this evaluation, a systematic parameter study is required to identify the design parameters associated with these variations.

10.2.3 "Inert" Gaseous Agents

The lack of a definition for the end of agent discharge prevented the data collected during these tests to be interpreted in terms of pass or fail. In general, the "inert" gas was capable of extinguishing all of the telltale fires in less than 180 seconds and all of the large fires in less than 75 seconds of system activation. The interpretation of these results is the responsibility of the approving administration.

The protocol needs to be revised to include a definition for the end of agent discharge, independent of the type of extinguishing agent (i.e., halocarbon or inert gas). If the intent was to use the discharge time definition, a uniform 95% mass delivered to the space should be used for the inert gases as well as for the halocarbons. If this was not the intent, the end of agent discharge needs to be defined as well as a technique for measuring it during the test.

11.0 SUMMARY

Each of the five CRADA participants (Ansul, 3M, Kidde-Fenwal, FMRC/Sea-Fire, and Chemetron) were evaluated using systems produced with 360° nozzles. Four CRADA participants (Ansul, Kidde-Fenwal, FMRC/Sea-Fire, and Chemetron) were also evaluated using systems containing 180° nozzles. All five CRADA participants were evaluated using systems that contained low temperature conditioned cylinders. Due to a lack of a definition, of the end of agent discharge, the results of these tests require interpretation.

The addition of a new nozzle type (i.e., 180° nozzles) or nozzle spacing was fairly evaluated by the protocol using a single telltale fire test (Fire Scenario 1). Additional large fire tests should not be required.

The effects of the low temperature discharge cylinders varied from system-to-system and were observed to be system parameter dependent (i.e., fill density and percent agent in pipe). The protocol needs to be revised to include provisions for evaluating systems that have agent storage cylinders located in unconditioned spaces. Due to the lack of a general understanding on how the various design parameters effect the discharge characteristics of the system, a systematic study was recommended to bound the problem.

The lack of a definition for the end of agent discharge prevented a quantitative analysis of the firefighting capabilities/performance of the inert gas Inergen. During these tests, Inergen was capable of extinguishing all of the telltale fires in less than 180 seconds and all the large fires in less than 75 seconds of system activation.

12.0 RECOMMENDATIONS.

During the initial evaluation of the IMO test protocol [2], a number of potential improvements to the protocol were identified. A limited number of these improvements were included during the last revision. The remaining improvements should still be considered. These improvements include:

Minimize the oxygen depletion that occurs during the preburn of the large fires by either reducing the fire size(s) or increasing the compartment ventilation during preburn.

Add additional telltale fires in the center of the space (at a minimum one on top of the engine mockup and one in the bilge).

Obstruct, baffle, or relocate the spray fires located on top of the engine mockup in Fire Scenario 2A.

Modify the test protocol to include an energetic long duration re-ignition source in Fire Scenario 3.

Increase the ventilation to the bilge to prevent Fire Scenario 4 from becoming ventilation limited during preburn.

It is recommended, based on this evaluation, that the IMO test protocol be revised to include a uniform definition of discharge time based upon 95% of the agent having been delivered to the protected space. This definition should serve as both the measure of discharge time and the end of agent discharge.

If it is problematic to measure the 95% discharge time, the extinguishment time requirements can be measured from system activation. For example, halocarbon agents may be required to extinguish all the test fires within 40 seconds of system activation. Inert gases may

be required to extinguish all test fires within 150 seconds of system activation. The extinguishment time requirements should be determined by the IMO.

Provision should also be added to the protocol for evaluating systems that have agent cylinders located in unconditioned spaces.

13.0 U.S. COAST GUARD'S INTERPRETATION OF THE RESULTS

Upon completion of the tests conducted with Inergen, Ansul requested a written interpretation of the IMO test requirements (MSC/CIRC 776) from Coast Guard Headquarters (Life Saving and Fire Safety Standards Division). Ansul specifically requested an interpretation of the discharge time requirements and the definition of the end of agent discharge. The Coast Guard's response is found in Appendix E.

The letter from the Coast Guard states that the discharge time requirements in paragraph 4 of the IMO test protocol are self explanatory and do not need further interpretation (i.e., 85% of the agent must be delivered to the space in 120 seconds or less). The Coast Guard does however, agree that the definition of the end of agent discharge is somewhat vague. The Coast Guard interprets the end of agent discharge as the time when there is "no substantial flow from the nozzles" or "when the first nozzle stops discharging," whichever comes first. This infers that all of the agent has been delivered to the space.

Using the Coast Guard's interpretation for the end of agent discharge, the results of these tests can be qualified with respect to meeting the IMO requirements. To consistently apply this interpretation to the various agents, the end of agent discharge has been defined as when the nozzle pressure drops below 35 kPa. This time is shown in the various tables as the 99.5% discharge time. In order to meet the IMO test requirements, all of the test fires must be extinguished within 30 seconds of this time.

13.1 Inergen Extinguishing Agent, Ansul CRADA, Ansul Hardware

All eight tests conducted using Inergen were extinguished within the time requirements stated in the IMO test protocol. In a majority of the telltale fire tests, the telltale cups were extinguished during agent discharge. During two of the tests, the telltale cups were not extinguished until after discharge was complete. Both of these tests were conducted with low temperature conditioned cylinders. All of the large fires were also extinguished before the end of agent discharge. In summary, the extinguishing agent Inergen discharged through a system produced with Ansul hardware successfully completed the IMO test protocol with a system containing one 360° nozzle and a design concentration of 37.5%. A two nozzle system design (two 180° nozzles) also met the IMO requirements by successfully extinguish the telltale fire test (Fire Scenario 1).

13.2 CEA-308 Extinguishing Agent, 3M CRADA, TEPG Hardware

All eight tests conducted using CEA-308 were extinguished within the time requirements stated in the IMO test protocol. All of the fires (large fires and telltales) were extinguished within 15 seconds of the end of agent discharge. In summary, the extinguishing agent CEA-308 discharged through a system produced with TEPG hardware successfully completed the IMO test protocol with a system containing four 360° nozzles and two design concentrations of 8.5 and 9.0%. The higher design concentration was used to minimize the production of HF during extinguishment.

13.3 FM-200 Extinguishing Agent, FMRC/Sea-Fire CRADA, Hygood Hardware

All six tests conducted using the FMRC/Sea-Fire system were extinguished within the time requirements stated in the IMO test protocol. In a majority of the tests, the fires were extinguished before the end of agent discharge. In summary, the FMRC/Sea-Fire system using FM-200 extinguishing agent successfully completed the IMO test protocol with a system containing four 360° nozzles and a design concentration of 8.7%. A system design consisting of four 180° nozzles and a design concentration of 8.7% also met the IMO requirements by successfully extinguishing the telltale fire test (Fire Scenario 1).

13.4 FM-200 Extinguishing Agent, Chemetron CRADA, Chemetron Hardware

All seven tests conducted using the Chemetron system were extinguished within the time requirements stated in the IMO test protocol. All of the test fires were extinguished within ten seconds of the end of agent discharge. In summary, the Chemetron system discharging FM-200 extinguish agent successfully completed the IMO test protocol with a system containing four 360° nozzles and a design concentration of 8.7%. Two additional system designs also met the requirements of the IMO test protocol by extinguishing the telltale fire test (Fire Scenario 1). These systems include a two 360° nozzle system and a two 180° nozzle system with the nozzles installed against a common bulkhead.

13.5 FM-200 Extinguishing Agent, Kidde-Fenwal CRADA, Kidde-Fenwal Hardware

All six tests conducted using the Kidde-Fenwal system were extinguished within the time requirements stated in the IMO test protocol. In a majority of the tests, the fires were extinguished before the end of agent discharge.

During the previous investigation [2], a Kidde-Fenwal system containing four 360° nozzles and a design concentration of 8.7% successfully completed the IMO test protocol. During this investigation, additional system designs were added by successfully extinguishing the telltale fire test (Fire Scenario 1). These systems include a two 360° nozzle system, a two 180° nozzle system with the nozzles installed at the centerline of opposing bulkheads, and a system containing two 180° nozzles positioned back-to-back in the center of the space.

14.0 REFERENCES

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APPENDIX A - IMO TEST PROTOCOL

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MSC/Circ.776
12 December 1996

Ref. T4/4.01

**GUIDELINES FOR THE APPROVAL OF EQUIVALENT FIXED GAS
FIRE-EXTINGUISHING SYSTEMS, AS REFERRED TO IN
SOLAS 74, FOR MACHINERY SPACES AND CARGO
PUMP-ROOMS**

- 1 The Maritime Safety Committee, at its sixty-seventh session (2 to 6 December 1996), approved Guidelines for the approval of equivalent fixed gas fire-extinguishing systems, as referred to in SOLAS 74, for machinery spaces and cargo pump-rooms, as set out in the annex.
- 2 Member Governments are requested to apply the annexed guidelines when approving equivalent fixed gas fire-extinguishing systems for use in machinery spaces of category A and cargo pump-rooms.

ANNEX

**GUIDELINES FOR THE APPROVAL OF EQUIVALENT FIXED GAS
FIRE-EXTINGUISHING SYSTEMS, AS REFERRED TO IN
SOLAS 74, FOR MACHINERY SPACES AND CARGO
PUMP-ROOMS**

General

1 Fixed gas fire-extinguishing systems for use in machinery spaces of category A and cargo pump-rooms equivalent to fire-extinguishing systems required by SOLAS regulations II-2/7 and II-2/63 should prove that they have the same reliability which has been identified as significant for the performance of fixed gas fire-extinguishing systems approved under the requirements of SOLAS regulation II-2/5. In addition, the system should be shown by test to have the capability of extinguishing a variety of fires that can occur in a ship's engine-room.

Principal requirements

2 All requirements of SOLAS Regulations II-2/5.1, 5.3.1, 5.3.2 to 5.3.3 except as modified by these guidelines, should apply.

3 The minimum extinguishing concentration should be determined by a cup burner test acceptable to the Administration. The design concentration should be at least 20 per cent above the minimum extinguishing concentration. These concentrations should be verified by full-scale testing described in the test method, as set out in the appendix.

4 For systems using halocarbon clean agents, 95 per cent of the design concentration should be discharged in 10 seconds or less. For inert gas systems, the discharge time should not exceed 120 seconds for 85 per cent of the design concentration.

5 The quantity of extinguishing agent for the protected space should be calculated using the design concentration based on the gross volume of the protected space including the casing. If the quantity of extinguishing agent when applied to the net volume of the protected space including casing exceeds the agent's LOAEL (Lowest Observed Adverse Effect Level), the quantity of agent should be reduced, but not below the agent's design concentration based on net volume.

6 No fire suppression agent should be used which is carcinogenic, mutagenic, or teratogenic at concentrations expected during use. No agent should be used in concentrations greater than the cardiac sensitization NOAEL (No Observed Adverse Effect Level), nor the ALC (Approximate Lethal Concentration), without the use of controls as provided in SOLAS 74 regulation II-2/5.1 and 5.3. In no case should an agent be used above its LOAEL (Lowest Observed Adverse Effect Level).

7 The system and its components should be suitably designed to withstand ambient temperature changes, vibration, humidity, shock, impact, clogging, and corrosion normally encountered in machinery spaces or cargo pump-rooms in ships.

8 The system and its components should be designed and installed in accordance with international standards acceptable to the Organization¹ and manufactured and tested to the satisfaction of the Administration. As a minimum, the design and installation standards should cover the following elements:

- .1 safety:
 - toxicity;
 - noise, nozzle discharge; and
 - decomposition products;
- .2 storage container design and arrangement:
 - strength requirements;
 - maximum/minimum fill density, operating temperature range;
 - pressure and weight indication;
 - pressure relief; and
 - agent identification and lethal requirements;
- .3 agent supply, quantity, quality standards;
- .4 pipe and fittings:
 - strength, material, properties, fire resistance; and
 - cleaning requirements;
- .5 valves:
 - testing requirements;
 - corrosion resistance; and
 - elastomer compatibility;
- .6 nozzles:
 - height and area testing requirements; and
 - corrosion and elevated temperature resistance;
- .7 actuation and control systems:
 - testing requirements; and
 - backup power requirements;

¹Until international standards are developed, national standards acceptable to the Administration should be used. Available national standards include, e.g., Standards Australia, United Kingdom and NFPA 2001.

.8 alarms and indicators:

predischarge alarm, agent discharge alarms as time delays;
abort switches;
supervisory circuit requirements; and
warning signs and audible and visual alarms should be located outside each entry
to the relevant space as appropriate;

.9 agent flow calculation:

approval and testing of design calculation method; and
fitting losses and/or equivalent length;

.10 enclosure integrity and leakage requirements:

enclosure leakage;
openings; and
mechanical ventilation interlocks;

.11 design concentration requirements, total flooding quantity;

.12 discharge time; and

.13 inspection, maintenance, and testing requirements.

9 The nozzle type, maximum nozzle spacing, maximum height and minimum nozzle pressure
should be within limits tested to provide fire extinction per the proposed test method.

10 Provisions should be made to ensure that escape routes which are exposed to leakage from the protected space are not rendered hazardous during or after discharge of the agent. Control stations and other locations that require manning during a fire situation should have provisions to keep HF and HCl below 5 ppm at that location. The concentrations of other products should be kept below concentrations considered hazardous for the required duration of exposure.

11 Agent containers may be stored within a protected machinery space if the containers are distributed throughout the space and the provisions of SOLAS regulation II-2/5.3.3 are met. The arrangement of containers and electrical circuits and piping essential for the release of any system should be such that in the event of damage to any one power release line through fire or explosion in the protected space, i.e. a single fault concept, at least five-sixths of the fire-extinguishing charge as required by paragraph 5 of this annex can still be discharged having regard to the requirement for uniform distribution of medium throughout the space. The arrangements in respect of systems for spaces requiring less than 6 containers should be to the satisfaction of the Administration.

12 A minimum agent hold time of 15 minutes should be provided.

13 The release of an extinguishing agent may produce significant over and under pressurization in the protected space. Measures to limit the induced pressures to acceptable limits should be provided.

14 For all ships, the fire-extinguishing system design manual should address recommended procedures for the control of products of agent decomposition. The performance of fire-extinguishing arrangements on passenger ships should not present health hazards from decomposed extinguishing agents, e.g., on passenger ships, the decomposition products should not be discharged in the vicinity of muster (assembly) stations.

APPENDIX

TEST METHOD FOR FIRE TESTING OF FIXED GAS FIRE-EXTINGUISHING SYSTEMS

1 Scope

1.1 This test method is intended for evaluating the extinguishing effectiveness of fixed gas fire-extinguishing systems for the protection of machinery spaces of category A and cargo pump-rooms.

1.2 Fire-extinguishing systems presently covered in regulation II-2/5, of SOLAS 1974, as amended, are excluded.

1.3 The test method covers the minimum requirements for fire-extinguishing.

1.4 This test method is applicable to gases, liquefied gases and mixtures of gases. The test method is not valid for extinguishant gases mixed with compounds in solid or liquid state at ambient conditions.

1.5 The test programme has two objectives: (1) establishing the extinguishing effectiveness of a given agent at its tested concentration, and (2) establishing that the particular agent distribution system puts the agent into the enclosure in such a way as to fully flood the volume to achieve an extinguishing concentration at all points.

2 Sampling

The components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings and technical data sufficient for the identification of the components.

3 Method of test

3.1 Principle

This test procedure enables the determination of the effectiveness of different gaseous agent extinguishing systems against spray fires, pool fires and class A fires.

3.2 Apparatus

3.2.1 Test room

The tests should be performed in 100 m² room, with no horizontal dimension less than 8 m, with a ceiling height of 5 m. The test room should be provided with a closable access door measuring approximately 4 m² in area. In addition, closable ventilation hatches measuring at least 6 m² in total area should be located in the ceiling.

3.2.2 Integrity of test enclosure

The test enclosure is to be nominally leak tight when doors and hatches are closed. The integrity of seals on doors, hatches, and other penetrations (e.g., instrumentation access ports) must be verified before each test.

3.2.3 Engine mock-up

- .1 An engine mock-up of size (width x length x height) 1 m x 3 m x 3 m should be constructed of sheet steel with a nominal thickness of 5 mm. The mock-up should be fitted with two steel tubes diameter 0.3 m and 3 m length that simulate exhaust manifolds and a solid steel plate. At the top of the mock-up a 3 m² tray should be arranged. See figures 1, 2 and 3.
- .2 A floor plate system 4 m x 6 m x 0.75 m high shall surround the mock-up. Provision shall be made for placement of the fuel trays, described in table 1, and located as described in table 2.

3.2.4 Instrumentation

Instrumentation for the continuous measurement and recording of test conditions should be employed. The following measurements should be made:

- .1 temperature at three vertical positions (e.g., 1, 2.5, and 4.5 m)
- .2 enclosure pressure
- .3 gas sampling and analysis, at mid-room height, for oxygen, carbon dioxide, carbon monoxide, and relevant halogen acid products, e.g., hydrogen iodide, hydrofluoric acid, hydrochloric acid
- .4 means of determining flame-out indicators
- .5 fuel nozzle pressure in the case of spray fire
- .6 fuel flow rate in the case of spray fires
- .7 discharge nozzle pressure

3.2.5 Nozzles

3.2.5.1 For test purposes, nozzles should be located within 1 m of the ceiling.

3.2.5.2 If more than one nozzle is used they should be symmetrically located.

3.2.6 Enclosure temperature

3.2.6.1 The ambient temperature of the test enclosure at the start of the test should be noted and serve as the basis for calculating the concentration that the agent would be expected to achieve at that temperature and with that agent weight applied in the test volume.

3.3 Test fires and programme

3.3.1 Fire types

The test programme, as described in table 3, should employ test fires as described in table 1.

Table 1 Parameters of Test Fires				
Fire	Type	Fuel ¹	Fire Size, MW	Remarks
A	76 - 100 mm ID Can	Heptane	0.0012 to 0.002	Tell tale
B	0.25 m ² Tray	Heptane	0.35	
C	2 m ² Tray	Diesel /Fuel Oil	3	
D	4 m ² Tray	Diesel /Fuel Oil	6	
E	Low pressure spray	Heptane 0.16 ± 0.01 kg/s	5.8	
F	Low pressure, low flow spray	Heptane 0.03 ± 0.005 kg/s	1.1	
G	High pressure spray	Diesel /Fuel Oil 0.05 ± 0.002 kg/s	1.8	
H	Wood Crib	Spruce or Fir	0.3	See Note 2
I	0.10 m ² tray	Heptane	0.14	

Notes to table 1:

- 1 Diesel /Fuel Oil means light diesel or commercial fuel oil.
- 2 The wood crib should be substantially the same as described in ISO/TC 21/SC5/WG 8 ISO Draft International Standard , *Gaseous fire extinguishing systems, Part 1: General Requirements*. The crib should consist of six, trade size 50 mm x 50 mm by 450 mm long, kiln dried spruce or fir lumber having a moisture content between 9 and 13 per cent. The members should be placed in 4 alternate layers at right angles to one another. Members should be evenly spaced forming a square structure.

Achieve ignition of the crib by burning commercial grade heptane in a square steel tray 0.25 m² in area. During the pre-burn period the crib should be placed centrally above the top of the tray a distance of 300 to 600 mm.

Table 2 Spray fire test parameters			
Fire type	Low pressure(E)	Low pressure, Low flow(F)	High pressure(G)
Spray nozzle	Wide spray angle (120 to 125°) full cone type	Wide spray angle (80°) full cone type	Standard angle (at 6 Bar) full cone type
Nominal fuel pressure	8 Bar	8.5 Bar	150 Bar
Fuel flow	0.16 ± 0.01 kg/s	0.03 ± 0.005 kg/s	0.050 ± 0.002 kg/s
Fuel temperature	20 ± 5°C	20 ± 5°C	20 ± 5°C
Nominal heat release rate	5.8 ± 0.6 MW	1.1 ± 0.1 MW	1.8 ± 0.2 MW

3.3.2 Test programme

The fire test programme should employ test fires singly or in combination, as outlined in table 3.

Table 3 Test Programme	
Test No.	Fire Combinations (See Table 1)
1	A: Tell tales, 8 corners. See note 1.
2-a See Note 2	B: 0.25 m ² heptane tray under engine mockup E: Horizontal LP spray directed at 15-25 mm rod 0.5 m away G: HP diesel/fuel oil spray on top of engine mock-up Total Fire Load: 7.95 MW
2-b See Note 2	B: 0.25 m ² heptane tray under mock-up I: 0.10 m ² heptane tray on deck plate located below solid steel obstruction plate Total Fire Load: 0.49 MW
3	C: 2 m ² diesel/fuel oil tray on deck plate located below solid steel obstruction plate H: Wood crib positioned as in Figure 1 F: Low pressure, low flow horizontal spray - concealed - with impingement on inside of engine mock-up wall. Total Fire Load: 4.4 MW
4	D: 4 m ² Diesel tray under engine mock-up Total Fire Load: 6 MW

Note to table 3:

- 1 Tell-tale fire cans should be located as follows:
 - (a) in upper corners of enclosure 150 mm below ceiling and 50 mm from each wall;
 - (b) in corners on floors 50 mm from walls.
- 2 Test 2-a is for use in evaluating extinguishing systems having discharge times of 10 seconds or less.

Test 2-b is for use in evaluating extinguishing systems having discharge times greater than 10 seconds.

3.3.2.1 All applicable tests of table 3 should be conducted for every new fire extinguishant gas, or mixture of gases.

3.3.2.2 Only Test 1 is required to evaluate new nozzles and related distribution system equipment (hardware) for systems employing fire extinguishants that have successfully completed the requirements of 3.3.2.1. Test 1 should be conducted to establish and verify the manufacturer's minimum nozzle design pressure.

3.4 Extinguishing system

3.4.1 System installation

The extinguishing system should be installed according to the manufacturer's design and installation instructions. The maximum vertical distance should be limited to 5 m.

3.4.2 Agent

3.4.2.1 Design concentration

The agent design concentration is that concentration (in volume per cent) required by the system designer for the fire protection application.

3.4.2.2 Test concentration

The concentration of agent to be used in the fire extinguishing tests should be the design concentration specified by the extinguishing system manufacturer, except for Test 1 which should be conducted at 83% of the manufacturer's recommended design concentration but in no case at less than the cup burner extinguishing concentration.

3.4.2.3 Quantity of agent

The quantity of agent to be used should be determined as follows:

3.4.2.3.1 Halogenated agents

$$W = (V/S) \cdot C/(100 - C) \text{ where}$$

W = agent mass, kg

V = volume of test enclosure, m³

S = agent vapour specific volume at temperature and pressure of the test enclosure, kg/m³

C = gaseous agent concentration, volume per cent

3.4.2.3.2 Inert gas agents

$$Q = V [294/(273 + T)] \cdot (P / 1.013) \cdot \ln[100/(100 - C)] \text{ where}$$

Q = volume of inert gas, measured at 294 K and 1.013 bar, discharged, m³

V = volume of test enclosure, m³

T = test enclosure temperature, Celsius

P = test enclosure pressure, bar

C = gaseous agent concentration, volume per cent

3.5 Procedure

3.5.1 Fuel levels in trays

The trays used in the test should be filled with at least 30 mm fuel on a water base. Freeboard should be 150 ± 10 mm.

3.5.2 Fuel flow and pressure measurements

For spray fires, the fuel flow and pressure should be measured before and during each test.

3.5.3 Ventilation

3.5.3.1 Pre-burn period

During the pre-burn period the test enclosure should be well ventilated. The oxygen concentration, as measured at mid-room height, shall not be less than 20 volume per cent at the time of system discharge.

3.5.3.2 End of pre-burn period

Doors, ceiling hatches, and other ventilation openings should be closed at the end of the pre-burn period.

3.5.4 Duration of test

3.5.4.1 Pre-burn time

Fires should be ignited such that the following burning times occur before the start of agent discharge:

- .1 sprays - 5 to 15 seconds
- .2 trays - 2 minutes
- .3 crib - 6 minutes

3.5.4.2 Discharge time

- .1 halogenated agents should be discharged at a rate sufficient to achieve delivery of 95% of the minimum design quantity in 10 seconds or less.
- .2 inert gas agents should be discharged at a rate sufficient to achieve 85% of the minimum design quantity in 120 seconds or less.

3.5.4.3 Soak time

After the end of agent discharge the test enclosure should be kept closed for 15 minutes.

3.5.5 Measurements and observations

3.5.5.1 Before test

- .1 temperature of test enclosure, fuel and engine mock-up
- .2 initial weights of agent containers
- .3 verification of integrity agent distribution system and nozzles
- .4 initial weight of wood crib

3.5.5.2 During test

- .1 start of the ignition procedure
- .2 start of the test (ignition)
- .3 time when ventilating openings are closed
- .4 time when the extinguishing system is activated
- .5 time from end of agent discharge
- .6 time when the fuel flow for the spray fire is shut off
- .7 time when all fires are extinguished
- .8 time of re-ignition, if any, during soak period
- .9 time at end of soak period
- .10 at the start of test initiate continuous monitoring as per 3.2.4

3.5.6 Tolerances

Unless otherwise stated, the following tolerances should apply:

.1	length	±2% of value
.2	volume	±5% of value
.3	pressure	±3% of value
.4	temperature	±5% of value
.5	concentration	±5% of value

These tolerances are in accordance with ISO standard 6182/1, February 1994 edition [4].

4 Classification criteria

4.1 Class B fires must be extinguished within 30 seconds of the end of agent discharge. At the end of the soak period there should be no re-ignition upon opening the enclosure.

4.2 The fuel spray should be shut off 15 seconds after extinguishment. At the end of the soak time, the fuel spray should be restarted for 15 seconds prior to reopening the door and there should be no reignition.

4.3 At the end of the test fuel trays must contain sufficient fuel to cover the bottom of the tray.

4.4 Wood crib weight loss must be no more than 60%.

5 Test report

The test report should include the following information:

- .1 name and address of the test laboratory
- .2 date and identification number of the test report
- .3 name and address of client
- .4 purpose of the test
- .5 method of sampling system components
- .6 name and address of manufacturer or supplier of the product
- .7 name or other identification marks of the product
- .8 description of the tested product
 - drawings
 - descriptions
 - assembly instructions
 - specification of included materials
 - detailed drawing of test set-up
- .9 date of supply of the product
- .10 date of test
- .11 test method
- .12 drawing of each test configuration
- .13 Identification of the test equipment and used instruments
- .14 conclusions
- .15 deviations from the test method, if any
- .16 test results including measurements and observations during and after the test; and
- .17 date and signature.

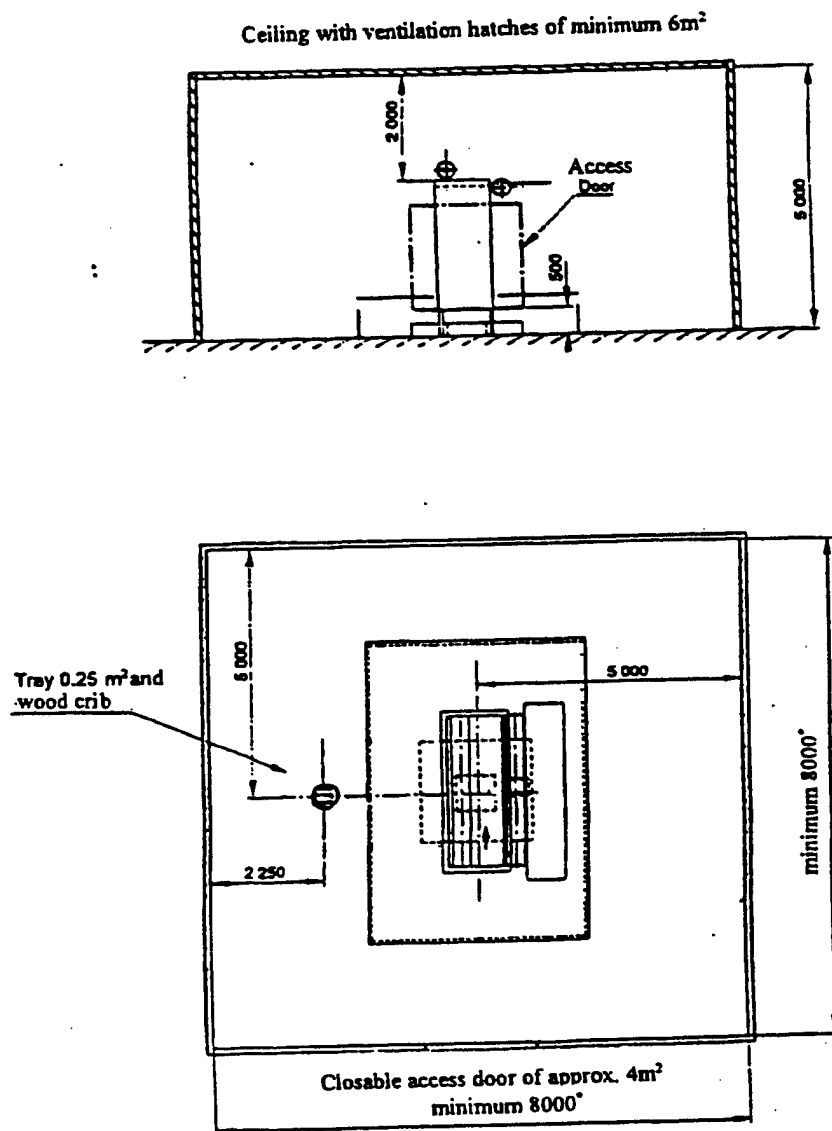


Figure 1

The area should be 100m²

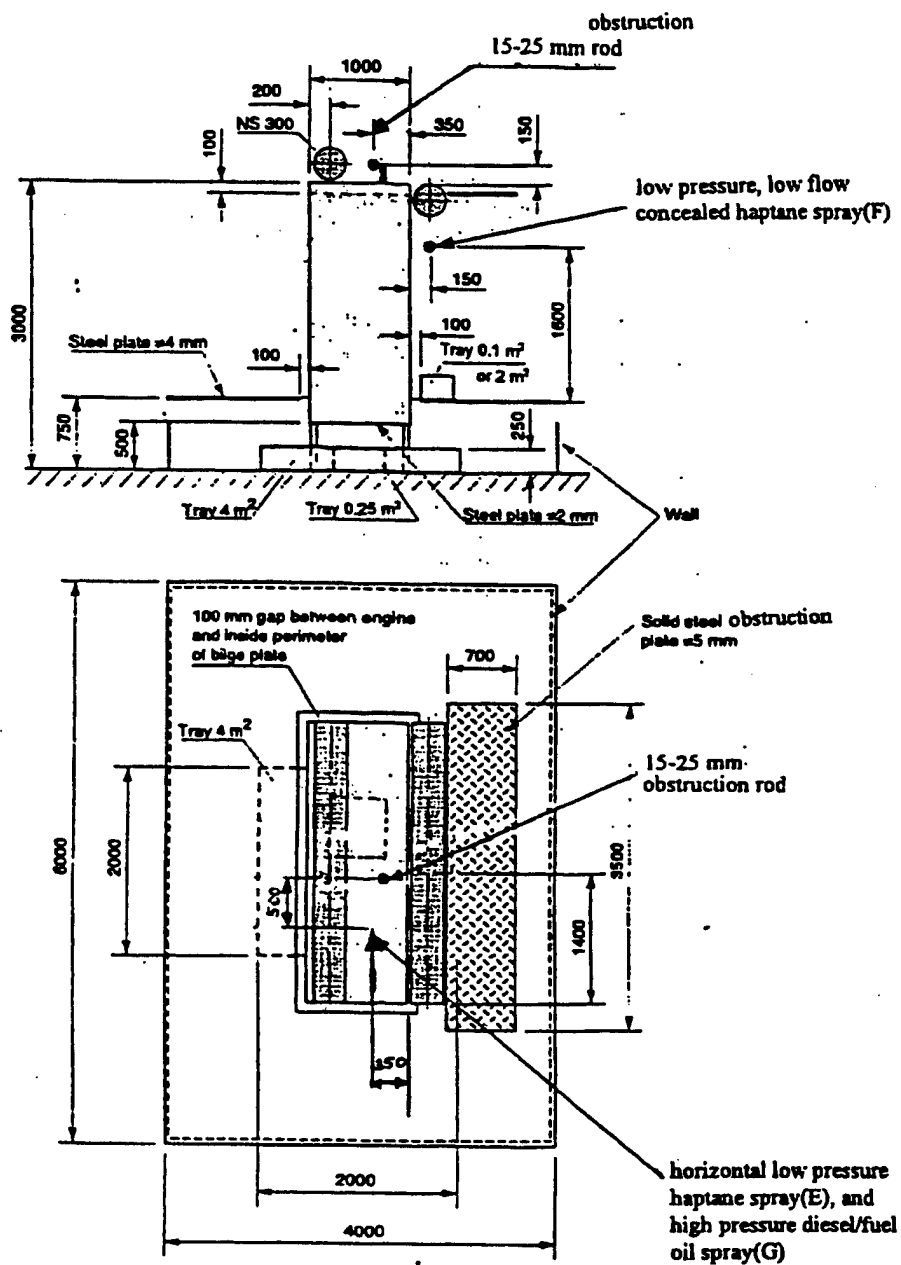


Figure 2

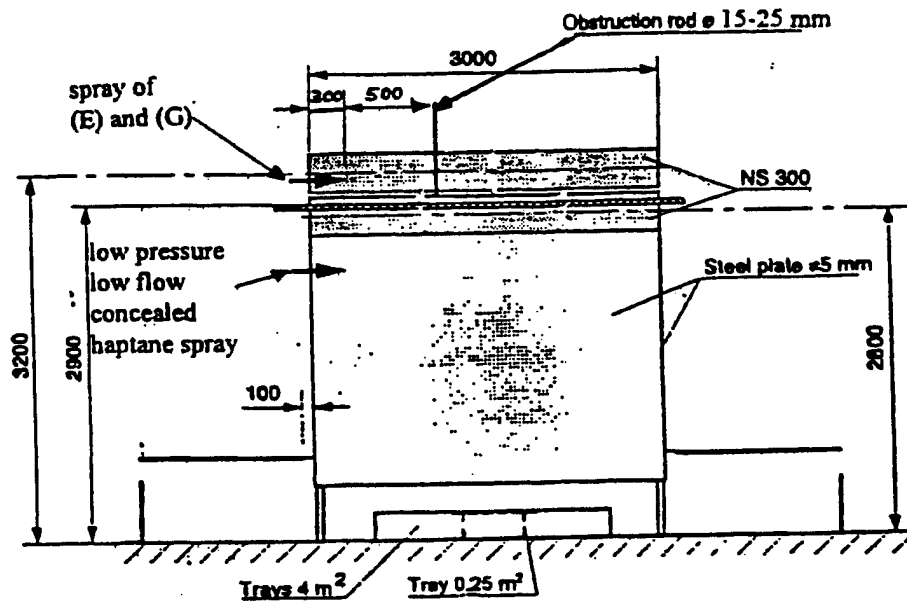


Figure 3

APPENDIX B - INSTRUMENTATION AND CAMERA DETAILS.

F.I.R.E.S.										Sheet: 1	
Test Name:		IMO Protocol Evaluation								Time for Each Test: < 25 min	
Test Series:		98CD								Port side, 02 level	
0		X	Humidity	8292031					Location		
#	SP	RE	ID	Instrumentation Description					Scan Interval: 0.10 and 1 sec.		
Total Number of Tests:										0-100% R.H.	
Project Number: 3301/3308.1.98										Eng. Unit	
										Measurement	
										Display &	
										Plotting	
										Output Range	
										91-106 kPa	
										0-44 m/s	
										0-360°C	
										0-50°C	
										0-1000°C	
										0-1000°C	
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F.I.R.E.S.										Sheet: 2			
Test Name:				IMO Protocol Evaluation									
Test Series:				98CD						Time for Each Test: < 25 min			
Total Number of Tests:										Scan Interval: 0.10 and 1 sec.			
Project Number: 3301/3308.1.98													
Channel				Instrumentation Description		Serial Number		Display & Plotting		Output Range		Remarks/Notes	
#	SP	RE	ID					Measurement		Eng. Unit		Location	
26	X	72		TC Type K 1/16 in. dia.		K50FT1/16I		0-800°C		0-1000°C		(9.9, 9.9, 4.9)	
27	X	72		TC Type K 1/16 in. dia.		K50FT1/16I		0-800°C		0-1000°C		(9.9, 9.9, 0.2)	
28	X	72		TC Type K 1/16 in. dia.		K50FT1/16I		0-800°C		0-1000°C		(0.0, 9.9, 4.9)	
29	X	72		TC Type K 1/16 in. dia.		K50FT1/16I		0-800°C		0-1000°C		(0.0, 9.9, 0.2)	
30	X	72		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.0, 5.0, 0.4)	
31		72		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(5.0, 5.0, 0.3)	
32	X	73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.0, 4.0, 1.0)	
33		73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(5.0, 4.0, 0.8)	
34	X	73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.0, 5.0, 3.3)	
35		73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(5.0, 4.4, 3.2)	
36	X	73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.7, 5.6, 2.4)	
37		73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(6.5, 5.6, 2.4)	
38	X	73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.0, 5.0, 3.5)	
39		73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(5.0, 5.0, 3.0)	
40	X	73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-800°C		0-1000°C		(5.0, 2.3, 0.9)	
41		73		TC Type K 1/8 in. dia.		K50FT1/8IN		0-100°C		0-1000°C		(5.0, 2.3, 0.7)	
42		X		CO Analyzer		41092		0-5%		0-10%		Gas Tree #1	
43		X		CO ₂ Analyzer		30606		0-15%		0-25%		Gas Tree #1	
44	X		X	O ₂ Analyzer		1001451		0-21%		0-25%		Gas Tree #1	
45				CO Analyzer		41093		0-5%		0-10%		Gas Tree #1	
46				CO ₂ Analyzer		31334		0-15%		0-25%		Gas Tree #1	
47	X			O ₂ Analyzer		2002910		0-21%		0-25%		Gas Tree #1	
48				CO Analyzer		41094		0-5%		0-10%		Gas Tree #1	
49				CO ₂ Analyzer		31335		0-15%		0-25%		Gas Tree #1	
50	X			O ₂ Analyzer		1001638		0-21%		0-25%		Gas Tree #1	

F.I.R.E.S.									
Test Name:				IMO Protocol Evaluation			Instrument List & Test Requirements		
Test Series:				98CD			Sheet:		
Total Number of Tests:							Time for Each Test:		
Project Number: 3301/3308.1.98							Scan Interval:		
							0.10 and 1 sec.		
</									

F.I.R.E.S.													Sheet: 4
Test Name:		IMO Protocol Evaluation											Time for Each Test: < 25 min
Test Series:		98CD											Scan Interval: 0.10 and 1 sec.
Total Number of Tests:													
Project Number: 3301/3308.1.98													
Channel													
#	SP	RE	ID	Instrumentation Description	Serial Number	Measurements	Output Range	Location	Remarks/Notes				
74				Pressure Transducer	586326	0-2000 kPa	0-6900 kPa	(5.0, 7.5, 5.0)	At Dist Sys Nozzle				
75				Pressure Transducer	586327	0-2000 kPa	0-6900 kPa	(5.0, 2.5, 5.0)	At Dist Sys Nozzle				
76				Pressure Transducer	586328	0-2500 kPa	0-6900 kPa	(5.0, 5.0, 5.0)	At 1st Dist Tee				
77				Pressure Transducer	586329	0-2500 kPa	0-6900 kPa	(5.0, 7.5, 5.0)	At 2nd Dist Tee				
78				Pressure Transducer	Dummy	0-3000 kPa	0-6900 kPa	Main Deck	Dist Manifold				
79				Pressure Transducer	908494	0-3000 kPa	0-6900 kPa	Main Deck	Man near cylidr				
80		88		TC Type K 1/16 in. dia.	K50FT1/16I	-40 - 40°C	0-1000°C	Main Deck	On Cylinder				
81					K50FT1/16I								
82		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40-800°C	0-1000°C	(5.0, 7.5, 5.0)	At Dist Sys Nozzle				
83		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40-800°C	0-1000°C	(5.0, 2.5, 5.0)	At Dist Sys Nozzle				
84		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40-800°C	0-1000°C	(5.0, 5.0, 5.0)	At 1st Dist Tee				
85		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40-800°C	0-1000°C	(5.0, 7.5, 5.0)	At 2nd Dist Tee				
86		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40 - 40°C	0-1000°C	Main Deck	Dist Manifold				
87		88		TC Type K 1/16 in. dia. Exp Tip	K50FT1/16I	-40 - 40°C	0-1000°C	Main Deck	Man near cylidr				
88				TC reference junction	TC5	0-50°C	0-50°C	2nd deck, 6 hold	Chnl 80-87				
89		88		TC Type K welded surf temp	KXFSTDXXWELD	-40 - 40°C	0-400°C	Surface Weld	Dist Manifold				
90		88		TC Type K welded surf temp	KXFSTDXXWELD	-40 - 40°C	0-400°C	Surface Weld	Manifold Cyl.				
91		88		TC Type K welded surf temp	KXFSTDXXWELD	-40-400°C	0-400°C	Surface Weld	At Dist Sys Nozzle				
92		88		TC Type K welded surf temp	KXFSTDXXWELD	-40-400°C	0-400°C	Surface Weld	At Dist Sys Nozzle				
93		88		TC Type K welded surf temp	KXFSTDXXWELD	-40-400°C	0-400°C	Surface Weld	At 2nd Dist Tee				
94		88		TC Type K welded surf temp	KXFSTDXXWELD	-40-400°C	0-400°C	Surface Weld	At 1st Dist Tee				
95													
96			X	Load Cell				Main Deck	Under Cylinder				
97													

APPENDIX C - INERGEN DISCHARGE TIME DETERMINATION

Unlike the halocarbon agents, where the nozzle liquid runout time serves as an indication that 95% or more of the agent has been delivered by the discharge system, there is no pressure inflexion or other clear indication marking the end of the agent discharge for Inergen. The discharge times could be determined by monitoring the weight of the cylinders with the end of agent discharge taken as the time when the desired fraction of the initial agent mass, adjusted for the piping volume, has left the cylinder.

Measuring the weight of a cylinder during the discharge is difficult and prone to significant errors. These errors are associated with how the cylinder is attached to the pipe network. This connection is typically made using a flexible hose, which must be installed, in a level, horizontal plane in order to not interfere with the measurement of the cylinder weight during the discharge. Unfortunately, the reaction forces of the pressurized flex hose always affect the weight measurement. These reaction forces reduce the accuracy of this measurement.

The mass of the agent in the cylinders was instead estimated by utilizing the temperatures and pressures measured in the cylinder manifold and the Soave-Redlich-Kwong equation of state [C-1, C-2]. The S-R-K equation of state is used to find the density of the agent at the measured temperature and pressure. Assuming that all the agent in the discharge system is at the same density, a conservative discharge time can be estimated based on a required outage fraction.

The S-R-K equation of state is cubic in nature and takes the following working form [C-1]:

$$Z^3 - Z^2 + Z^* (A - B - B^2) - AB = 0$$

where Z is the compressibility and A and B are constants depending on the composition of the mixture, the critical pressure, the critical temperature, and pitzer acentric factor for each species as follows:

$$Z = Pv/RT$$

$$A = y_i y_j (A_i A_j)^{0.5}$$

$$B = y_i B_i$$

$$A_i = 0.4247 * a_{z_i} * (P/P_{c_i}) / (T/T_{c_i})^2$$

$$a_{z_i} = [1. + z_{m_i} * (1. - [T/T_{c_i}]^{0.5})]^2$$

$$zm_i = 0.48 + 1.574w_i - 0.176w_i^2$$

$$B_i = 0.08664*(P/P_{c_i})/(T/T_{c_i})$$

$$p = (y_i MW_i)/v$$

where P is the pressure, v is the molal volume, p is the density, R is the ideal gas constant, T is the temperature, y_i is the mole fraction of species I in the mixture, MW_i is the molecular weight of species I, P_{c_i} is the critical pressure of species I, T_{c_i} is the critical temperature of species I, and w_i is the pitzer acentric factor for species I.

In practice, the density is first determined utilizing the total system volume and initial agent mass. The compressibility, Z, and the value of the S-R-K working equation are then found for two bracketing time steps. The time at which the end of the discharge occurred is found by linear interpolation between these points. This was done using an Excel Spreadsheet for each of the eight tests conducted for both 85% and 95% outages as shown in Tables C-1 through C-16.

References.

- C-1. Henley, E. J. and Seader, J. D., *Equilibrium-Stage Separation Operations in Chemical Engineering*, John Wiley & Sons, New York, NY, 1981.
- C-2. Reid, R. C., Prausnitz, J. M., and Sherwood, T. K., *The Properties of Gases and Liquids*, Third Edition, McGraw-Hill Book Company, New York, NY, 1977.

Table C2 - Test #1 - 95% Discharge Time Calculation

S-R-K Equation			Outage		95%		Test=Test1			
Of State	Inergen	Argon	Nitrogen	CO2	Argon	CO2	zm	az	Nitrogen	CO2
Agent	627.737493psia	707.07	492.45	1070.16	707.07	1070.16			0.54268	0.82524
Pc	271.3896R	271.44	227.16	547.56	271.44	547.56			0.58502	1.13082
Tc	1.3411869ft3/lbmole	1.1997766	1.433644981	1.5057277	1.1997766	1.5057277			0.01085	0.05606
Vc	0.28914	0.291	0.29	0.274	0.291	0.274			0.00772	0.00856
Zc	0.03632	-0.004	0.04	0.225	-0.004	0.225			0.52000	0.08000
w	34.30546lb/lbmole	39.95	28.013	44.01	39.95	44.01				
MW	72.5 s	Pav		136.8Psig						
End Time	466.7R	Z		0.98963073						
T	90.1psia	SRK		-0.00339						
P	1545ft lbf/lbmole R									
R	54.9658313ft3/lbmole									
v	0.6241234lbm/ft3									
p	626.62254lb	Fill Density		13.4lb/ft3						
Minit	50.200214ft3									
Total Vol	31.3311268lb									
Mtarget	16									
Num Of Cyl	439ft3									
Expanded Vol	39.163909lb									
Mass per Cyl	2.93ft3									
Cyl Vol (each)	3.320214ft3 (w/o diptube)									
Pipe Vol	467.087R			time (s)			72 Cylinder			
TPav(abs)	91.475psia	1.00330147P (gauge)	Z	time (s)			76.775			
PPav(abs)	462.378R	0.01025T (F)	SRK	time (s)			7.387			
TPav(abs)	76.855psia	0.85153357P (gauge)	Z	time (s)			77 Cylinder			
PPav(abs)		-0.10246T (F)	SRK				62.155			
Start							2.678			
End										
CO2										
zm	0.54268	0.47370	0.82524	Zm			0.54268	0.47370	0.82524	
az	0.58447	0.72643	1.13008	Az			0.59050	0.73179	1.13828	
A	0.01098	0.01357	0.05675	A	0.014431A		0.00951	0.01172	0.04901	0.0124803
B	0.00783	0.00651	0.00868	B	0.0073701B		0.00664	0.00553	0.00737	0.0062552
y	0.52000	0.40000	0.08000	Y			0.52000	0.40000	0.08000	

Table C4 - Test#2 - 95% Discharge Time Calculation

S-R-K Equation			Outage		95%		Test#2			
Of State	Inergen	Nitrogen	Argon	CO2						
Agent										
Pc	627.74psia	492.45	707.07	1070.16	zm		Nitrogen	Argon	CO2	
Tc	271.3896R	227.16	271.44	547.56	az		0.54268	0.47370	0.82524	
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277	A		0.60066	0.74081	1.15208	
Zc	0.28914	0.29	0.291	0.274	B		0.01136	0.01394	0.05828	0.0148775863
w	0.03632	0.04	-0.004	0.225	y		0.00767	0.00639	0.00851	0.007225615
MW	34.30546lb/lbmole	28.013	39.95	44.01			0.52000	0.40000	0.08000	
End Time	73.7 s		Pav	132.7psig						
T	454.5R	Z		0.98363593795						
P	87.3psia	SRK		-0.00847						
R	1545ft lbf/lbmole R									
v	54.966ft3/lbmole									
p	0.6241234lbm/ft3									
Minit	626.62254lb	Fill Density		13.4lb/ft3						
Total Vol	50.200214ft3									
Mtarget	31.331lb									
# of Cyl	16									
Expanded Vol	439ft3									
Mass per Cyl	39.163909lb									
Cyl Vol (each)	2.93ft3									
Pipe Vol	3.320214ft3 (w/o diptube)									
				time (s)	72Cylinder					
TPav(abs)	455.275R	Z	1.0405P (gauge)		77.766					
PAV(abs)	92.466psia	SRK	0.05202T (F)		-4.425					
				time (s)	76Cylinder					
TPav(abs)	453.554R	Z	0.9057P (gauge)		65.482					
PAV(abs)	80.182psia	SRK	-0.07107T (F)		-6.146					
Start				End						
	Nitrogen	Argon	CO2		Nitrogen	Argon	CO2			
zm	0.54268	0.47370	0.82524	zm	0.54268	0.47370	0.82524			
az	0.59971	0.73997	1.15079	az	0.60196	0.74197	1.15385			
A	0.01198	0.01470	0.06148	0.0156912A	0.01051	0.01288	0.05386	0.0137536		
B	0.00812	0.00676	0.00900	0.0076432B	0.00707	0.00588	0.00784	0.006653		
y	0.52000	0.40000	0.08000	y	0.52000	0.40000	0.08000			

Table C7 - Test 4 85% Discharge Time Calculation

S-R-K Equation Of State		Outage		85%		Test=Test4			
Agent	Inergen	Nitrogen	Argon	CO2		Nitrogen	Argon	CO2	
Pc	627.74psia	492.45	707.07	1070.16	zm	0.54268	0.47370	0.82524	
Tc	271.3896R	227.16	271.44	547.56	az	0.58586	0.72767	1.13197	
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277	A	0.03130	0.03866	0.16167	0.0411287328
Zc	0.28914	0.29	0.291	0.274	B	0.02221	0.01848	0.02464	0.020914058
w	0.03632	0.04	-0.004	0.225	y	0.52000	0.40000	0.08000	
MW	34.30546lb/lbmole	28.013	39.95	44.01					
End Time	36.3 s	Pav	235.4psig						
T	466.0R	Z	0.9576						
P	259.0psia	SRK	-0.02082						
R	1545ft lb/lbmole R								
v	18.487ft3/lbmole								
p	1.8556474lbm/ft3								
Minit	626.62254lb	Fill Density	13.4lb/ft3						
Total Vol	50.652607ft3								
Mtarget	93.993lb								
Num Of Cyl	16								
Expanded Vol	439ft3								
Mass per Cyl	39.163909lb								
Cyl Vol (each)	2.93ft3								
Pipe Vol	3.772607ft3 (without diptube)								
				time (s)	33Cylinder				
TPav(abs)	465.912R	Z	1.0999P (gauge)	282.714					
PPav(abs)	297.41psia	SRK	0.14467T (F)	6.212					
			time (s)		38Cylinder				
TPav(abs)	466.043R	Z	0.883P (gauge)	224.118					
PPav(abs)	238.82psia	SRK	-0.07585T (F)	6.343					
Start			End						
zm	Nitrogen	Argon	CO2			Nitrogen	Argon	CO2	
	0.54268	0.47370	0.82524	zm		0.54268	0.47370	0.82524	
az	0.58597	0.72776	1.13212	az		0.58580	0.72761	1.13189	
A	0.03596	0.04442	0.18577	0.0472586A		0.02885	0.03564	0.14905	0.0379173
B	0.02551	0.02123	0.02830	0.0240229B		0.02048	0.01704	0.02272	0.0192845
y	0.52000	0.40000	0.08000	y		0.52000	0.40000	0.08000	

Table C8 - Test #4 - 95% Discharge Time Calculation

S-R-K Equation Of State		Outage		95%		Test#4			
Agent	Inergen	Nitrogen	Argon	CO2		Nitrogen	Argon	CO2	
Pc	627.74psia	492.45	707.07	1070.16	zm	0.54268	0.47370	0.82524	
Tc	271.3896R	227.16	271.44	547.56	az	0.60557	0.74516	1.15873	
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277	A	0.01143	0.01399	0.05847	0.014943381
Zc	0.28914	0.29	0.291	0.274	B	0.00759	0.00632	0.00842	0.00714869
w	0.03632	0.04	-0.004	0.225	y	0.52000	0.40000	0.08000	
MW	34.30546lb/lbmole	28.013	39.95	44.01					
End Time	63.1 s	Pav	154.0psig						
T	450.8R	Z	0.9819						
P	85.6psia	SRK	-0.00992						
R	1545ft lb/lbmole R								
v	55.461ft3/lbmole								
p	0.6185491lbm/ft3								
Minit	626.62254lb	Fill Density		13.4lb/ft3					
Total Vol	50.652607ft3								
Mtarget	31.331lb								
Num Of Cyl	16								
Expanded Vol	439ft3								
Mass per Cyl	39.163909lb								
Cyl Vol (each)	2.93ft3								
Pipe Vol	3.772607ft3 (without diptube)								
TPav(abs)	454.278R	Z	1.1095P (gauge)	82.807	60Cylinder				
PAV(abs)	97.507psia	SRK	0.14413T (F)	-5.422					
			time (s)		64Cylinder				
TPav(abs)	449.756R	Z	0.9425P (gauge)	67.302					
PAV(abs)	82.002psia	SRK	-0.04413T (F)	-9.944					
Start			End						
	Nitrogen	Argon	CO2			Nitrogen	Argon	CO2	
zm	0.54268	0.47370	0.82524	zm		0.54268	0.47370	0.82524	
az	0.60101	0.74113	1.15256	az		0.60697	0.74640	1.16063	
A	0.01272	0.01560	0.06522	0.0166499A		0.01102	0.01348	0.05635	0.0144048
B	0.00858	0.00714	0.00952	0.0080776B		0.00729	0.00606	0.00808	0.0068614
y	0.52000	0.40000	0.08000	y		0.52000	0.40000	0.08000	

Table C9 - Test #5 - 85% Discharge Time Calculation

Table C9 - Test #3 - 85% Discharge 11me Calculation											
S-R-K Equation Of State			Outage		85%		Test= test5				
Agent	Inergen		Nitrogen	Argon	CO2				Nitrogen	Argon	CO2
Pc	627.74psia		492.45	707.07	1070.16		zm		0.54268	0.47370	0.82524
Tc	271.3896R		227.16	271.44	547.56		az		0.61274	0.75151	1.16844
Vc	1.3411869ft3/lbmole		1.433644981	1.1997766	1.5057277		A		0.03582	0.04369	0.18264
Zc	0.28914		0.29	0.291	0.274		B		0.02323	0.01934	0.02577
w	0.03632		0.04	-0.004	0.225		y		0.52000	0.40000	0.08000
MW	34.30546lb/lbmole		28.013	39.95	44.01						
End Time	33.3 s			Pav	365.1psig						
T	445.4R		Z	Z	0.9585						
P	258.9psia			SRK	-0.01576						
R	1545ft lb/lbmole R										
v	17.69ft3/lbmole										
p	1.9392588lbm/ft3										
Minit	744.11426lb			Fill Density	13.4lb/ft3						
Total Vol	57.556597ft3										
Mtarget	111.62lb										
Num Of Cyl	19										
Expanded Vol	439ft3										
Mass per Cyl	39.163909lb										
Cyl Vol (each)	2.93ft3										
Pipe Vol	1.886597ft3 (without diptube)										
					time (s)		30Cylinder				
TPav (abs)	448.205R		Z	1.0841P (gauge)	280.007						
Pav (abs)	294.71psia		SRK	0.12675T (F)	-11.495						
					time (s)		35Cylinder				
TPav(abs)	443.96R		Z	0.8925P (gauge)	225.617						
Pav(abs)	240.32psia		SRK	-0.06600T (F)	-15.74						
Start			End								
			Nitrogen	Argon	CO2				Nitrogen	Argon	CO2
zm	0.54268		0.82524	zm	0.54268	0.47370			0.54268	0.47370	0.82524
az	0.60902		1.16341	az	0.61468	0.75323			0.61468	0.75323	1.17107
A	0.04002		0.04889	0.0522776A	0.03357	0.04091			0.03357	0.04091	0.17100
B	0.02628		0.02187	0.0247446B	0.02163	0.01800			0.02163	0.01800	0.0203708
y	0.52000		0.08000	y	0.52000	0.40000			0.52000	0.40000	0.08000

Table C10 - Test #5 - 95% Discharge Time Calculation

Table C10 - Test #5 - 95% Discharge Time Calculation												
S-R-K Equation Of State				Outage		95%		Test=Test5				
Agent	Inergen	Nitrogen	Argon	CO2						Nitrogen	Argon	CO2
Pc	627.74psia	492.45	707.07	1070.16				zm		0.54268	0.47370	0.82524
Tc	271.3896R	227.16	271.44	547.56				az		0.60858	0.74783	1.16281
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277				A		0.01189	0.01453	0.06074
Zc	0.28914	0.29	0.291	0.274				B		0.00782	0.00651	0.00867
w	0.03632	0.04	-0.004	0.225				y		0.52000	0.40000	0.08000
MW	34.30546lb/lbmole	28.013	39.95	44.01								
End Time	58.3 s		Pav	238.0psigs								
T	448.5R		Z	0.9677								
P	87.8psia		SRK	-0.02248								
R	1545ft lb/lbmole R											
v	53.07ft3/lbmole											
p	0.6464196lbm/ft3											
Minit	744.11426lb		Fill Density	13.4lb/ft3								
Total Vol	57.556597ft3											
Mtarget	37.206lb											
Num Of Cyl	19											
Expanded Vol	439ft3											
Mass per Cyl	39.163909lb											
Cyl Vol (each)	2.93ft3											
Pipe Vol	1.886597ft3 (w/o diptube)											
				time (s)				55Cylinder				
TPav (abs)	449.054R	Z	1.1134P (gauge)					86.38				
Pav (abs)	101.08psia	SRK	0.15077T (F)					-10.646				
				time (s)				60Cylinder				
TPav(abs)	448.262R	Z	0.8894P (gauge)					65.9				
Pav(abs)	80.6psia	SRK	-0.08095T (F)					-11.438				
Start			End									
	Nitrogen	Argon	CO2					Nitrogen	Argon	CO2		
zm	0.54268	0.47370	0.82524					0.54268	0.47370	0.82524		
az	0.60789	0.74722	1.16189					0.60894	0.74815	1.16331		
A	0.01365	0.01668	0.06975					0.01094	0.01337	0.05588	0.0142924	
B	0.00900	0.00749	0.00998					0.00719	0.00598	0.00797	0.0067666	
y	0.52000	0.40000	0.08000					0.52000	0.40000	0.08000		

Table C11 - test #6 - 85% Discharge Time Calculation

S-R-K Equation Of State		Outage		85%	Test=test6			
Agent	Inergen	Nitrogen	Argon	CO2		Nitrogen	Argon	CO2
Pc	627.74psia	492.45	707.07	1070.16	zm	0.54268	0.47370	0.82524
Tc	271.3896R	227.16	271.44	547.56	az	0.61430	0.75289	1.17055
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277	A	0.03589	0.04374	0.18285
Zc	0.28914	0.29	0.291	0.274	B	0.02316	0.01927	0.02180606
w	0.03632	0.04	-0.004	0.225	y	0.52000	0.40000	0.08000
MW	34.30546lb/lbmole	28.013	39.95	44.01				
End Time	34.1 s	Pav		352.8psig				
T	444.2R	Z		0.95536958705				
P	257.4psia	SRK		-0.01831				
R	154.5ft.lbf/lbmole R							
v	17.69ft3/lbmole							
p	1.9392588lbm/ft3							
Minit	744.11426lb	Fill Density		13.4lb/ft3				
Total Vol	57.556597ft3							
Mtarget	111.62lb							
Num Of Cyl	19							
Expanded Vol	439ft3							
Mass per Cyl	39.163909lb							
Cyl Vol (each)	2.93ft3							
Pipe Vol	1.886597ft3 (w/o diptube)							
				time (s)	32Cylinder			
TPav(abs)	445.289R	Z	1.0397P(gauge)		266.095			
Pav(abs)	280.8psia	SRK	0.06921T(F)		-14.411			
				time (s)	37Cylinder			
TPav(abs)	442.783R	Z	0.8366P(gauge)		209.965			
Pav(abs)	224.67psia	SRK	-0.09694T(F)		-16.917			
Start			End					
	Nitrogen	Argon			Nitrogen	Argon	CO2	
zm	0.54268	0.47370	0.82524	zm	0.54268	0.47370	0.82524	
az	0.61290	0.75166	1.16866	az	0.61626	0.75462	1.17320	
A	0.03888	0.04742	0.19821	0.0507363A	0.03163	0.03852	0.16101	0.0412453
B	0.02520	0.02097	0.02795	0.0237309B	0.02028	0.01688	0.02249	0.0190947
y	0.52000	0.40000	0.08000	y	0.52000	0.40000	0.08000	

Table C12 - Test #6 - 95% Discharge Time Calculation

S-R-K Equation Of State				Outage		95%		Test=Test6			
Agent	Inergen	Nitrogen	Argon	CO2							
Pc	627.74psia	492.45	707.07	1070.16				zm		Nitrogen	CO2
Tc	271.3896R	227.16	271.44	547.56				az		0.54268	0.82524
Vc	1.3411869ft3/lbmole	1.433644981	1.1997766	1.5057277				A		0.62329	1.18270
Zc	0.28914	0.29	0.291	0.274				B		0.01254	0.06360
w	0.03632	0.04	-0.004	0.225				Y		0.00785	0.00871
MW	34.30546lb/lbmole	28.013	39.95	44.01						0.52000	0.08000
End Time	58.6 s	Pav		233.3psig							
T	437.6R	Z		0.9719							
P	86.0psia	SRK		-0.01807							
R	1545ft lb/ft3/lbmole										
v	53.07ft3/lbmole										
p	0.6464196lbm/ft3										
Minit	744.11426lb	Fill Density		13.4lb/ft3							
Total Vol	57.556597ft3										
Mtarget	37.206lb										
Num Of Cyl	19										
Expanded Vol	439ft3										
Mass per Cyl	39.163909lb										
Cyl Vol (each)	2.93ft3										
Pipe Vol	1.886597ft3 (w/o diptube)										
				time (s)				55 Cylinder			
TPav (abs)	439R	Z		1.1269P (gauge)				85.318			
PAV (abs)	100.02psia	SRK		0.17249T (F)				-20.7			
				time (s)				60 Cylinder			
TPav(abs)	437.045R	Z		0.9135P (gauge)				66.014			
PAV(abs)	80.714psia	SRK		-0.06465T (F)				-22.655			
Start				End							
	Nitrogen	Argon	CO					Nitrogen	Argon	CO2	
zm	0.54268	0.47370	0.82524	zm				0.54268	0.47370	0.82524	
az	0.62136	0.75913	1.18009	az				0.62402	0.76147	1.18368	
A	0.01444	0.01755	0.07335	0.0188106A				0.01181	0.01433	0.05990	0.0153716
B	0.00911	0.00758	0.01010	0.0085739B				0.00738	0.00614	0.00819	0.0069501
Y	0.52000	0.40000	0.08000	Y				0.52000	0.40000	0.08000	

Table C13 - Test #7 - 85% Discharge Time Calculation

S-R-K Equation				Outage		85%		Test=test7			
Of State				Nitrogen		Argon		CO2		CO2	
Agent	Inergen	627.74psia		492.45	707.07	1070.16	zm	0.54268	0.47370	0.82524	
Pc		271.3896R		227.16	271.44	547.56	az	0.60587	0.74543	1.15914	
Tc		1.3411869ft3/lbmole		1.433644981	1.1997766	1.5057277	A	0.03511	0.04296	0.17961	0.0459025762
Vc		0.28914		0.29	0.291	0.274	B	0.02330	0.01939	0.02584	0.0219385528
Zc		0.03632		0.04	-0.004	0.225	y	0.52000	0.40000	0.08000	
W		34.30546lb/lbmole		28.013	39.95	44.01					
MW		33.5		Pav		363.2psig					
End Time		450.6R		Z		0.9612					
T		262.7psia		SRK		-0.01431					
P		1545ft lb/ft3/lbmole R									
R		17.69ft3/lbmole									
v		1.9392588lbm/ft3									
p		744.11426lb		Fill Density		13.4lb/ft3					
Minit		57.556597ft3									
Total Vol		111.62lb									
Mtarget		19									
Num Of Cyl		439ft3									
Expanded Vol		39.163909lb									
Mass per Cyl		2.93ft3									
Cyl Vol (each)		1.886597ft3 (w/o diptube)									
Pipe Vol						time (s)	30Cylinder				
TPav (abs)		451.848R		Z	1.0933P (gauge)		284.928				
Pav (abs)		299.63psia		SRK	0.13910T (F)		-7.852				
						time (s)	35Cylinder				
TPav(abs)		450.059R		Z	0.9059P (gauge)		232.568				
Pav(abs)		247.27psia		SRK	-0.05799T (F)		-9.641				
Start					End						
	Nitrogen	Argon	CO2					Nitrogen	Argon	CO2	
zm	0.54268	0.47370	0.82524		zm			0.54268	0.47370	0.82524	
az	0.60420	0.74396	1.15689		az			0.60656	0.74605	1.16008	
A	0.03972	0.04863	0.20333		0.0519471A			0.03317	0.04057	0.16961	0.0433535
B	0.02650	0.02206	0.02940		0.024955B			0.02196	0.01827	0.02436	0.020676
y	0.52000	0.40000	0.08000		y			0.52000	0.40000	0.08000	

Table C14 - Test #7 - 95% Discharge Time Calculation

S-R-K Equation Of State			Outage		95%		Test=Test7			
Agent	Inergen		Nitrogen	Argon	CO2		Nitrogen	Argon	CO2	
Pc	627.74 psia		492.45	707.07	1070.16	zm	0.54268	0.47370	0.82524	
Tc	271.3896 R		227.16	271.44	547.56	az	0.61298	0.75173	1.16877	
Vc	1.3411869 ft ³ /lbmole		1.433644981	1.1997766	1.5057277	A	0.01208	0.01473	0.06156	0.01575871
Zc	0.28914		0.29	0.291	0.274	B	0.00783	0.00651	0.00868	0.00736905
w	0.03632		0.04	-0.004	0.225	y	0.52000	0.40000	0.08000	
MW	34.30546 lb/lbmole		28.013	39.95	44.01					
End Time	58.6 s		Pav		237.3 psig					
T	445.2 R		Z		0.9686					
P	87.2 psia		SRK		-0.02154					
R	1545 ft lbf/lbmole R									
v	53.07 ft ³ /lbmole									
p	0.6464196 lbm/ft ³									
Minit	744.11426 lb				13.4 lb/ft ³					
Total Vol	57.556597 ft ³									
Mtarget	37.206 lb									
Num Of Cyl	19									
Expanded Vol	439 ft ³									
Mass per Cyl	39.163909 lb									
Cyl Vol (each)	2.93 ft ³									
Pipe Vol	1.886597 ft ³ (w/o diptube)									
TPav (abs)	446.11 R	Z		1.1349 P (gauge)	time (s)	55 Cylinder				
PAV (abs)	102.36 psia	SRK		0.18465 T (F)	87.66					
					-13.59					
TPav(abs)	444.889 R	Z		0.9039 P (gauge)	time (s)	60 Cylinder				
PAV(abs)	81.3 psia	SRK		-0.07156 T (F)	66.6					
					-14.811					
Start				End						
	Nitrogen	Argon	CO2				Nitrogen	Argon	CO2	
zm	0.54268	0.47370	0.82524	zm			0.54268	0.47370	0.82524	
az	0.61181	0.75069	1.16718	az			0.61344	0.75213	1.16939	
A	0.01410	0.01720	0.07190	0.0183993 A			0.01129	0.01376	0.05753	0.0147272
B	0.00917	0.00763	0.01017	0.0086349 B			0.00730	0.00608	0.00810	0.0068771
y	0.52000	0.40000	0.08000	y			0.52000	0.40000	0.08000	

Table C15 - Test #8 - 85% Discharge Time Calculation

S-R-K Equation Of State				Outage		85%		Test=Test8			
				Nitrogen	Argon	CO2					
Agent	Inergen										
Pc	627.74psia			492.45	707.07	1070.16	zm		Nitrogen	Argon	CO2
Tc	271.3896R			227.16	271.44	547.56	az		0.54268	0.47370	0.82524
Vc	1.3411869ft3/lbmole			1.433644981	1.1997766	1.5057277	A		0.62220	0.75987	1.18122
Zc	0.28914			0.29	0.291	0.274	B		0.03614	0.04389	0.18344
w	0.03632			0.04	-0.004	0.225	y		0.02272	0.01891	0.0213931
MW	34.30546lb/lbmole			28.013	39.95	44.01			0.52000	0.40000	0.08000
End Time	68.6 s			Pav		285.1psig					
T	438.4R			Z		0.9708					
P	249.2psia			SRK		-0.00409					
R	1545ft lbf/lbmole R										
v	18.322ft3/lbmole										
p	1.8723701lbm/ft3										
Minit	626.62254lb			Fill Density		13.4lb/ft3					
Total Vol	50.200214ft3										
Mtarget	93.993lb										
Num Of Cyl	16										
Expanded Vol	439ft3										
Mass per Cyl	39.163909lb										
Cyl Vol (each)	2.93ft3										
Pipe Vol	3.320214ft3 (w/o diptube)										
						time (s)		67 Cylinder			
TPav (abs)	439.525R			Z		1.0038P (gauge)		243.665			
PAV (abs)	258.37psia			SRK		0.02869T (F)		-20.175			
						time (s)		72 Cylinder			
TPav(abs)	436.058R			Z		0.9027P (gauge)		215.817			
PAV(abs)	230.52psia			SRK		-0.05857T (F)		-23.642			
Start						End					
	Nitrogen	Argon	CO2						Nitrogen	Argon	CO2
zm	0.54268	0.47370	0.82524			zm		0.54268	0.47370	0.82524	
az	0.62065	0.75850	1.17913			az		0.62536	0.76266	1.18549	
A	0.03718	0.04519	0.18886			0.0484283A		0.03396	0.04118	0.17212	0.0441803
B	0.02349	0.01955	0.02606			0.0221216B		0.02113	0.01758	0.02343	0.0198942
y	0.52000	0.40000	0.08000			y		0.52000	0.40000	0.08000	

Table C16 - Test #8 - 95% Discharge Time Calculation

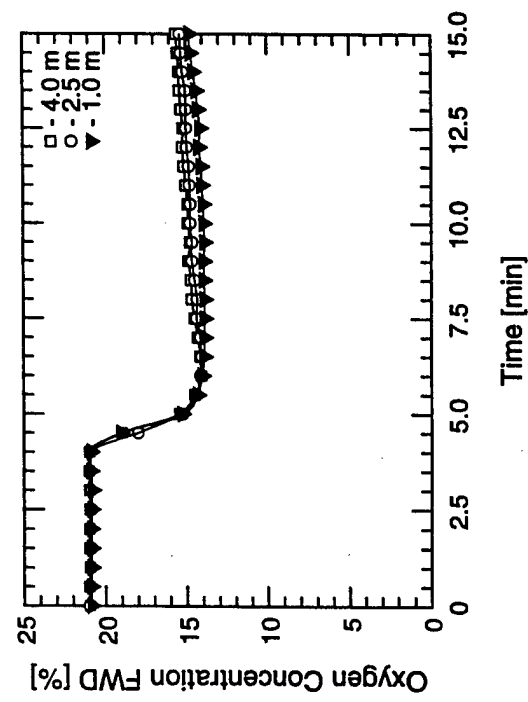
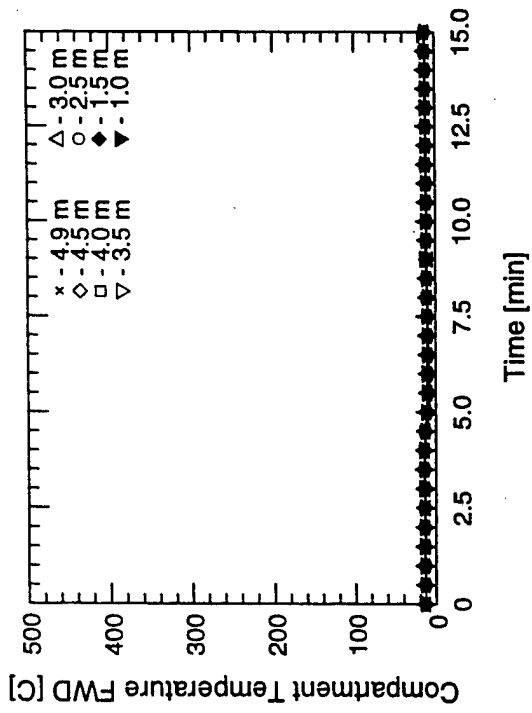
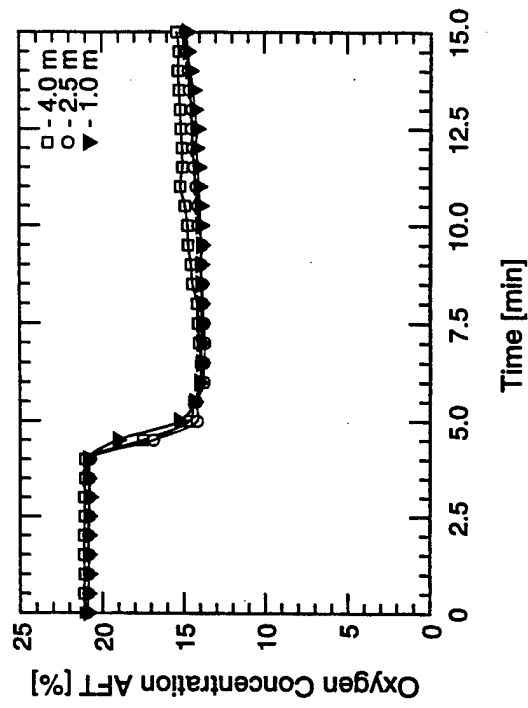
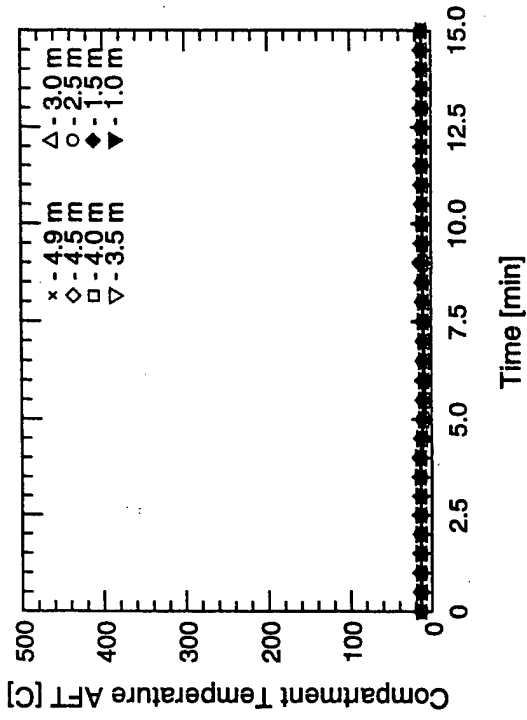
Table C10 - Test #8 - 95% Nitrogen Gas Time Calculation											
S-R-K Equation Of State			Outage		95%		Test=Test8				
Agent	Inergen		Nitrogen	Argon	CO2				Nitrogen	Argon	CO2
Pc	627.74psia		492.45	707.07	1070.16		zm		0.54268	0.47370	0.82524
Tc	271.3896R		227.16	271.44	547.56		az		0.64050	0.77599	1.20587
Vc	1.3411869ft3/lbmole		1.433644981	1.1997766	1.5057277		A		0.01299	0.01565	0.06541
Zc	0.28914		0.29	0.291	0.274		B		0.00769	0.00640	0.00853
w	0.03632		0.04	-0.004	0.225		y		0.52000	0.40000	0.08000
MW	34.30546lb/lbmole		28.013	39.95	44.01						
End Time	115.4 s		Pav		188.8psig						
T	425.1R		Z		0.9863						
P	81.8psia		SRK		-0.00403						
R	1545ft lb/ft3/lbmole R										
v	54.966ft3/lbmole										
p	0.6241234lbm/ft3										
Minit	626.62254lb			Fill Density	13.4lb/ft3						
Total Vol	50.200214ft3										
Mtarget	31.331lb										
Num Of Cyl	16										
Expanded Vol	439ft3										
Mass per Cyl	39.163909lb										
Cyl Vol (each)	2.93ft3										
Pipe Vol	3.320214ft3 (w/o diptube)										
					time (s)		113Cylinder				
TPav (abs)	425.125R		Z	1.0404P (gauge)				71.634			
Pav (abs)	86.334psia		SRK	0.05404T (F)				-34.575			
					time (s)		117Cylinder				
TPav(abs)	425.068R		Z	0.9488P (gauge)				64.02			
Pav(abs)	78.72psia		SRK	-0.03753T (F)				-34.632			
Start					End						
			Nitrogen	Argon	CO2				Nitrogen	Argon	CO2
zm	0.54268	0.47370	0.82524		zm			0.54268	0.47370	0.82524	
az	0.64045	0.77594	1.20581		az			0.64053	0.77601	1.20591	
A	0.01370	0.01651	0.06898	0.0177643A				0.01250	0.01506	0.06292	0.0162037
B	0.00812	0.00675	0.00900	0.0076424B				0.00740	0.00616	0.00821	0.0069694
y	0.52000	0.40000	0.08000		y			0.52000	0.40000	0.08000	

APPENDIX D - TEST DATA

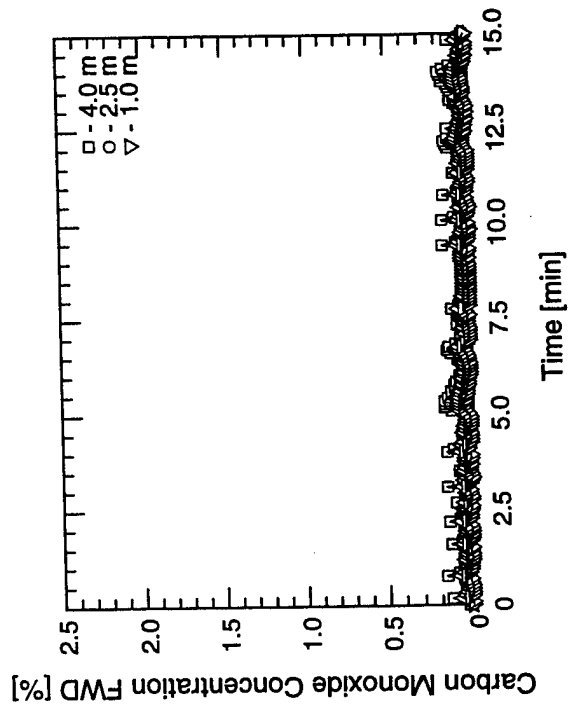
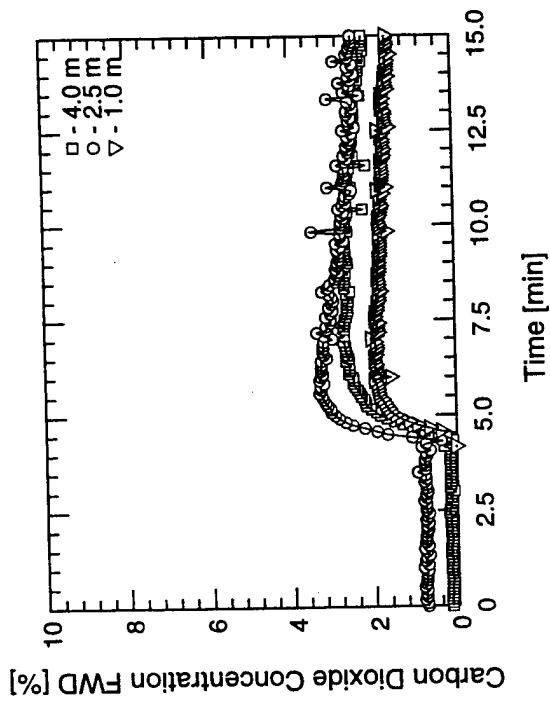
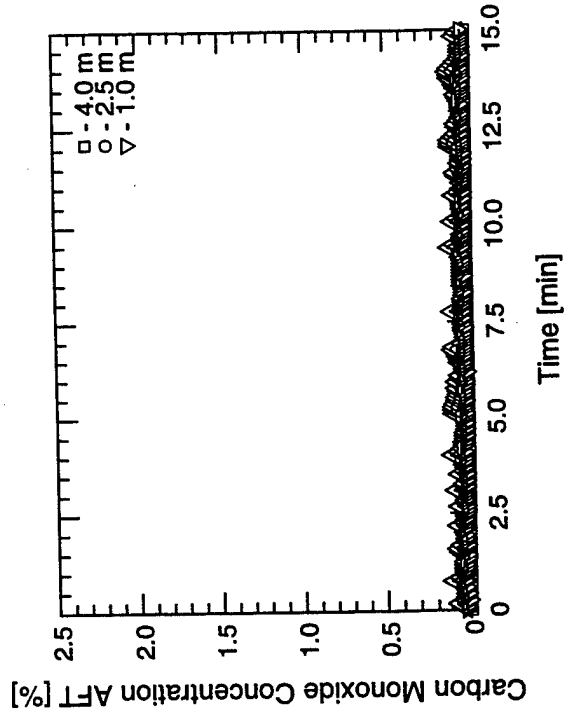
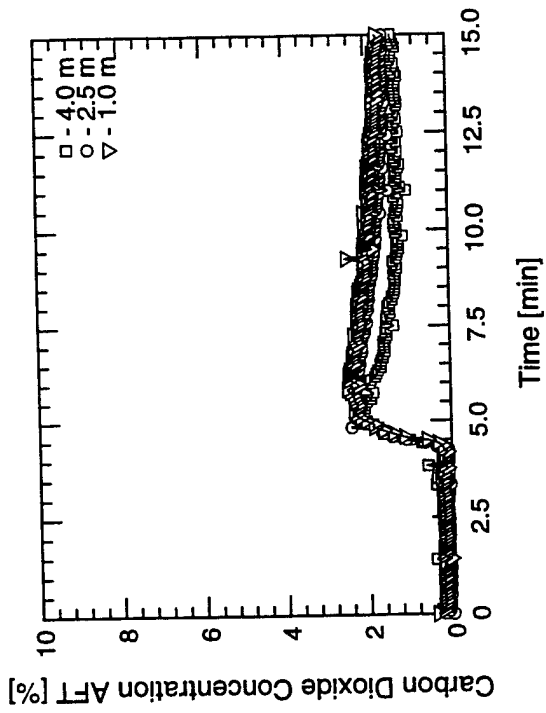
Test #	CRADA	Agent	System	Fire Scenario	Page
1	Ansul	Inergen	1 - 360°	1	D-3
2	Ansul	Inergen	1 - 360°	5	D-6
3	Ansul	Inergen	1 - 360°	5	D-9
4	Ansul	Inergen	2 - 180°	5	D-12
5	Ansul	Inergen	1 - 360°	2B	D-15
6	Ansul	Inergen	1 - 360°	3	D-18
7	Ansul	Inergen	1 - 360°	4	D-21
8	Ansul	Inergen	1 - 360°	5	D-24
9	Ansul	NAF-SIII	4 - 360°	5	D-27
10	Ansul	NAF-SIII	4 - 360°	5	D-30
11	3M	CEA-308	4 - 360°	1	D-33
12	3M	CEA-308	4 - 360°	5	D-36
13	3M	CEA-308	4 - 360°	3	D-39
14	3M	CEA-308	4 - 360°	4	D-42
15	3M	CEA-308	4 - 360°	4	D-45
16	3M	CEA-308	4 - 360°	3	D-48
17	3M	CEA-308	4 - 360°	4	D-51
18	3M	CEA-308	4 - 360°	4	D-54
19	3M	CEA-308	4 - 360°	2A	D-57
20	3M	CEA-308	4 - 360°	2A	D-60
21	FMRC/Sea-Fire	FM-200	4 - 360°	1	D-63
22	FMRC/Sea-Fire	FM-200	4 - 360°	5	D-66
23	FMRC/Sea-Fire	FM-200	4 - 360°	3	D-69
24	FMRC/Sea-Fire	FM-200	4 - 360°	2A	D-72
25	FMRC/Sea-Fire	FM-200	4 - 360°	4	D-75
26	FMRC/Sea-Fire	FM-200	4 - 180°	1	D-78
27	Kidde-Fenwal	FM-200	4 - 360°	5	D-81
28	Kidde-Fenwal	FM-200	2 - 360°	5	D-84
29	Kidde-Fenwal	FM-200	2 - 180° *	5	D-87
30	Kidde-Fenwal	FM-200	2 - 180° *	1	D-90
31	Kidde-Fenwal	FM-200	2 - 180°	5	D-93
32	Kidde-Fenwal	FM-200	2 - 180°	1	D-96
33	Chemetron	FM-200	4 - 360°	1	D-99
34	Chemetron	FM-200	4 - 360°	5	D-102
35	Chemetron	FM-200	4 - 360°	2A	D-105
36	Chemetron	FM-200	4 - 360°	3	D-108
37	Chemetron	FM-200	4 - 360°	4	D-111
38	Chemetron	FM-200	2 - 360°	5	D-114
39	Chemetron	FM-200	2 - 180°	5	D-117

* Back to back nozzles.

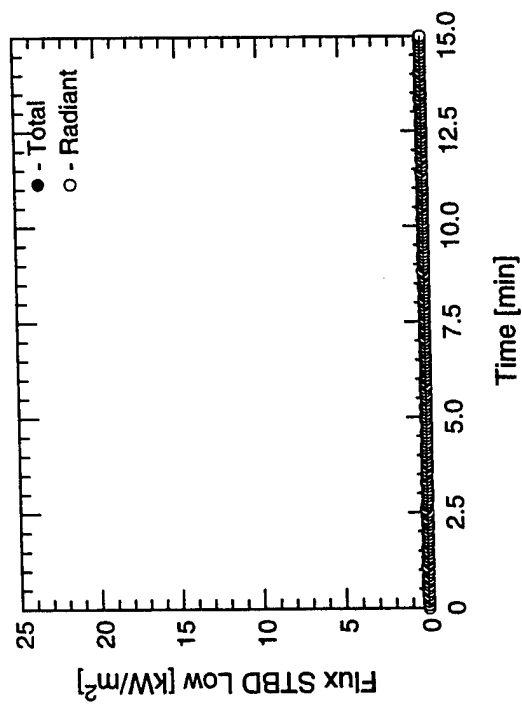
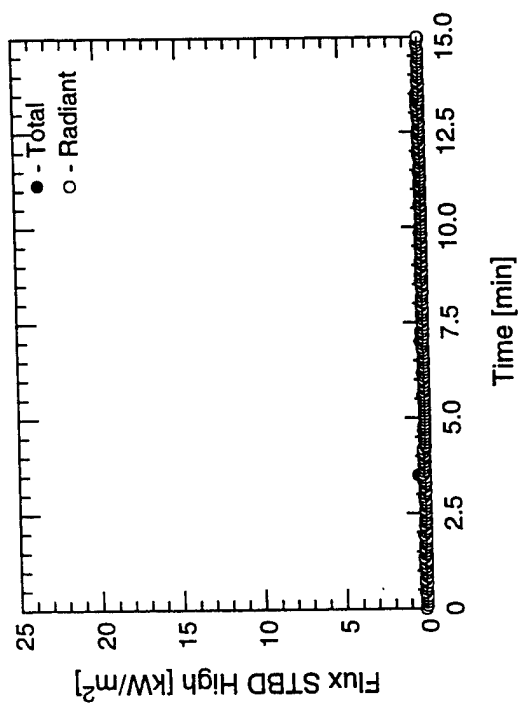
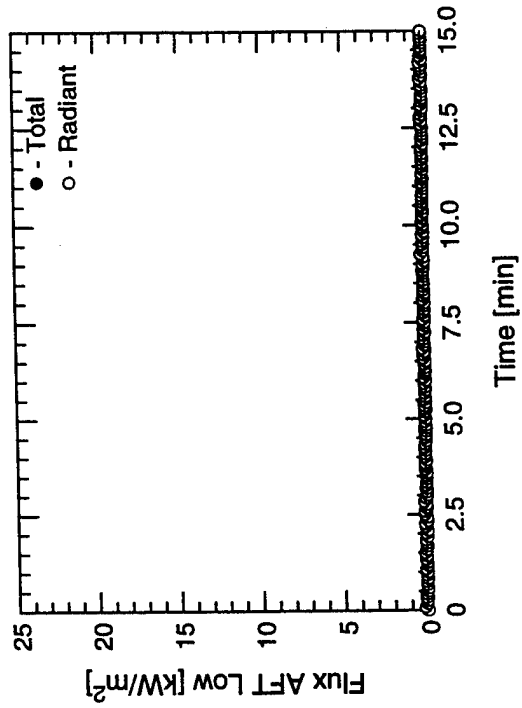
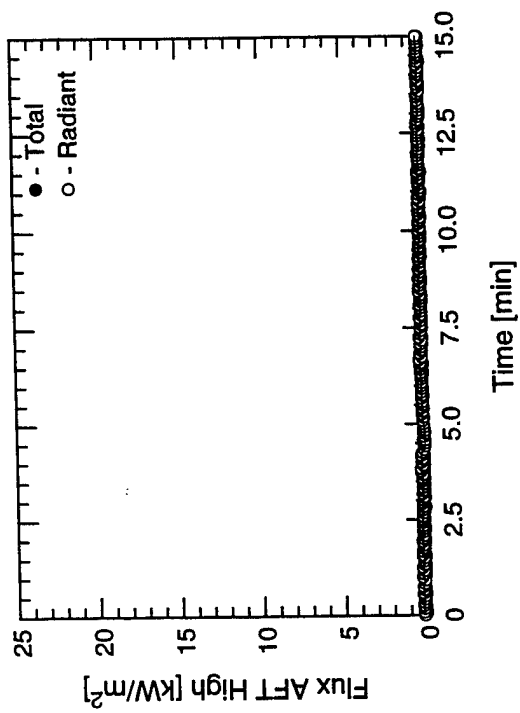
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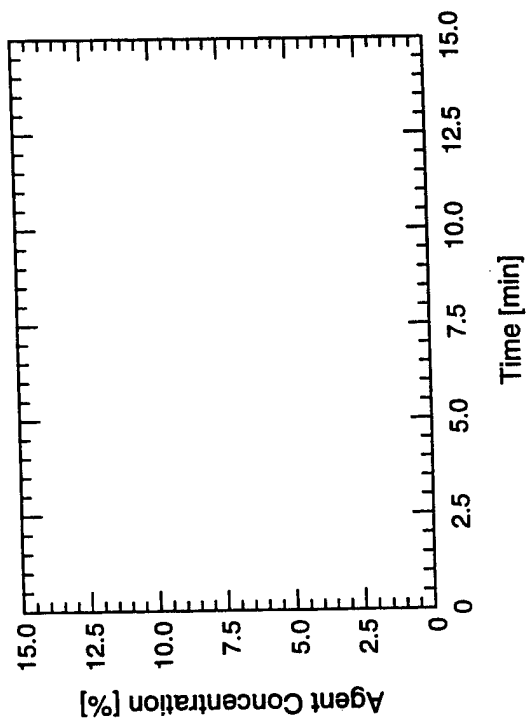
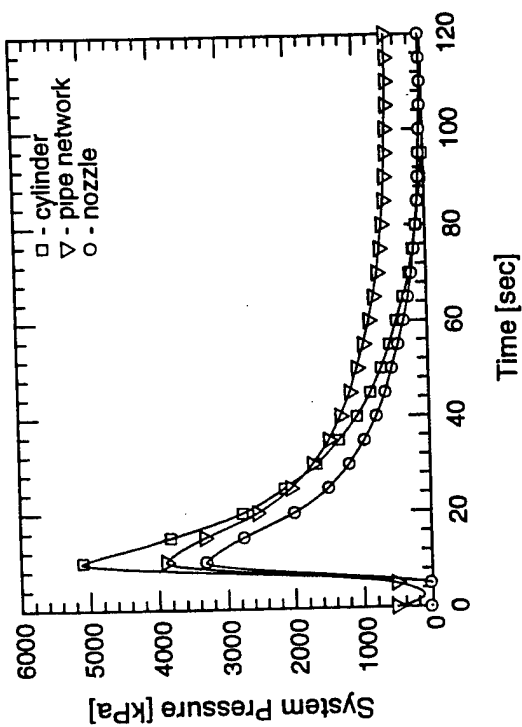
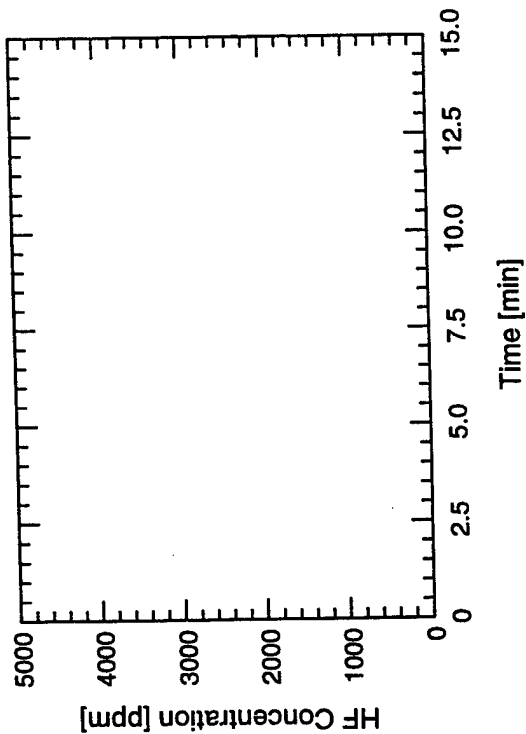
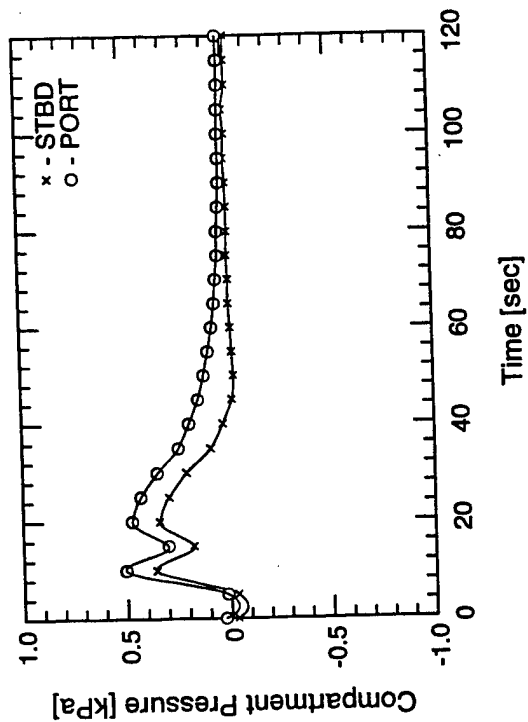


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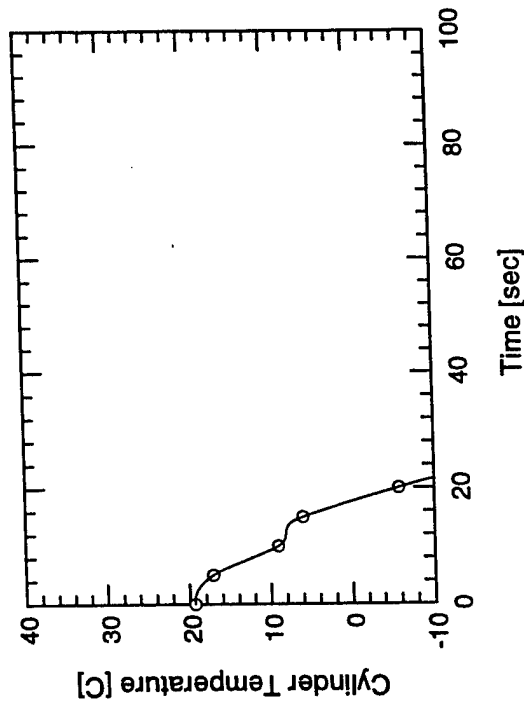
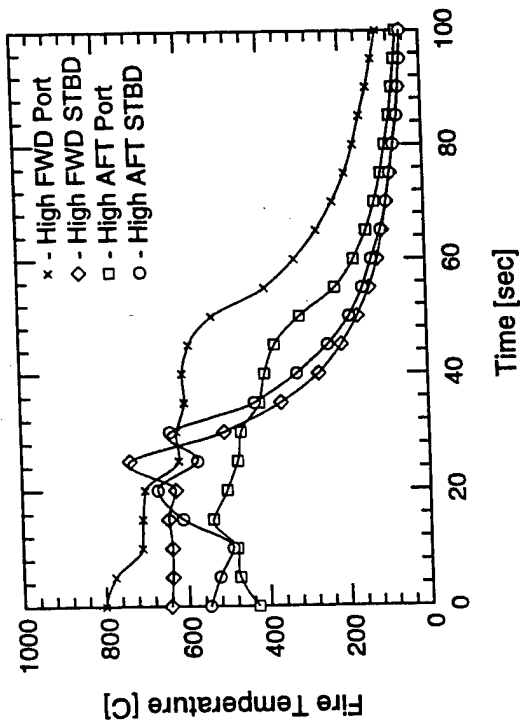
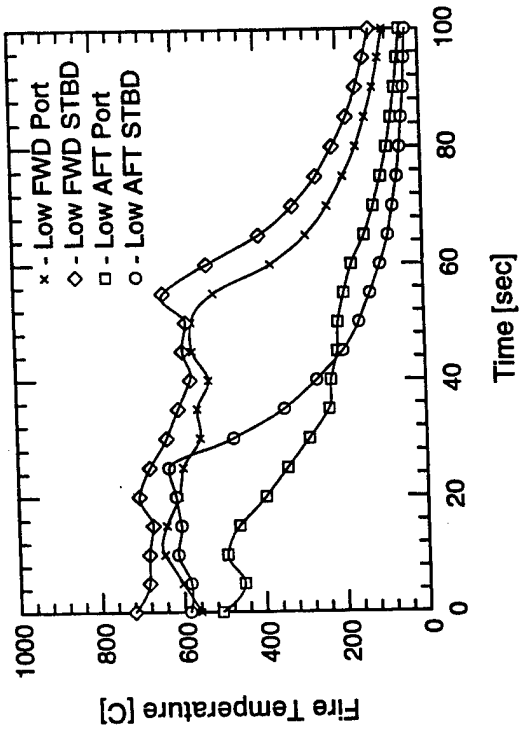


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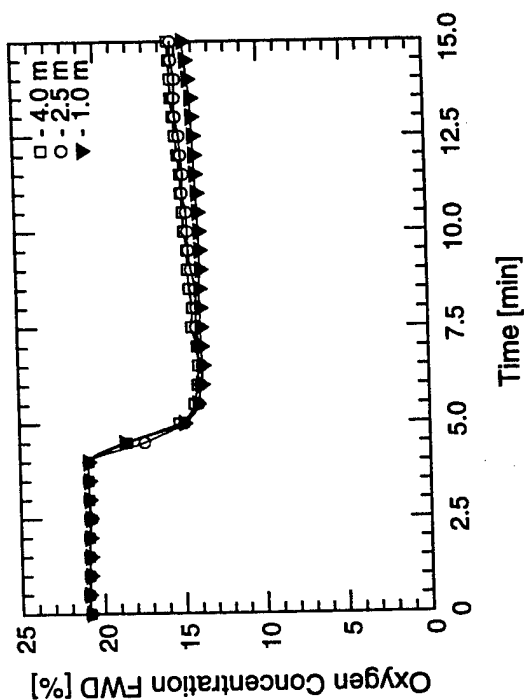
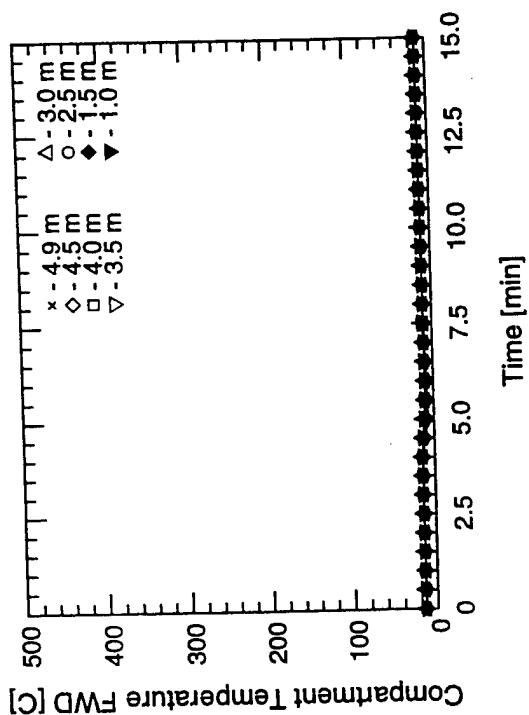
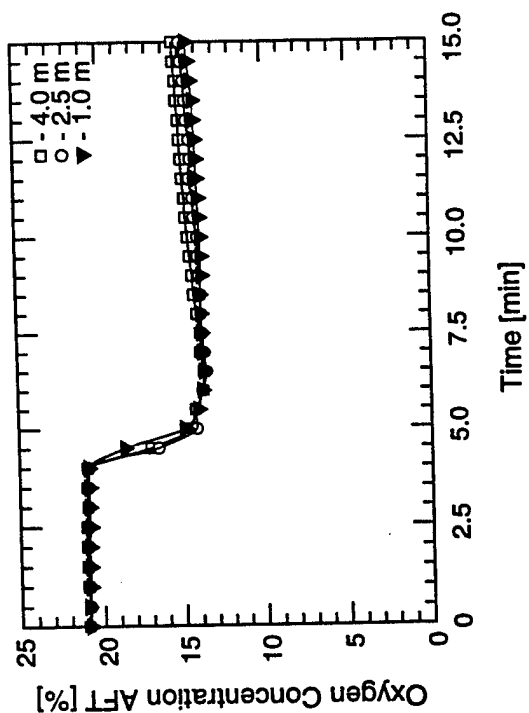
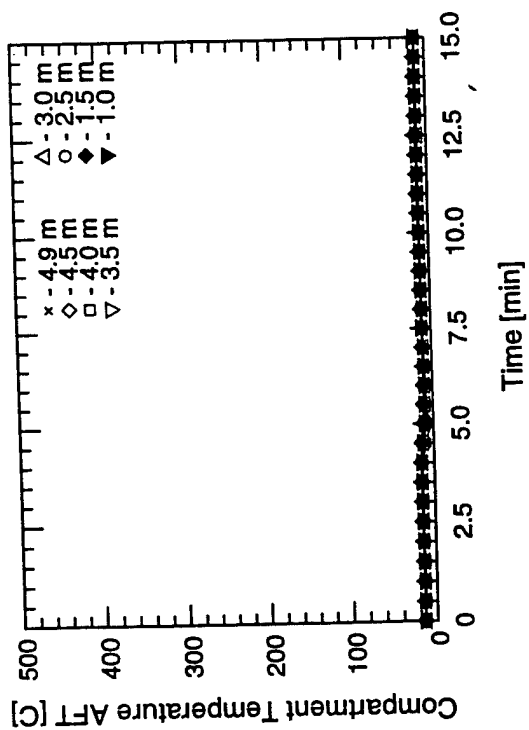




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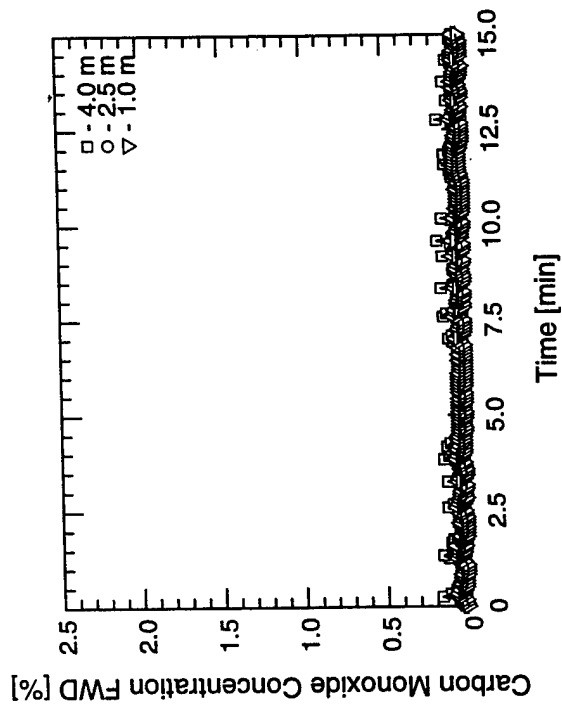
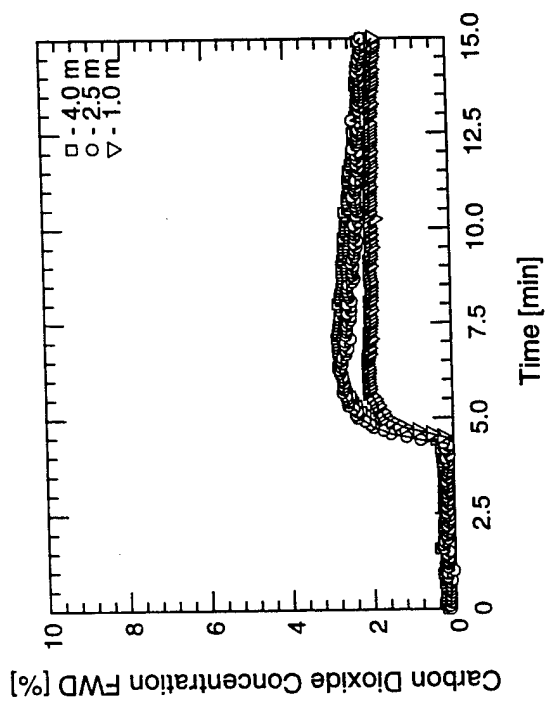
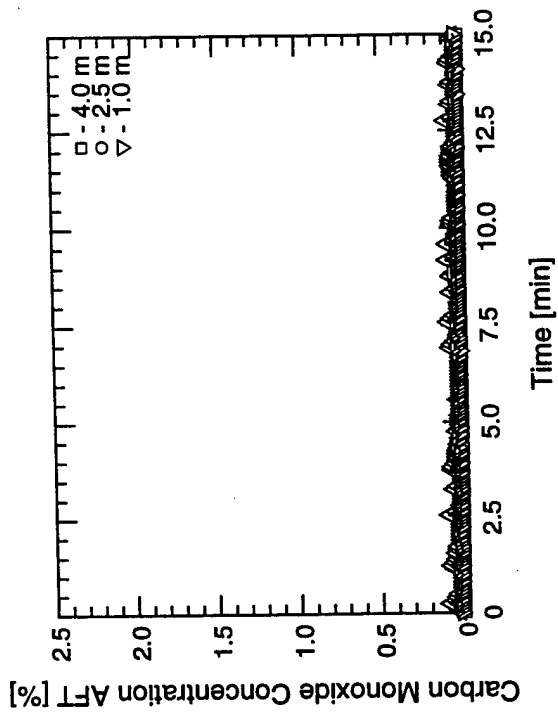
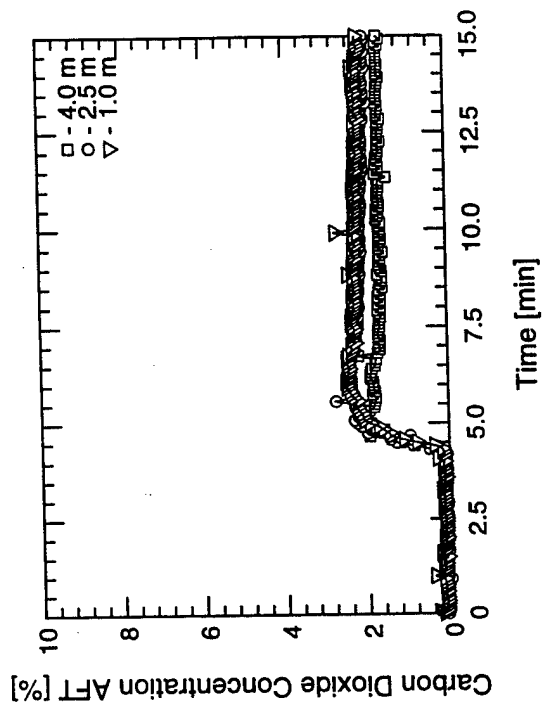


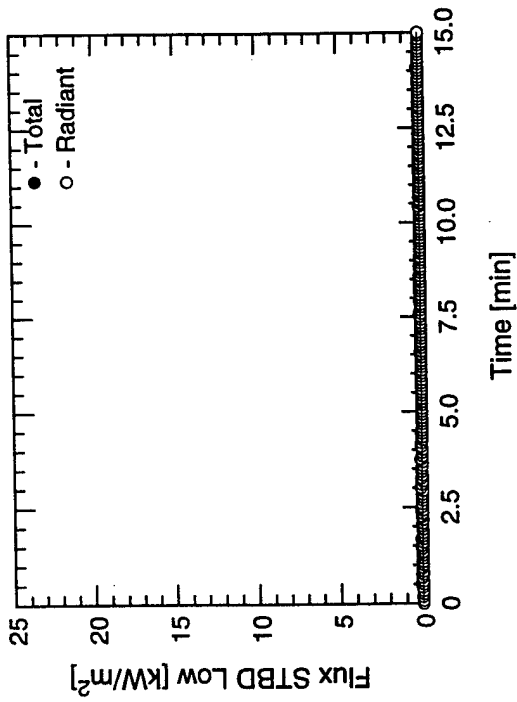
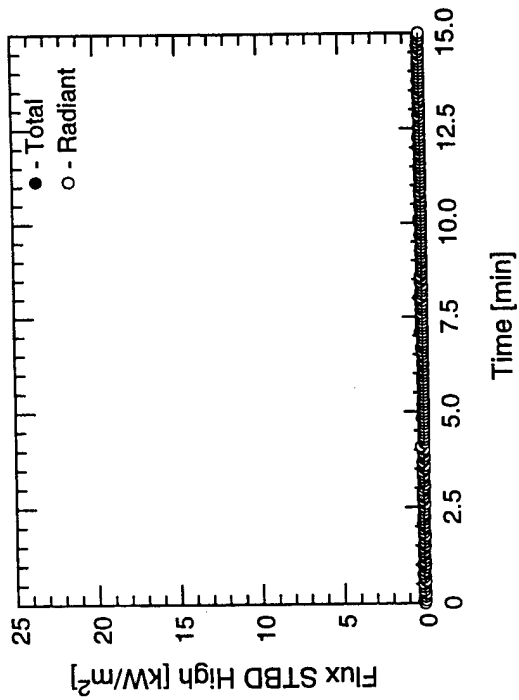
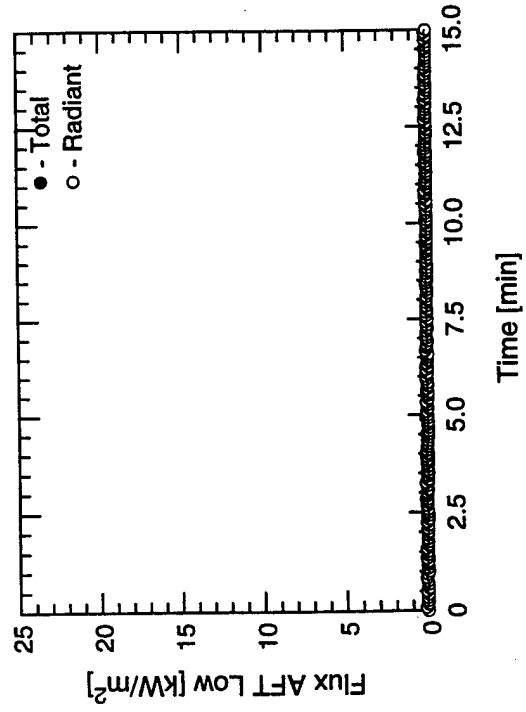
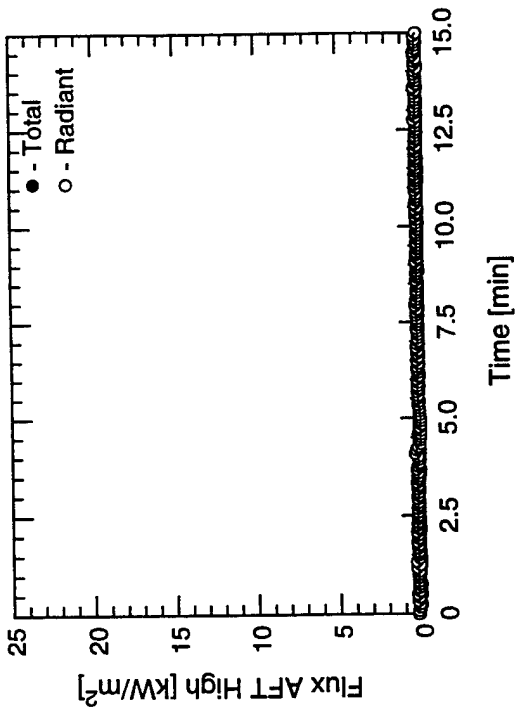
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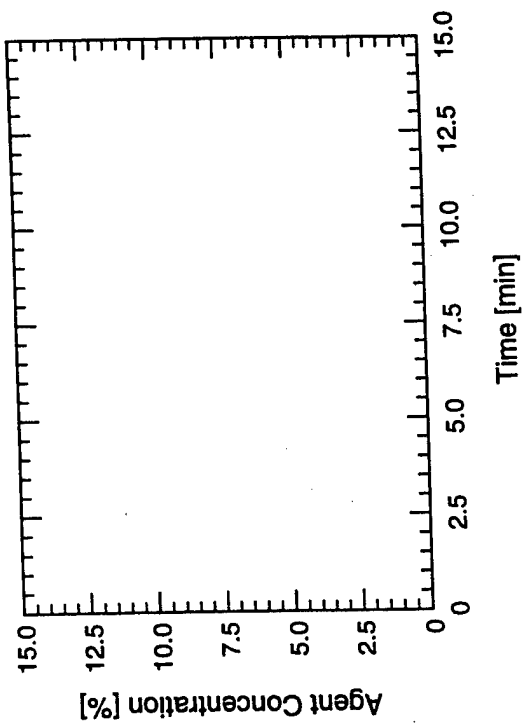
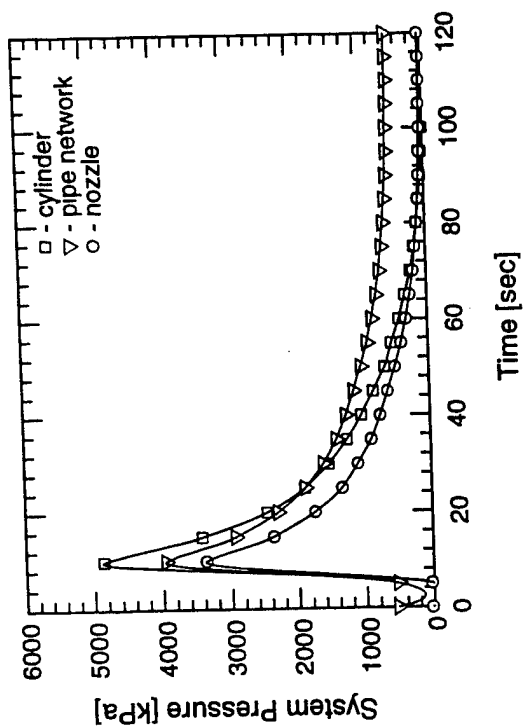
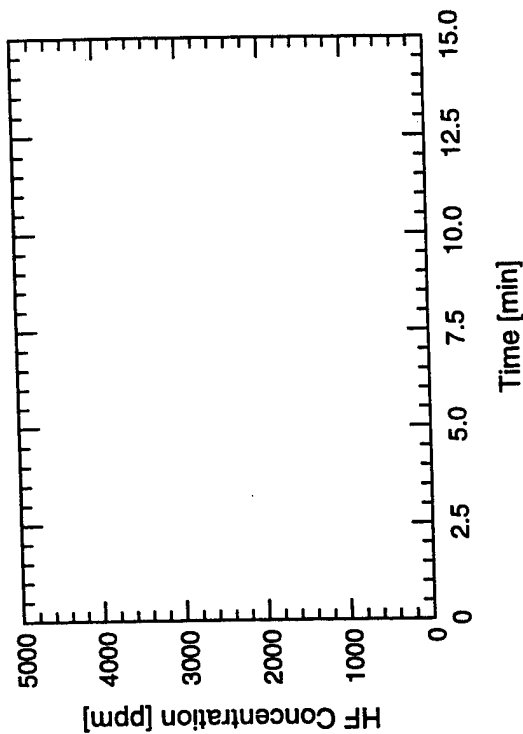
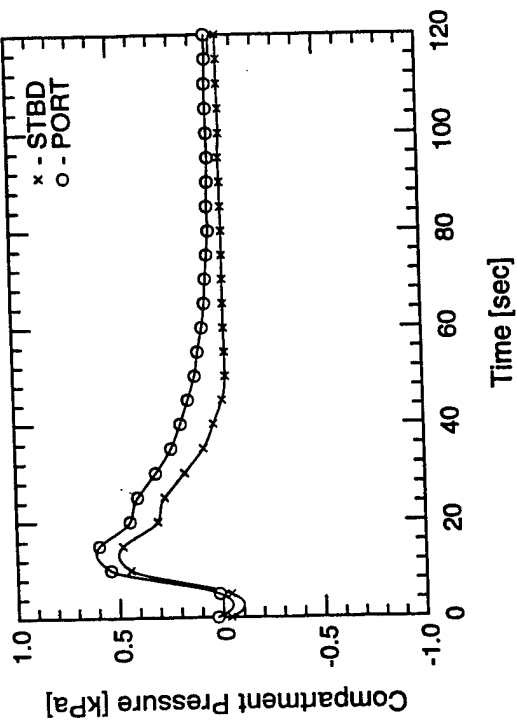
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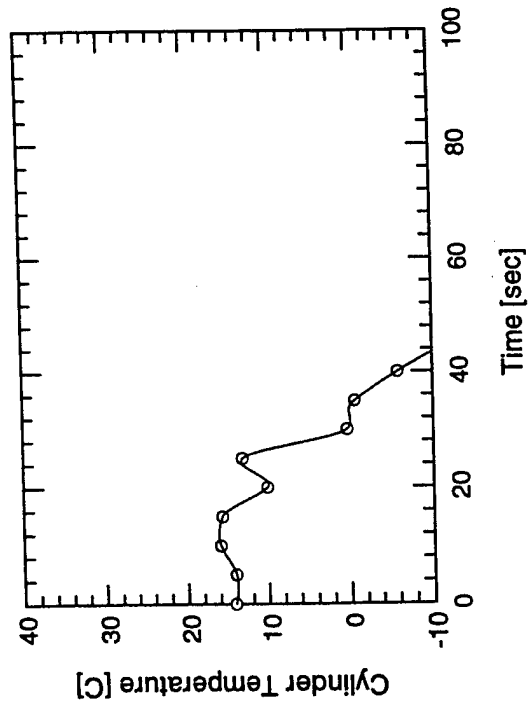
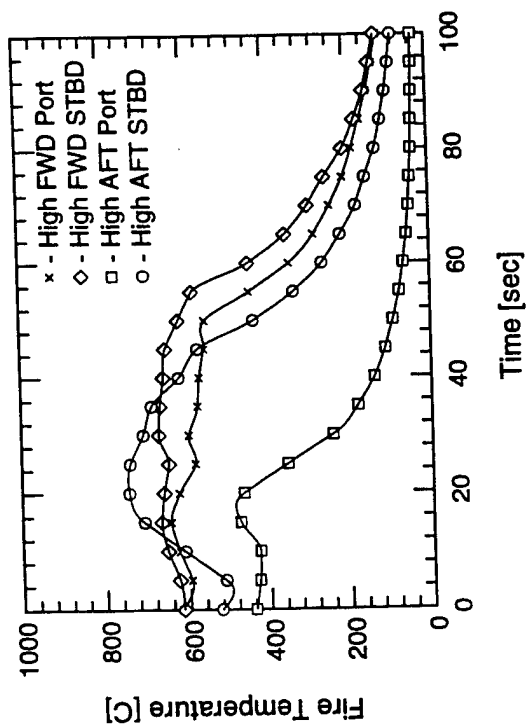
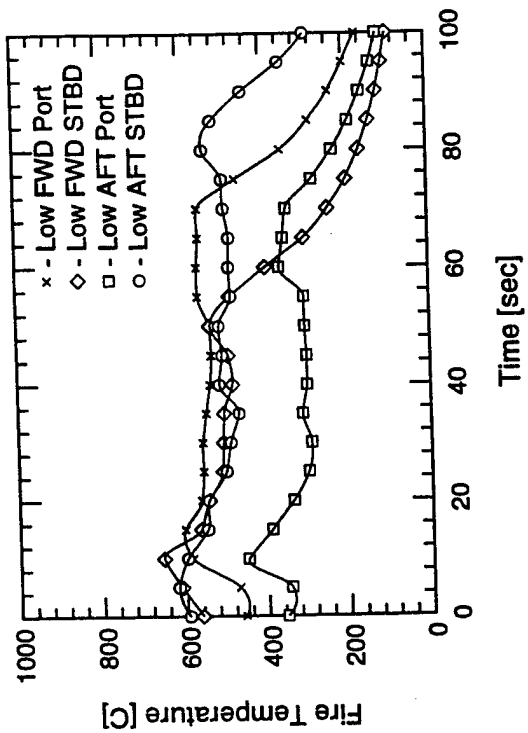




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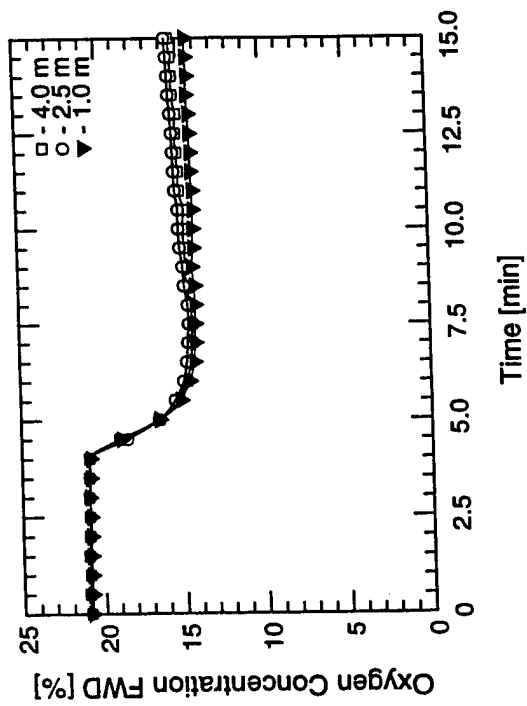
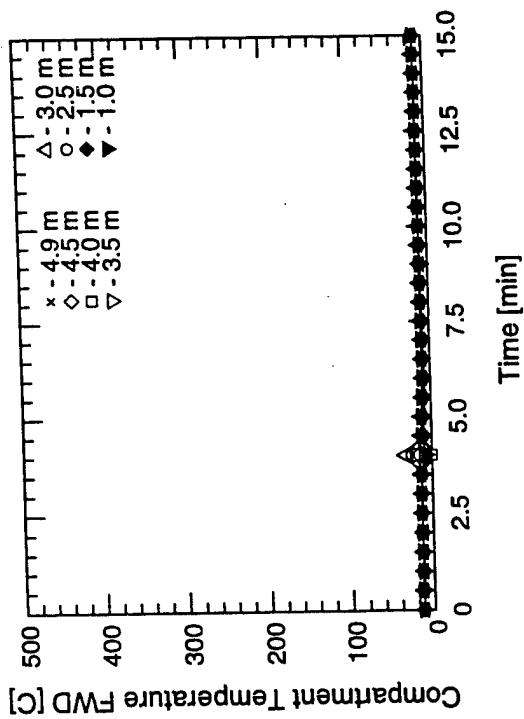
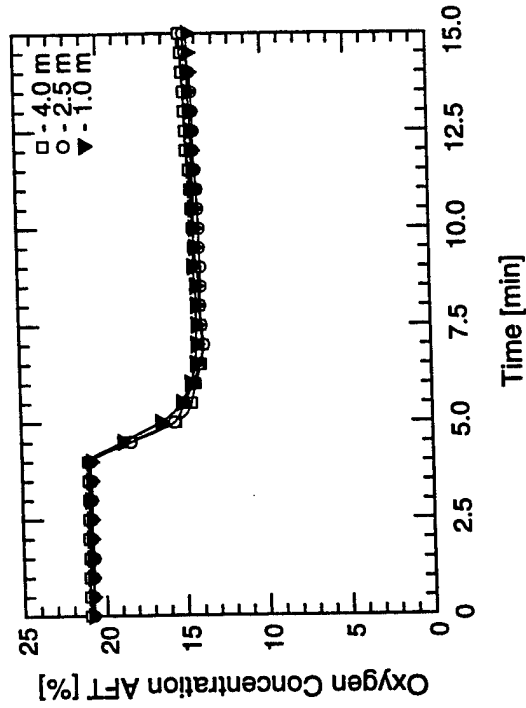
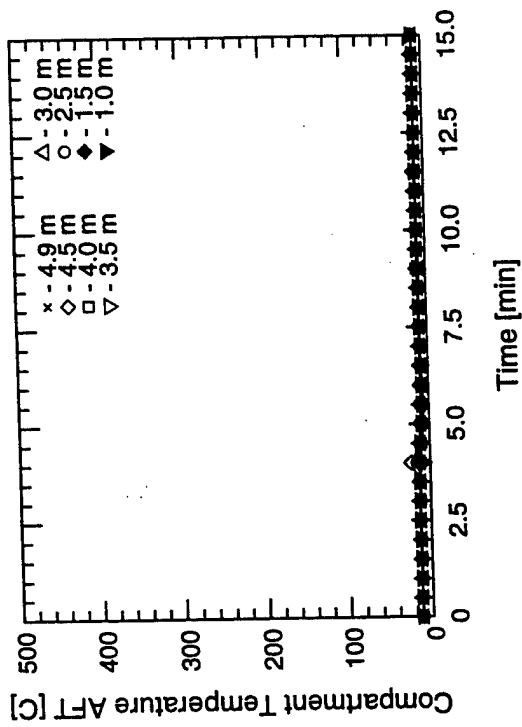
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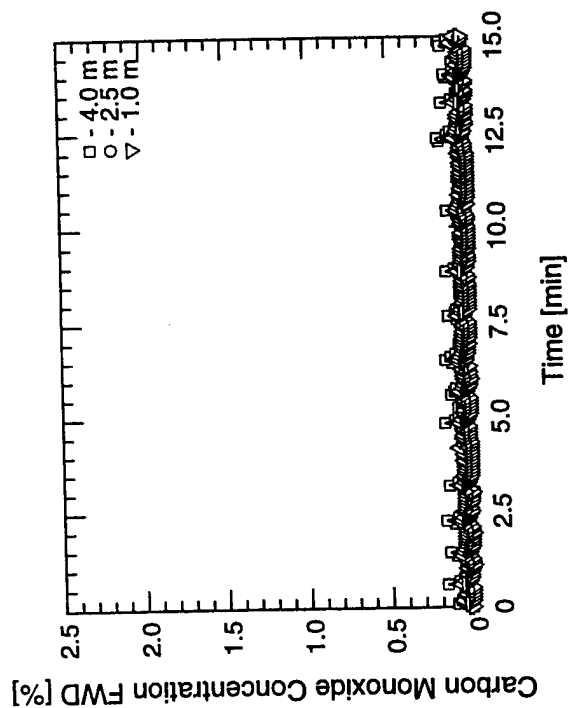
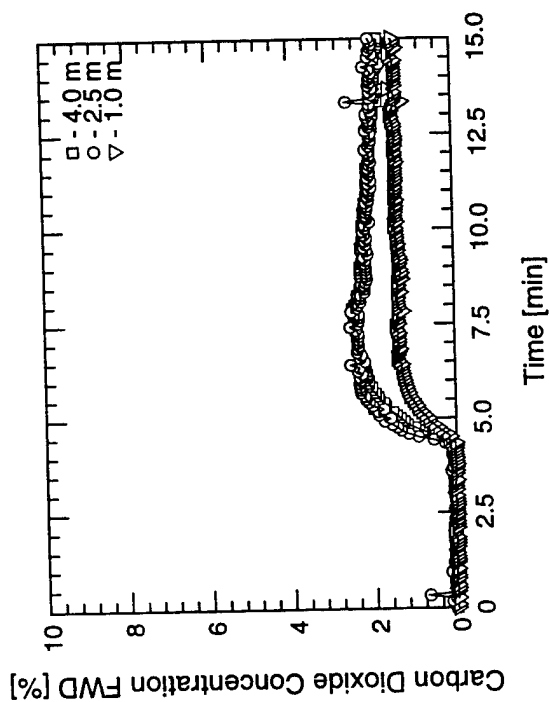
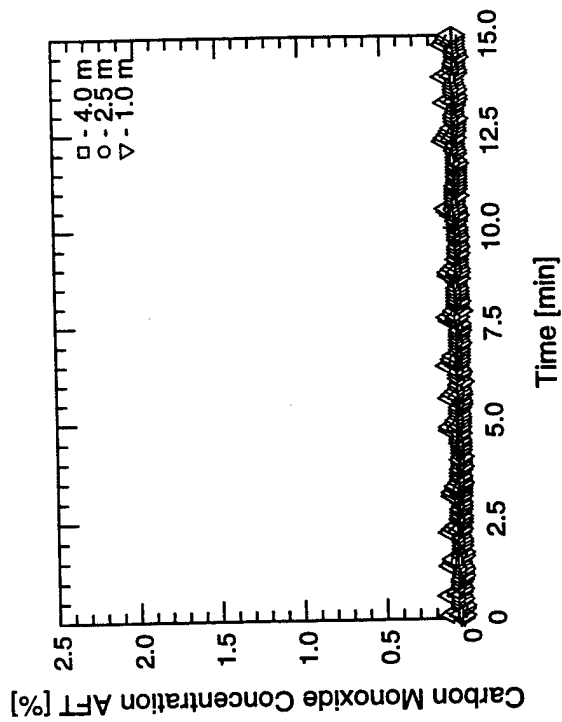
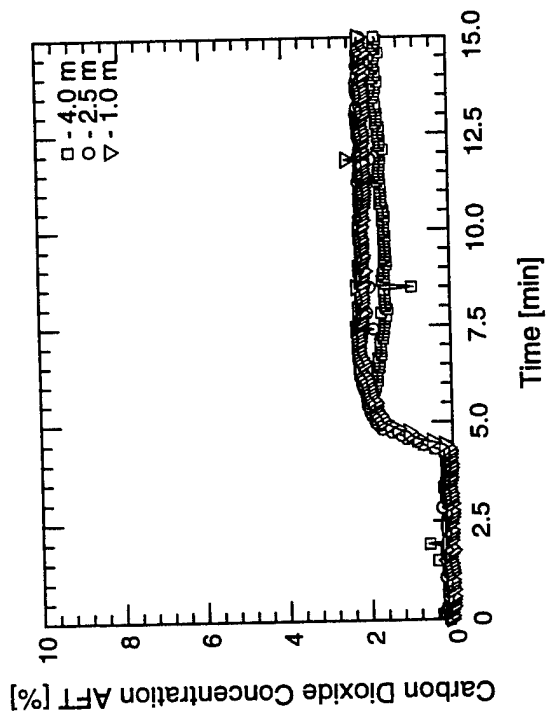




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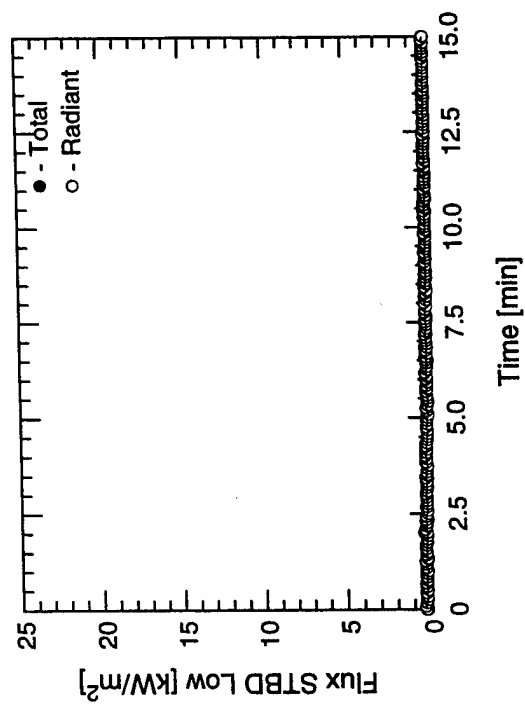
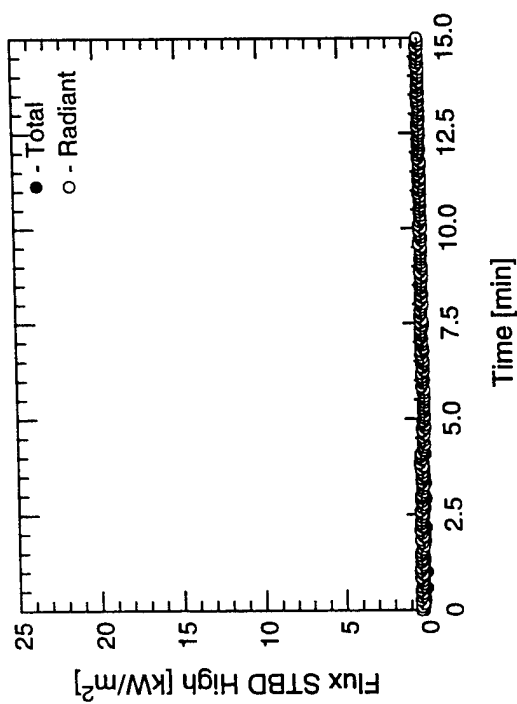
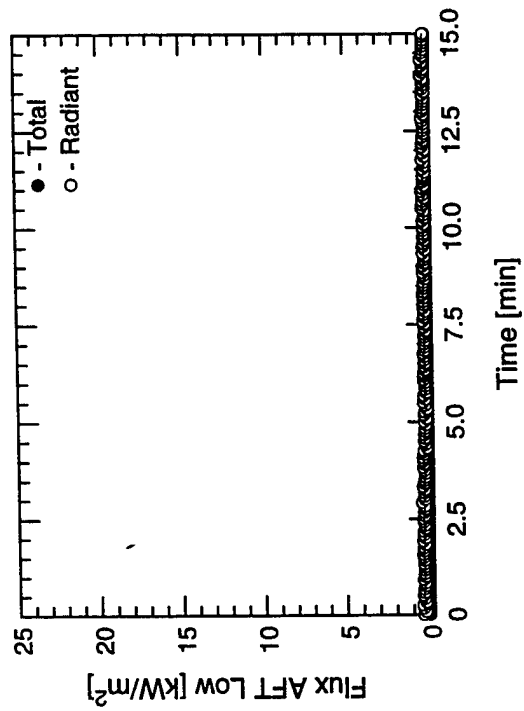
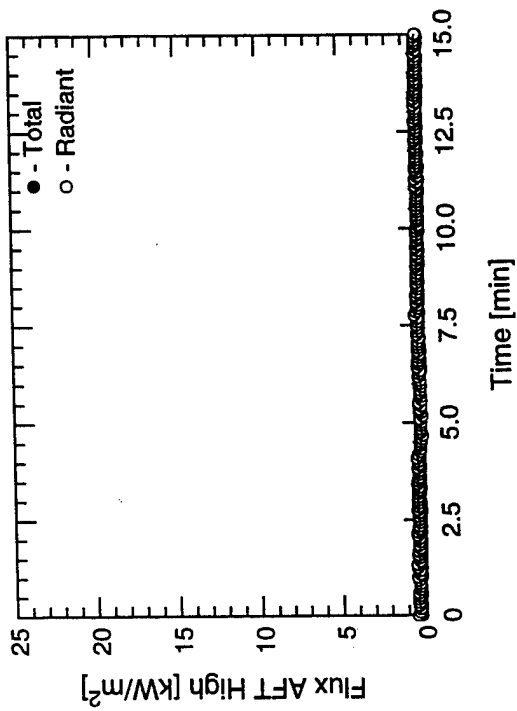
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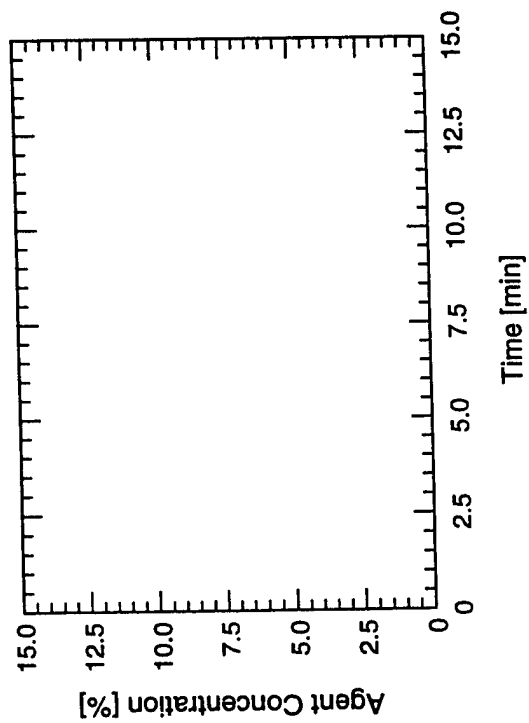
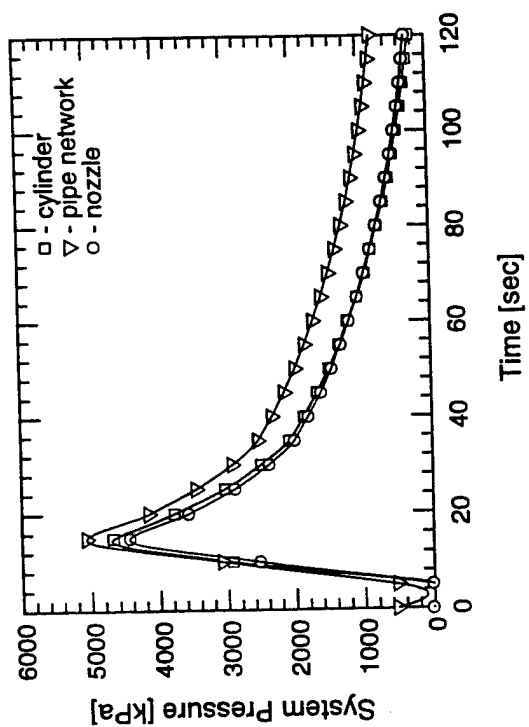
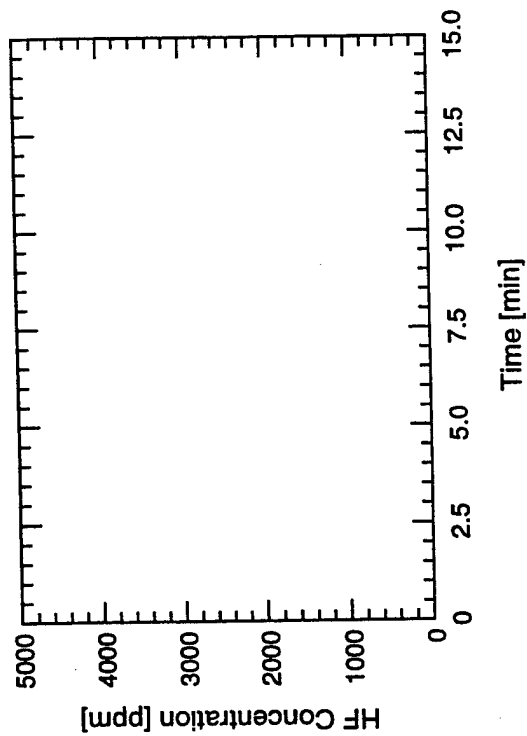
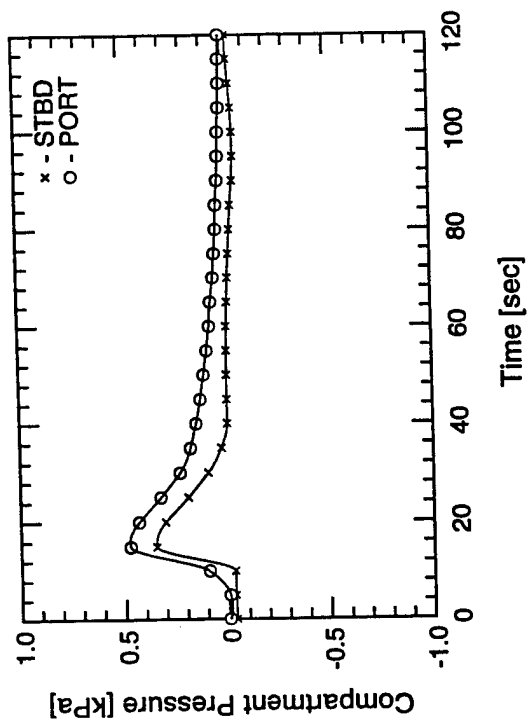




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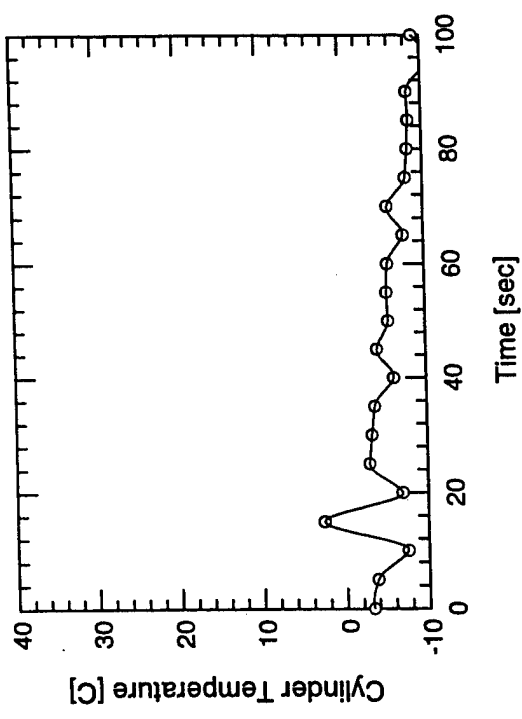
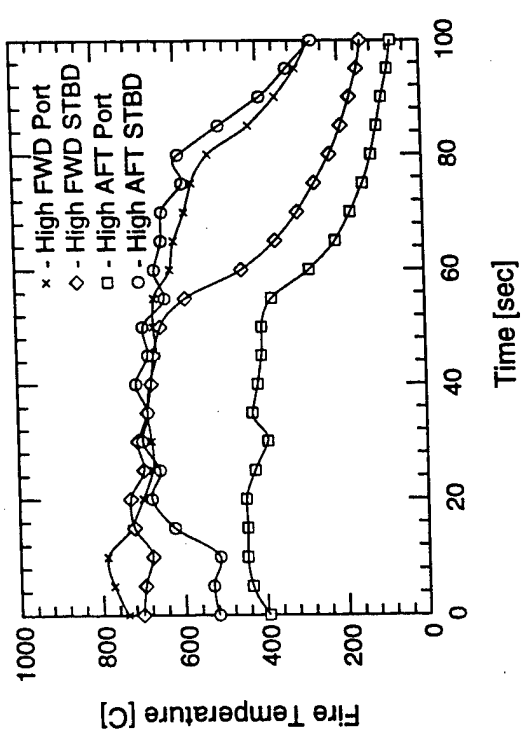
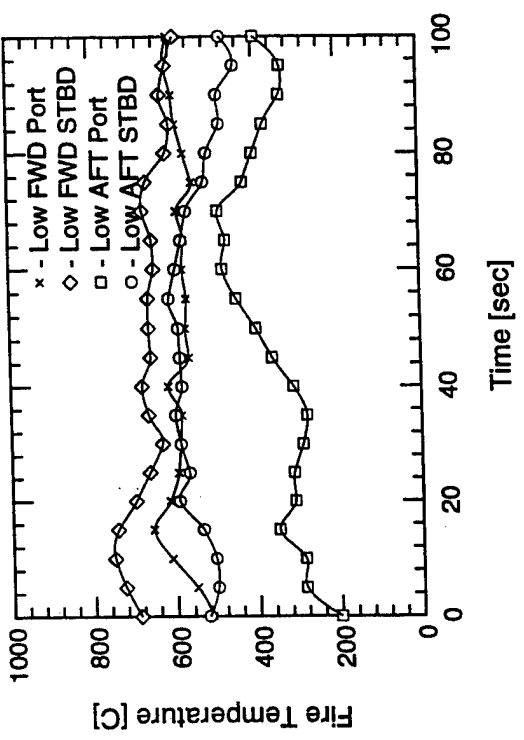
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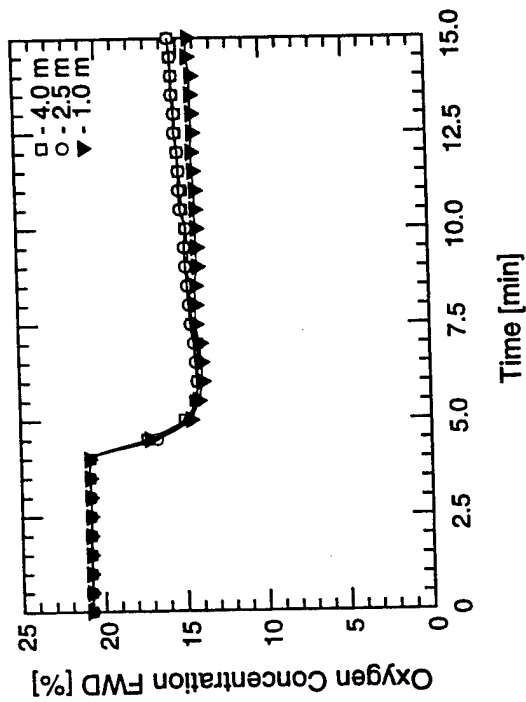
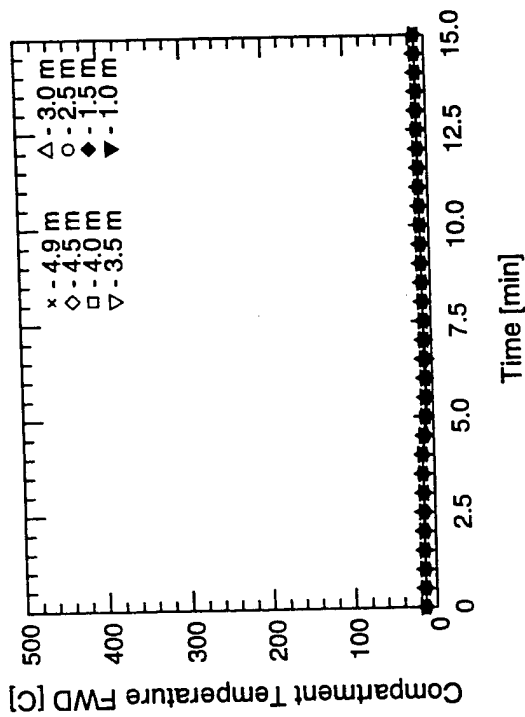
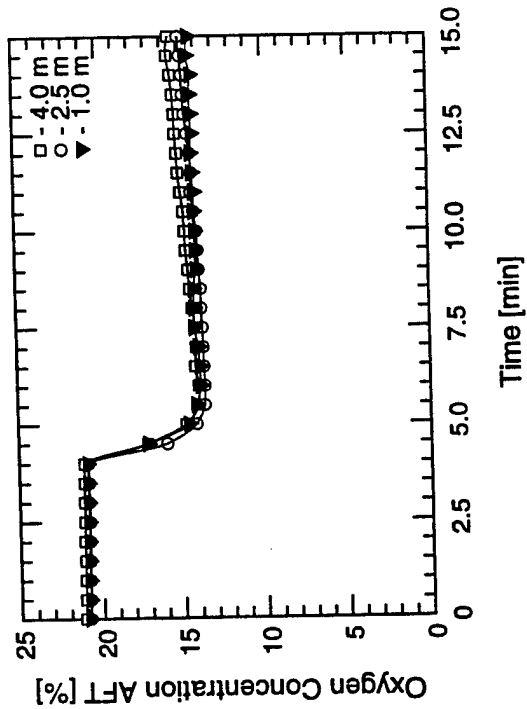
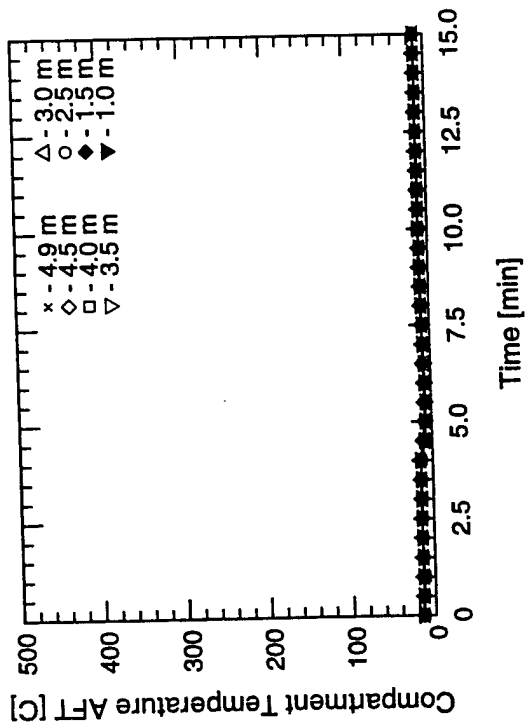




Test #3

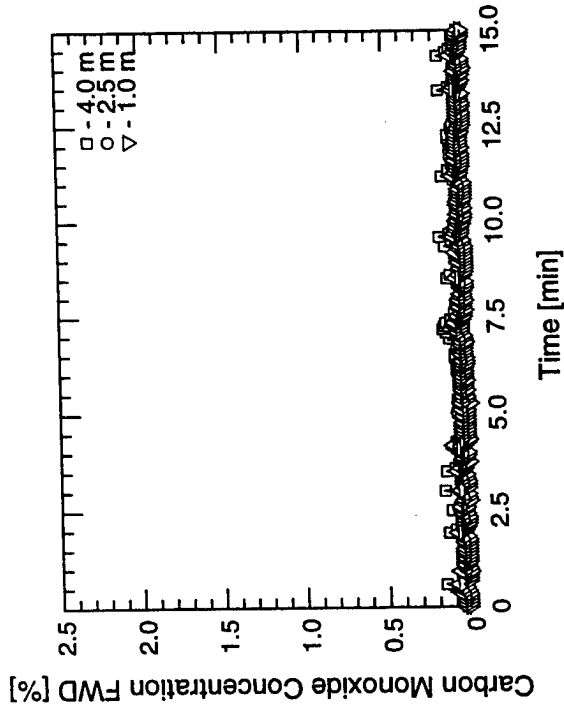
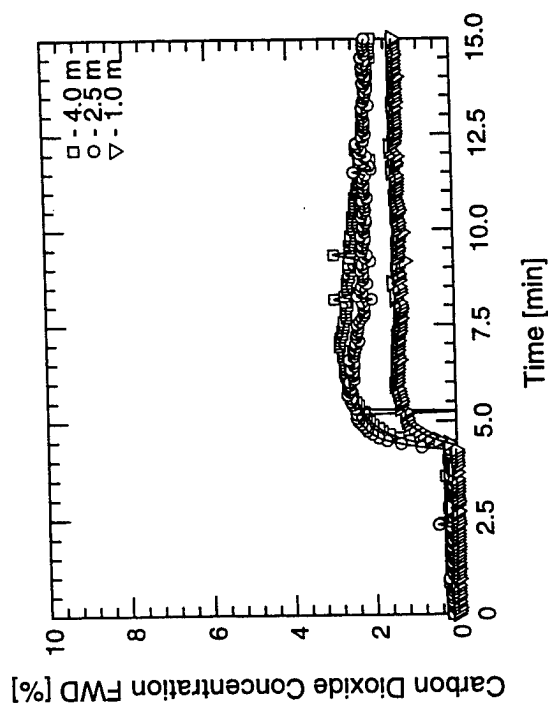
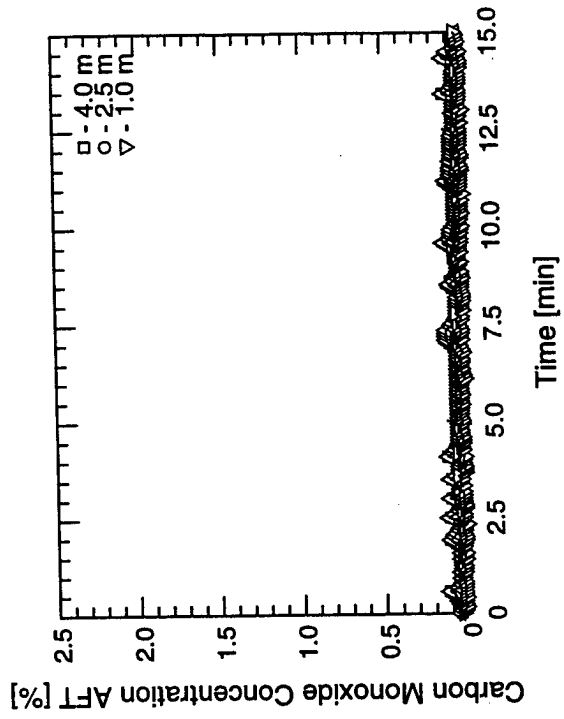
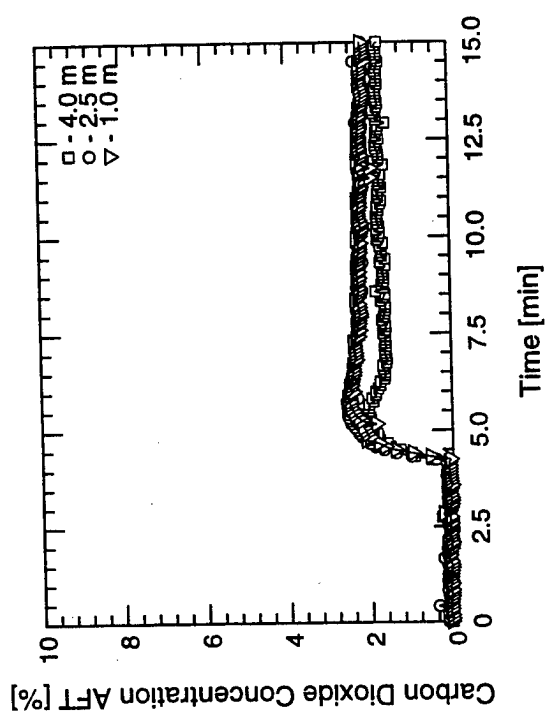
Test #3

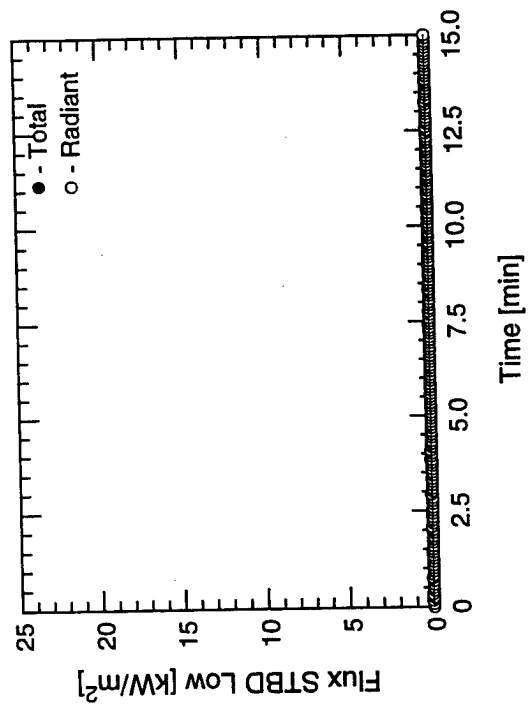
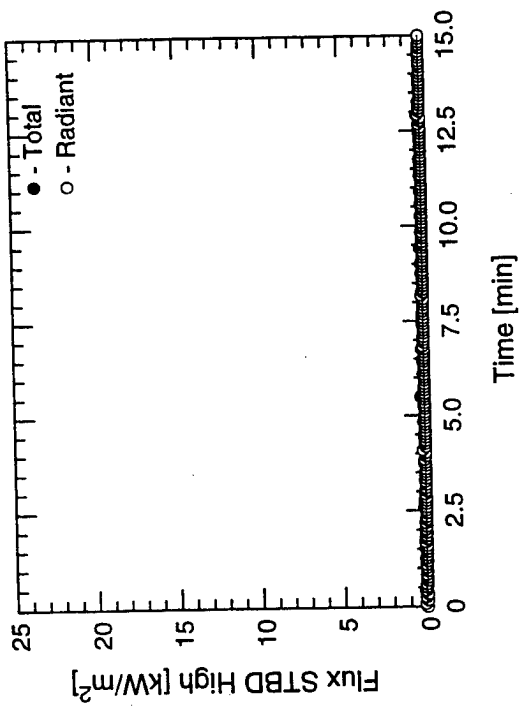
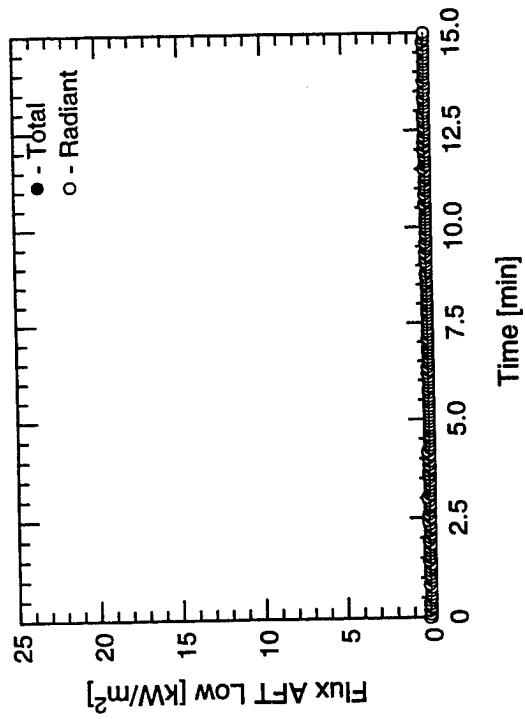
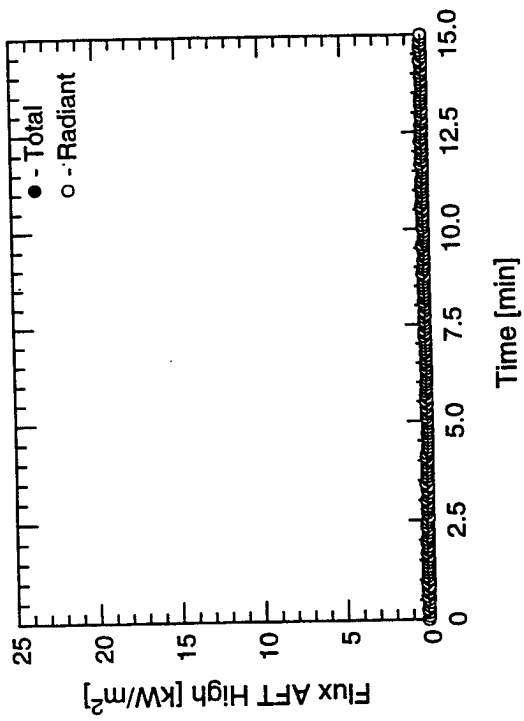




Test #4

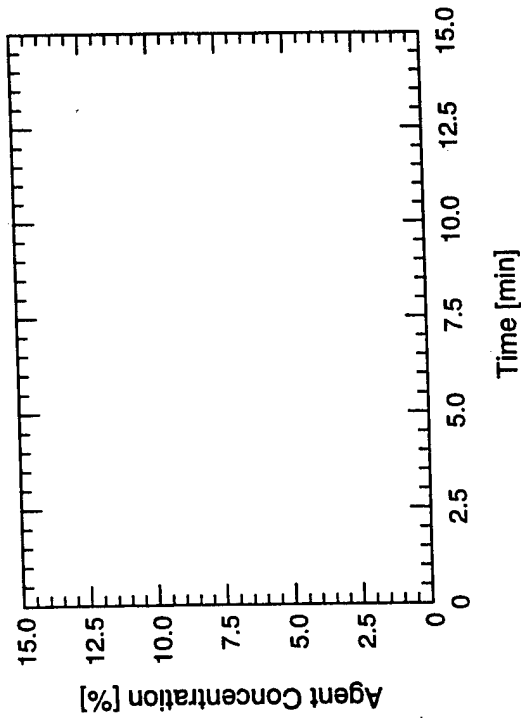
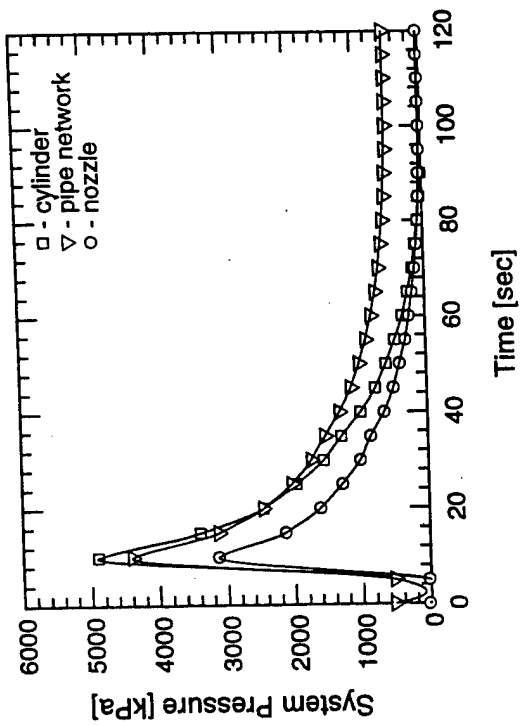
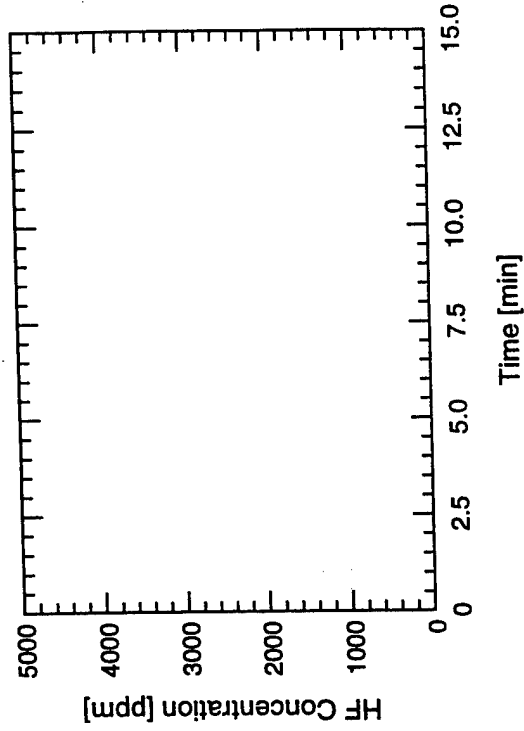
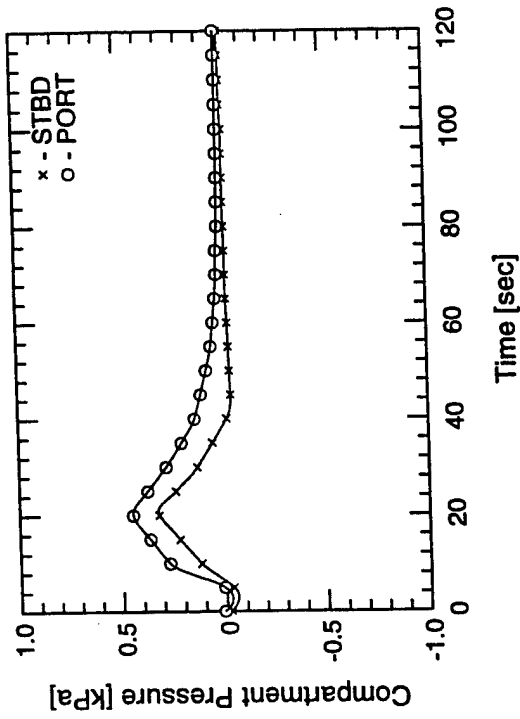
Test #4



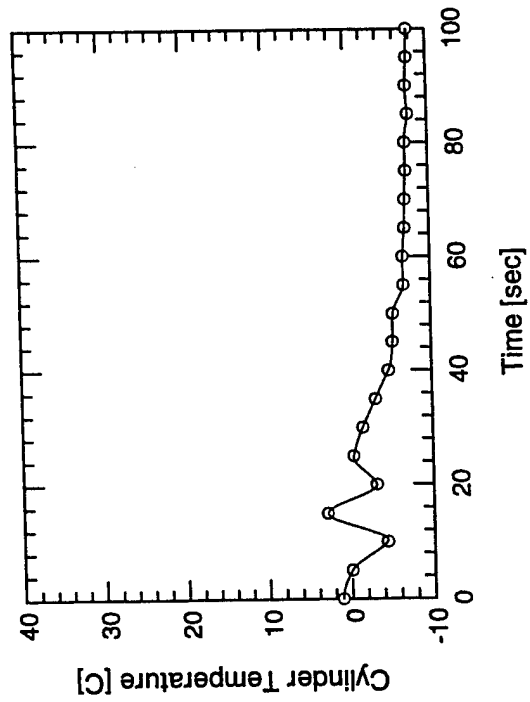
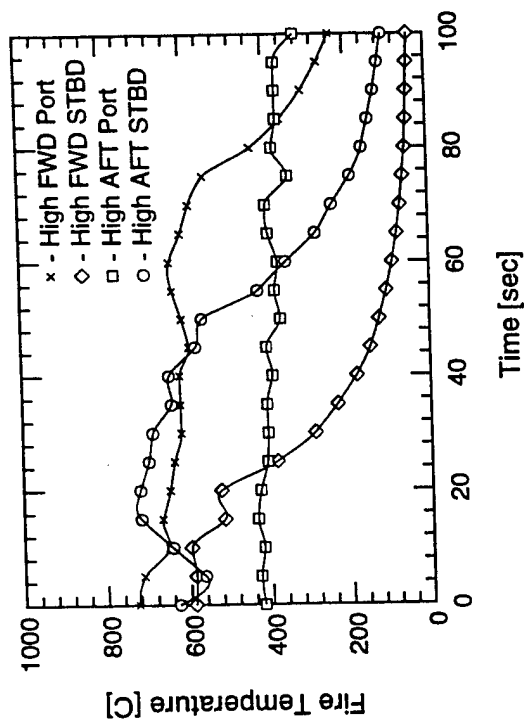
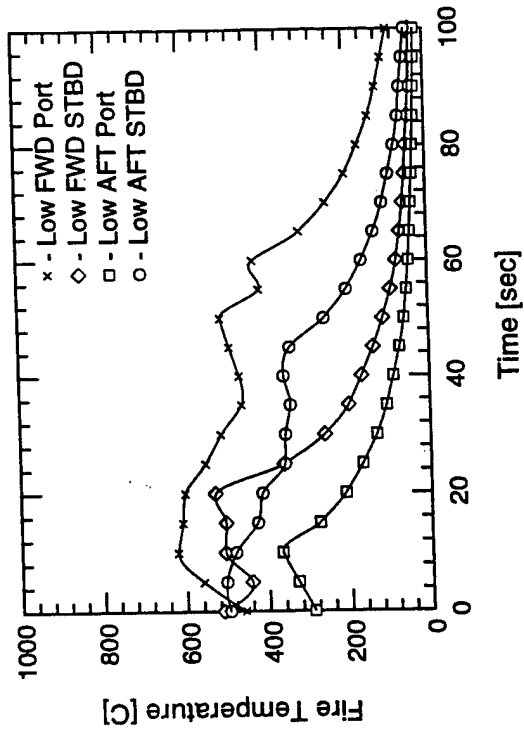


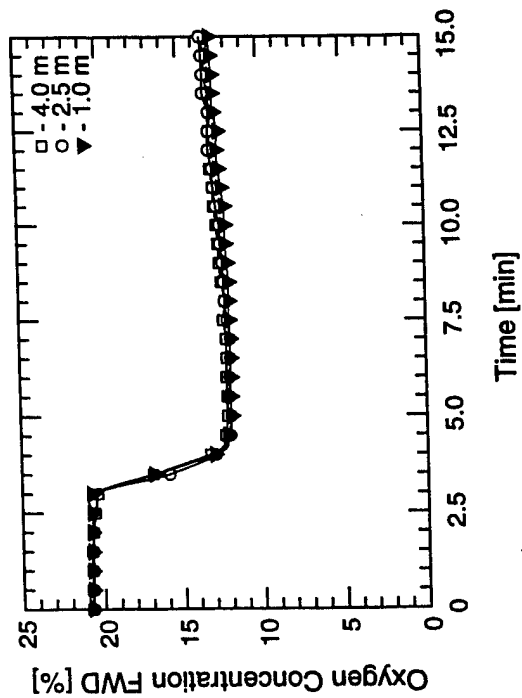
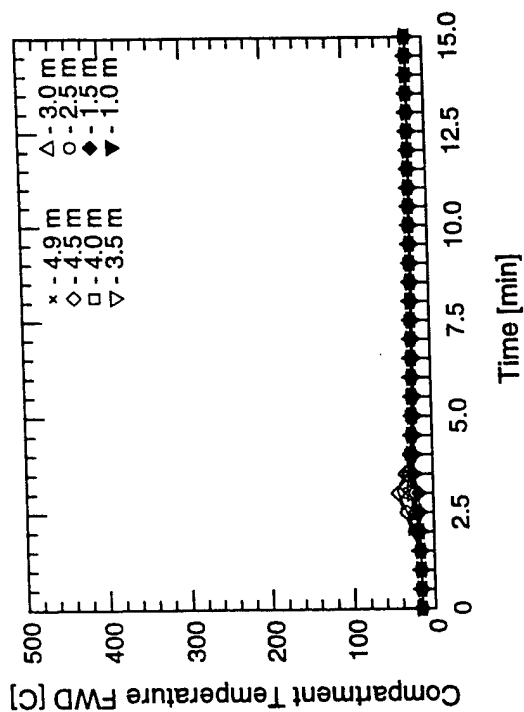
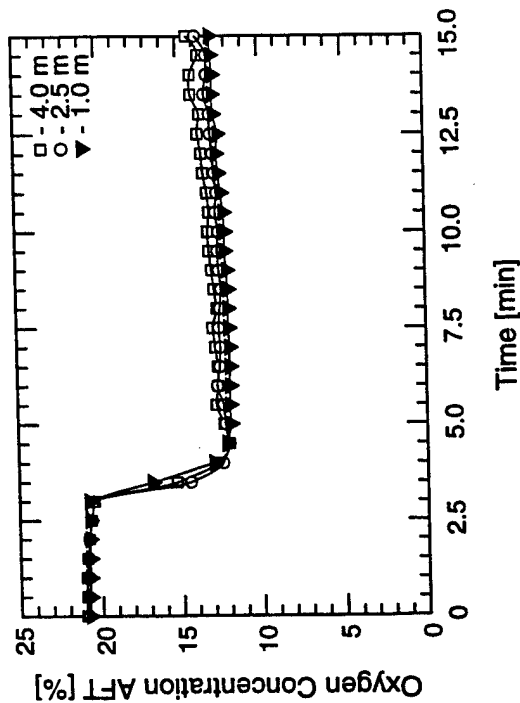
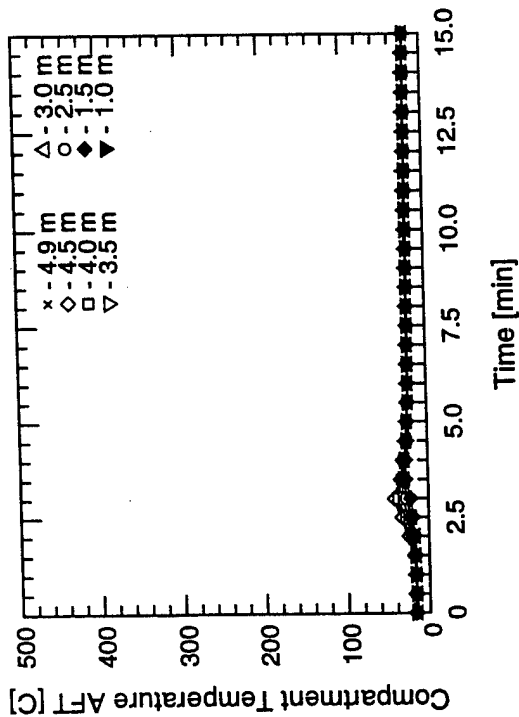
Test #4

Test #4



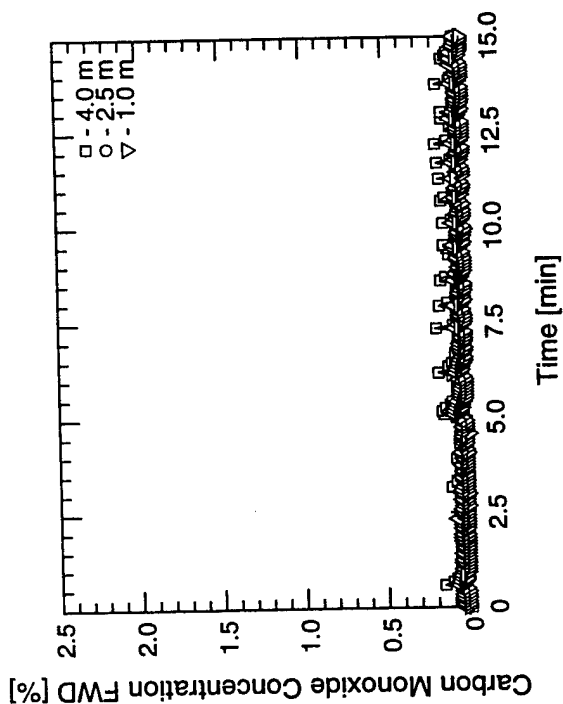
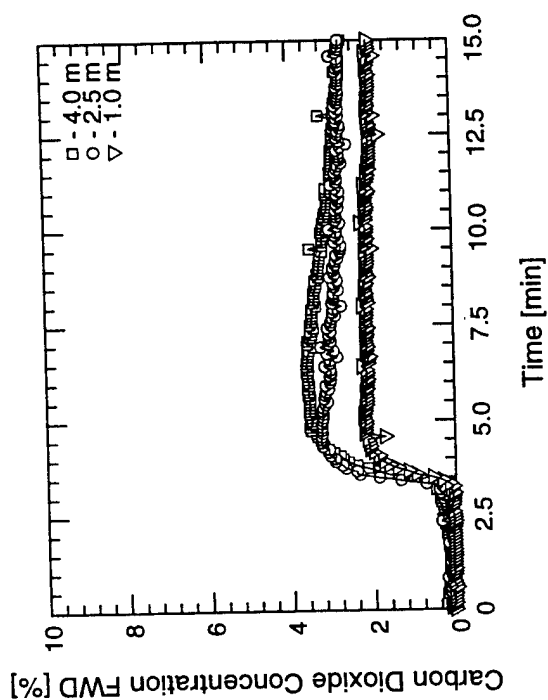
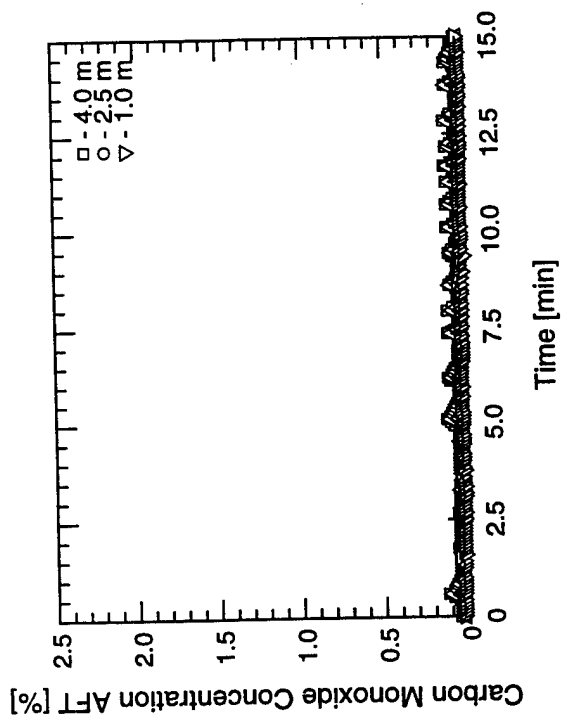
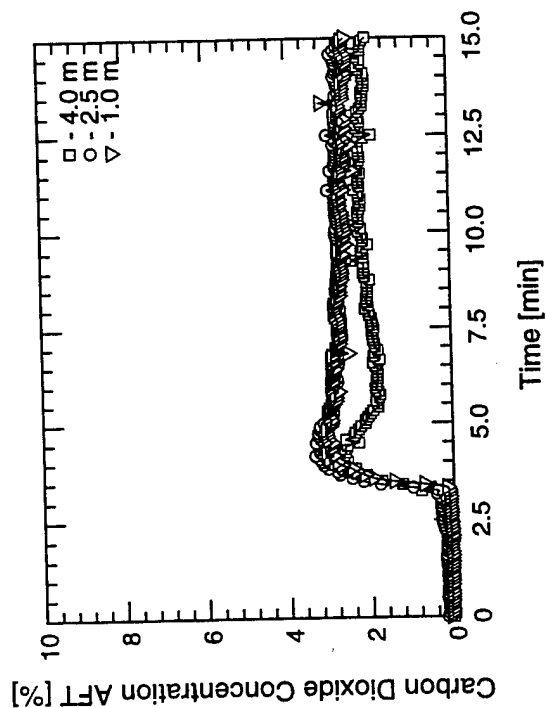
Test #4

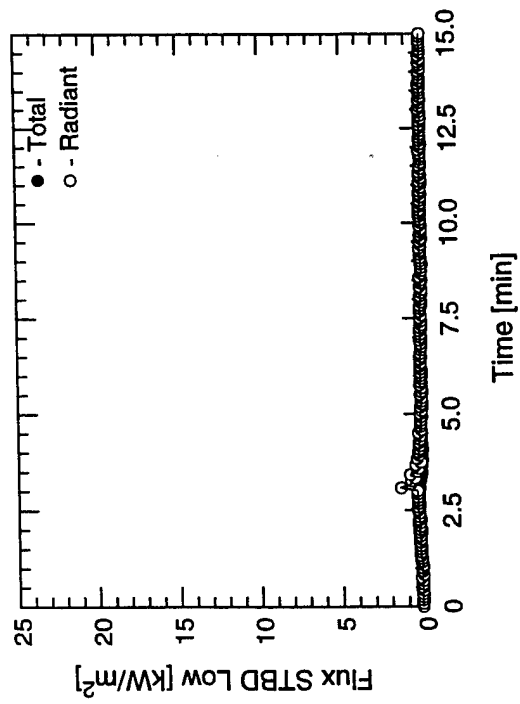
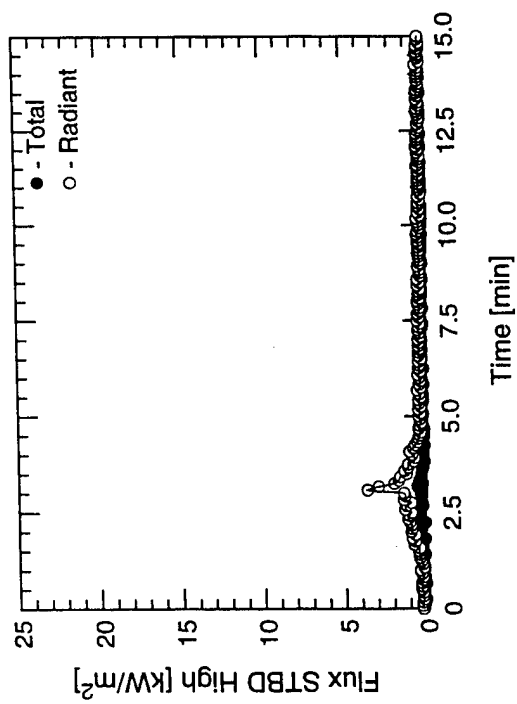
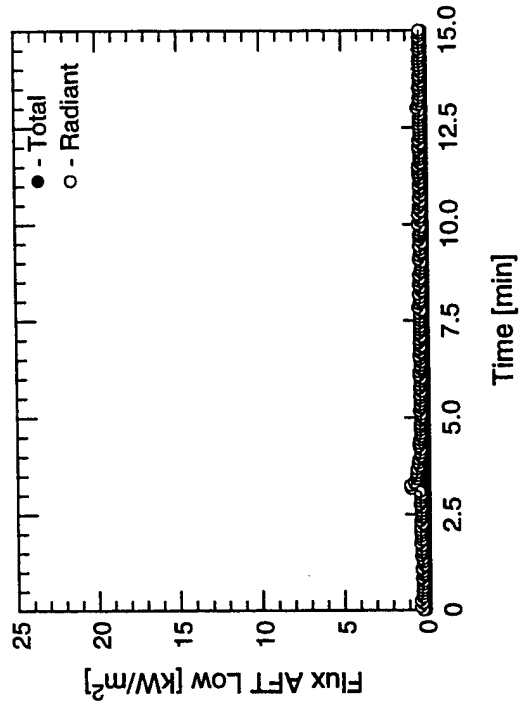
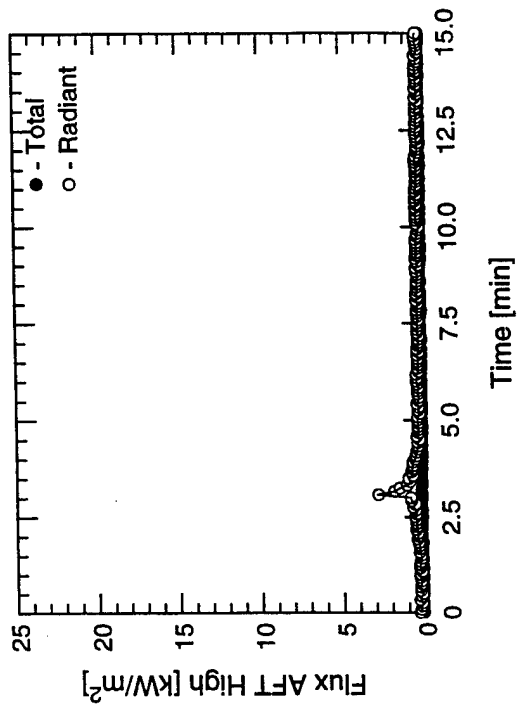




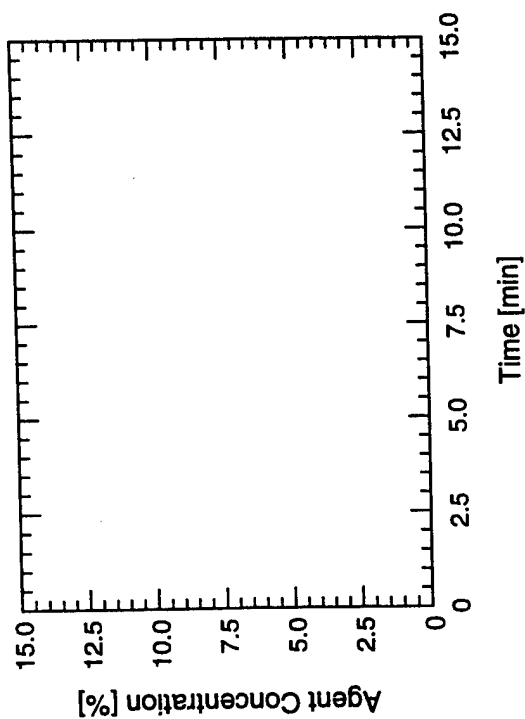
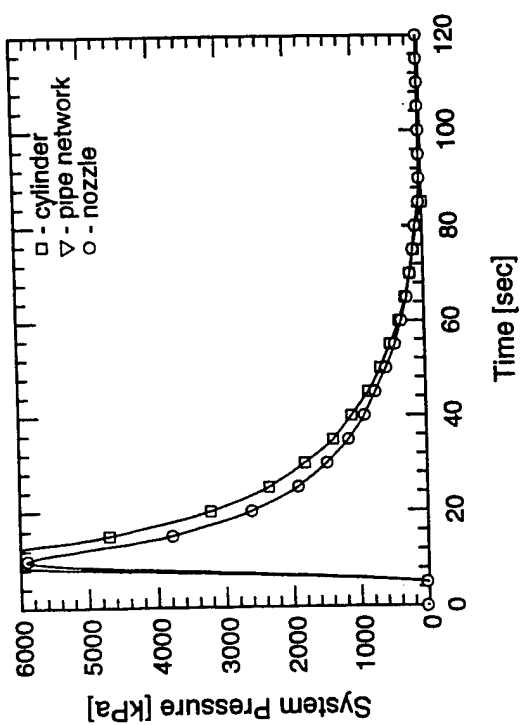
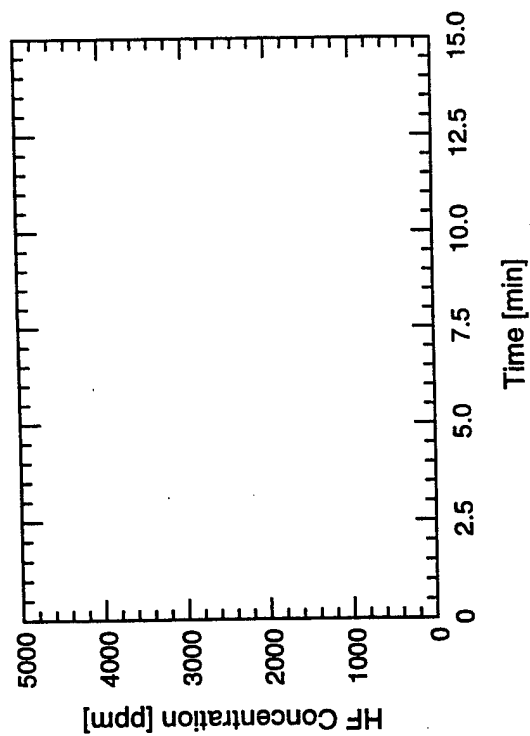
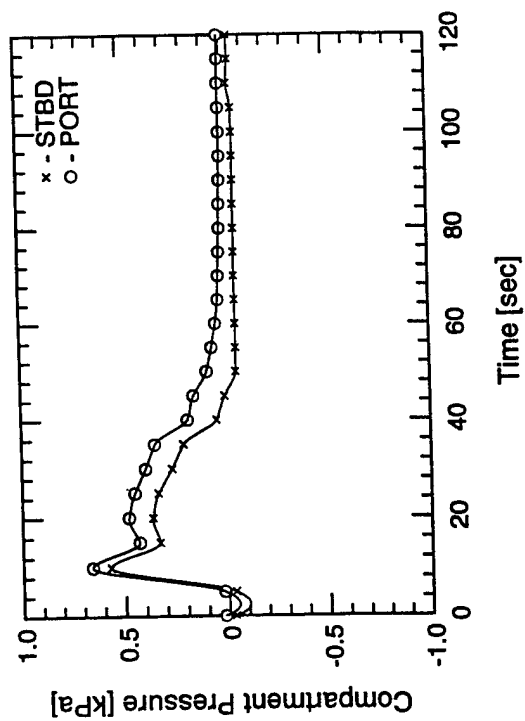
Test #5

Test #5



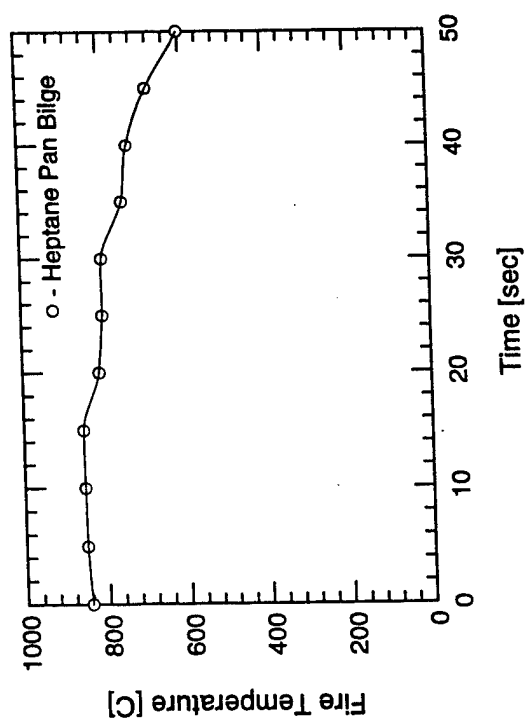
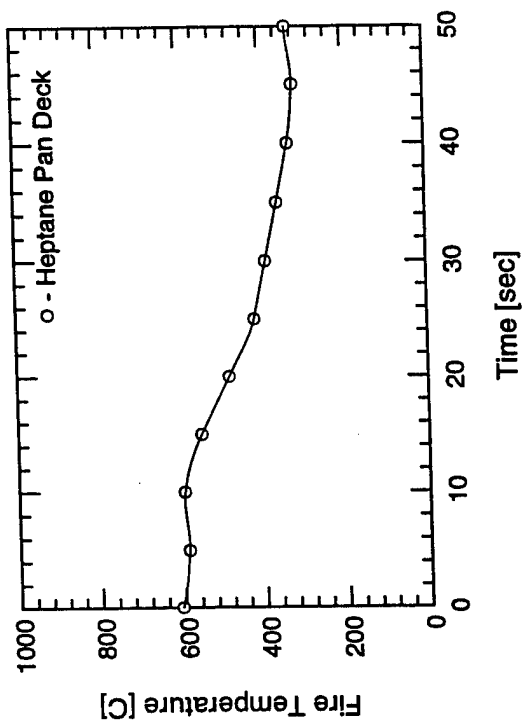


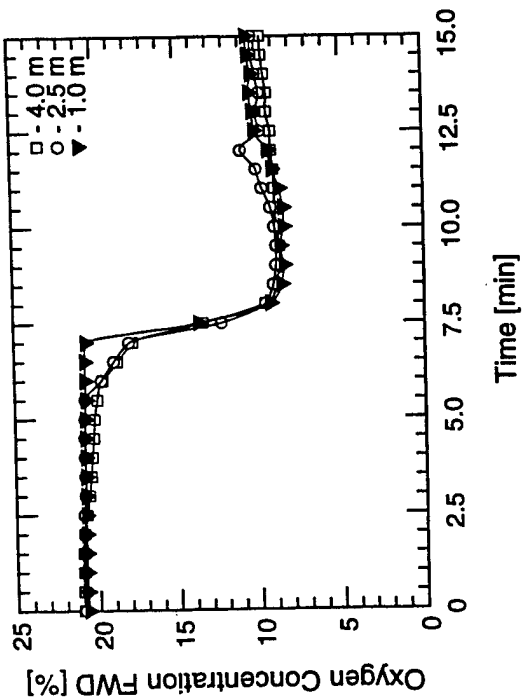
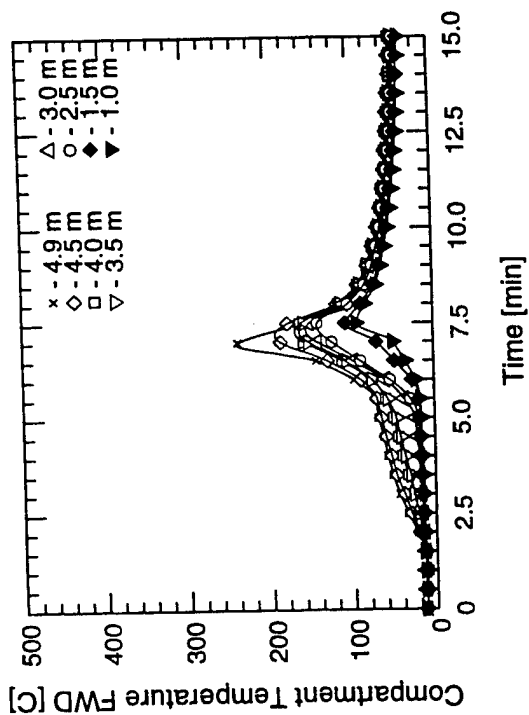
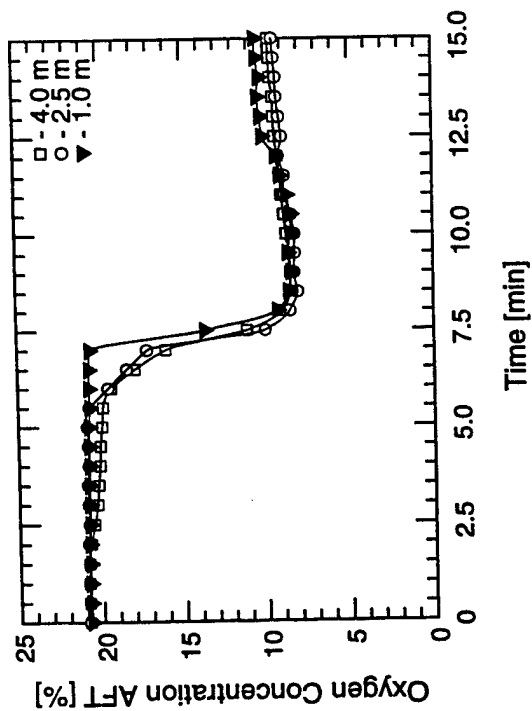
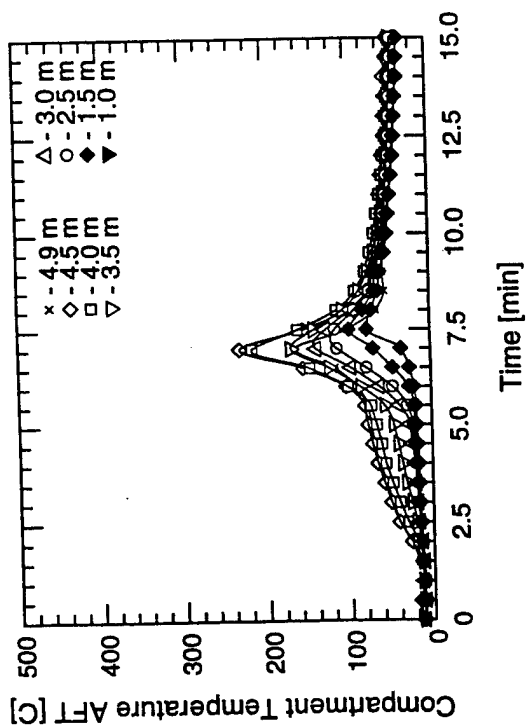
Test #5



Test #5

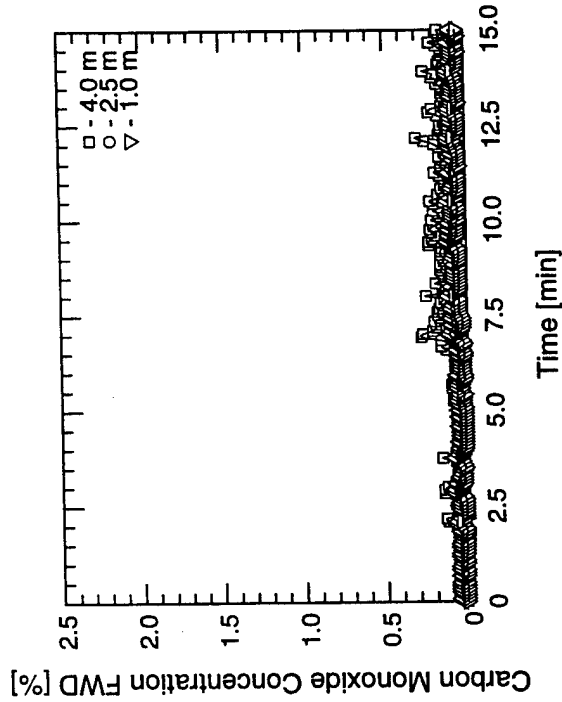
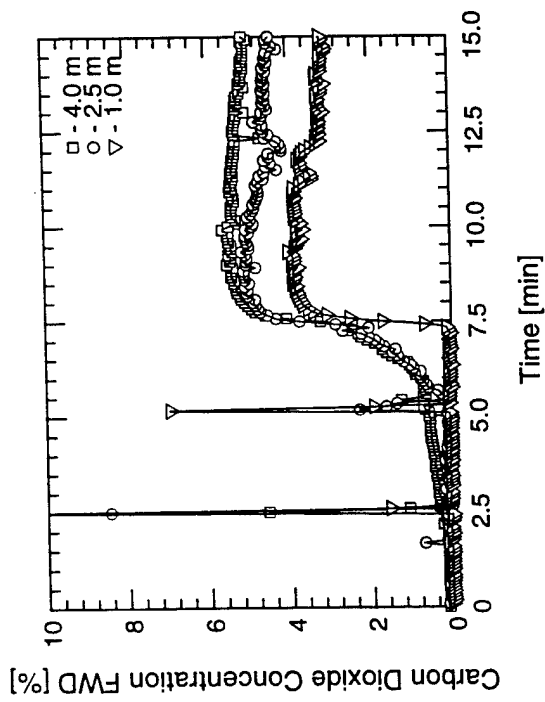
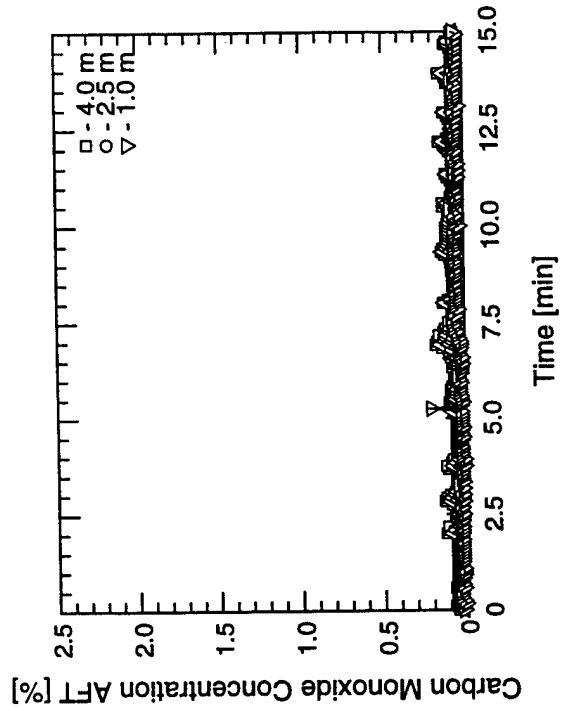
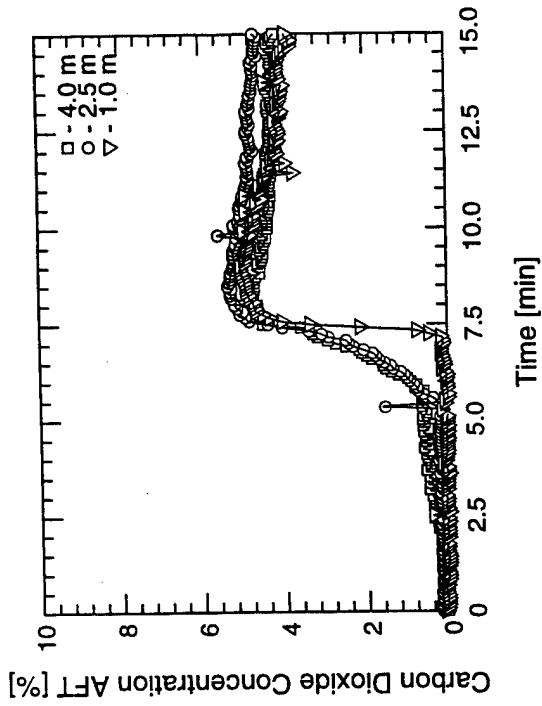
Test #5

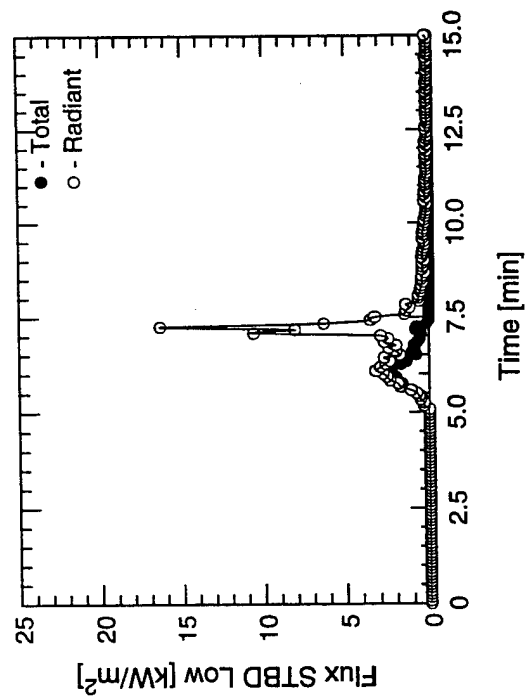
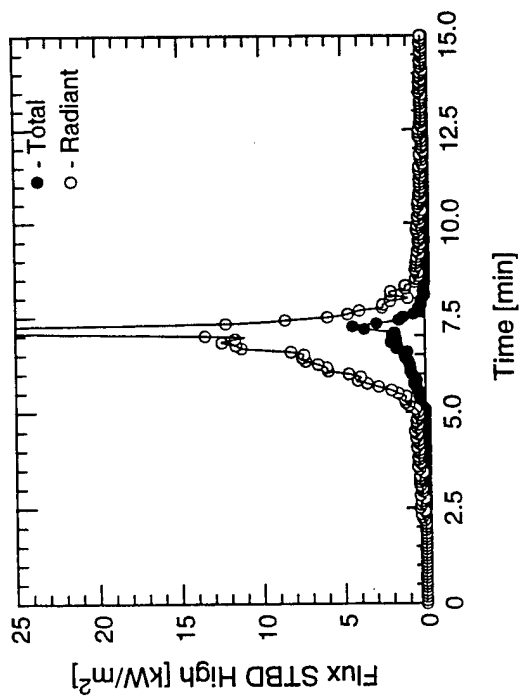
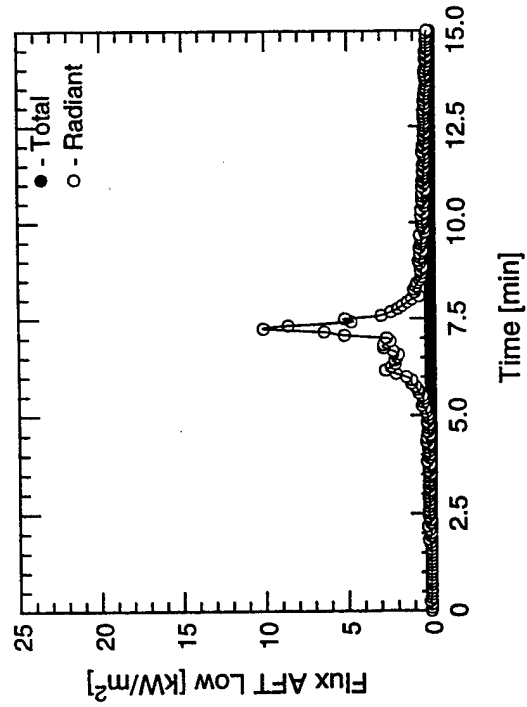
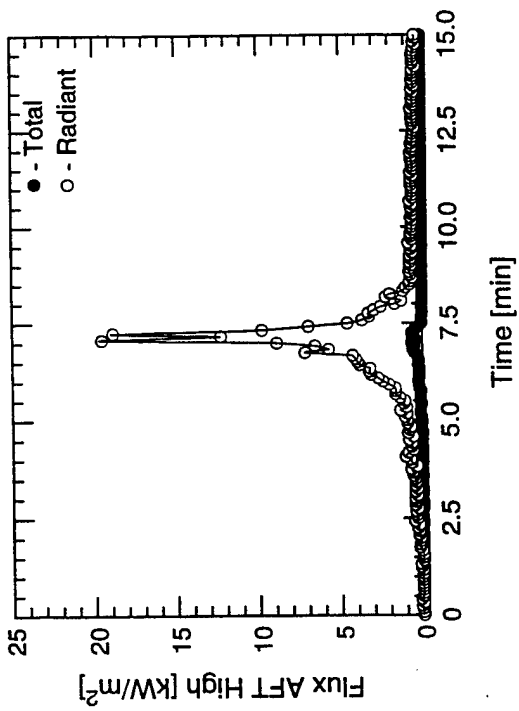




Test #6

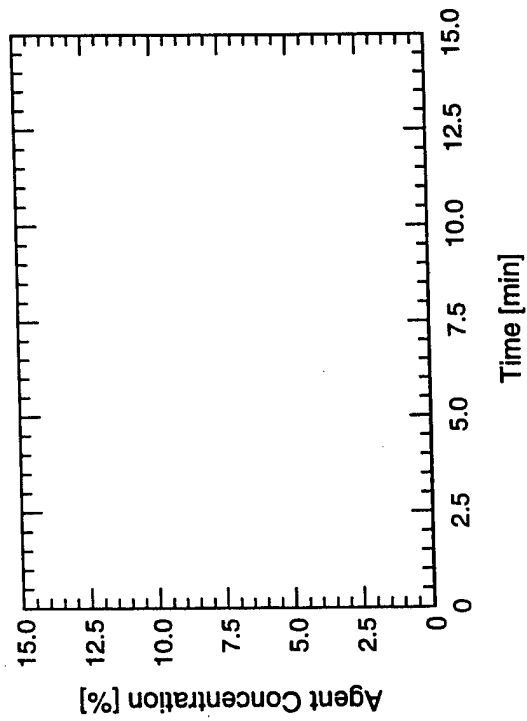
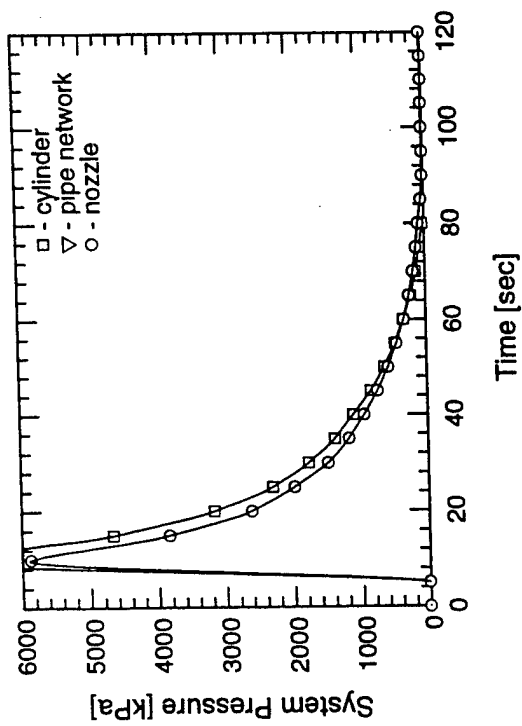
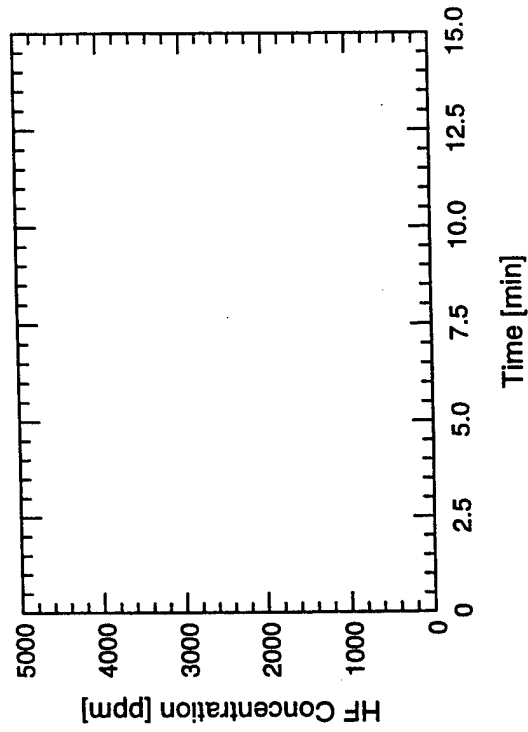
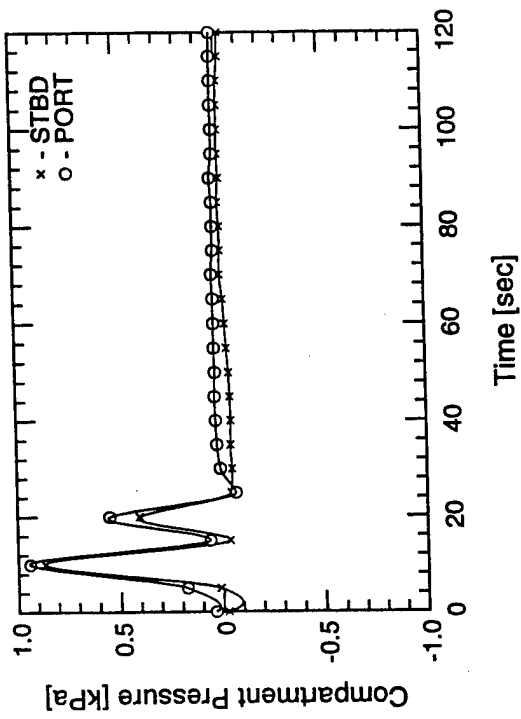
Test #6

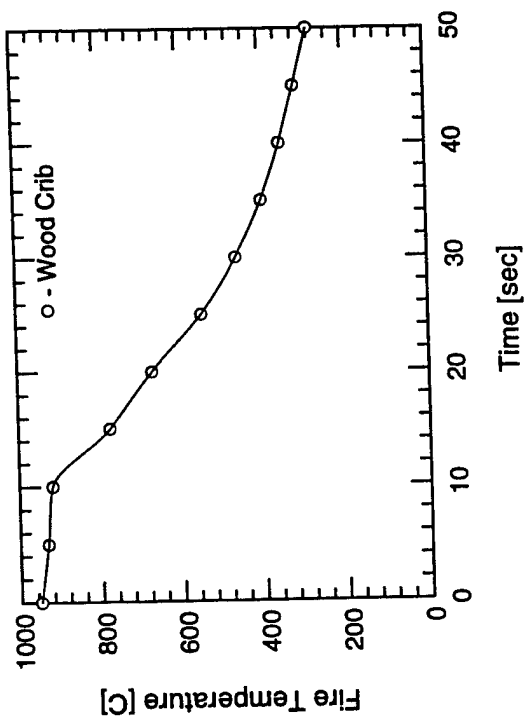
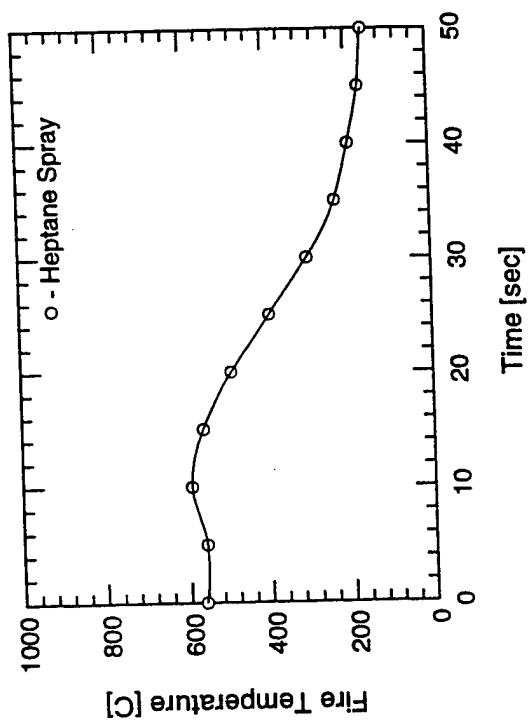
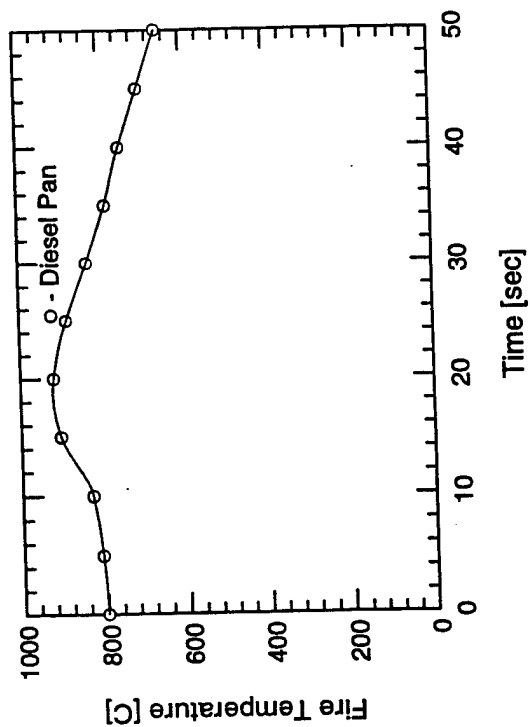




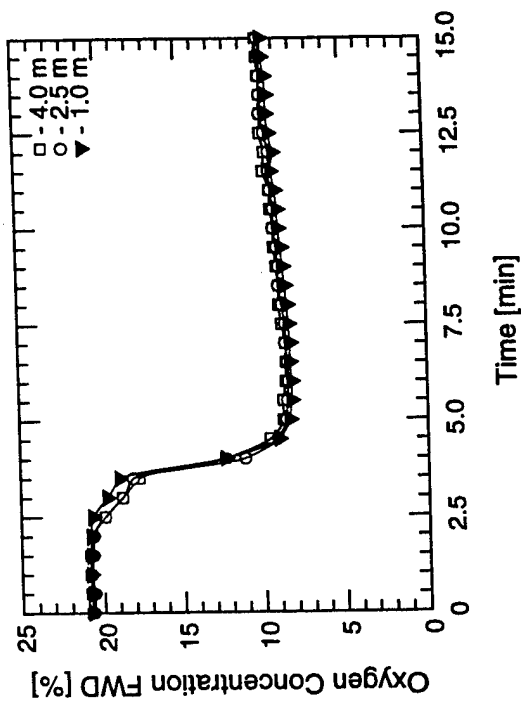
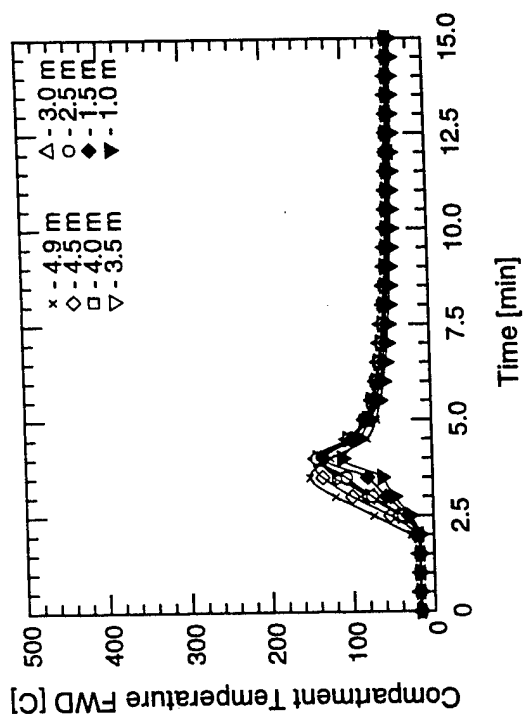
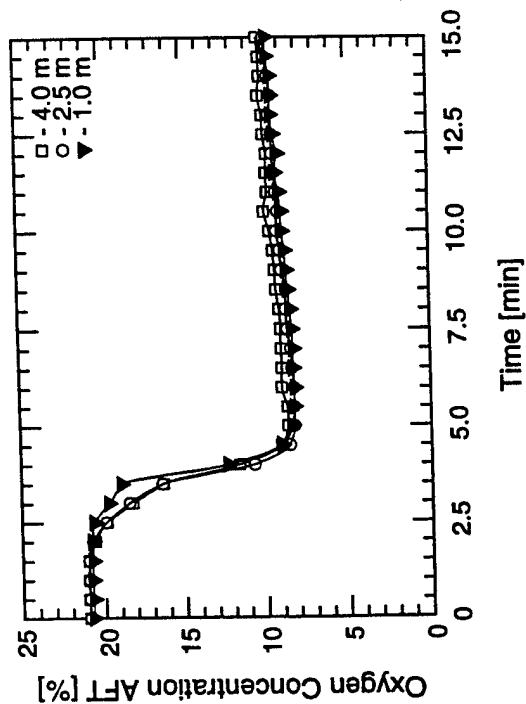
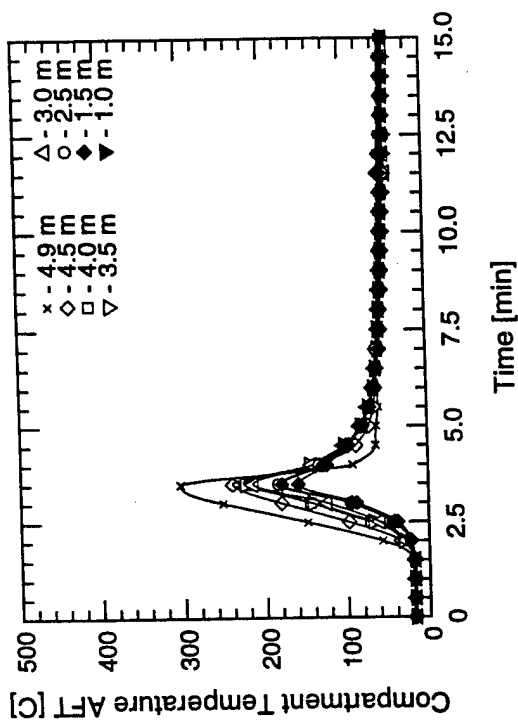
Test #6

Test #6



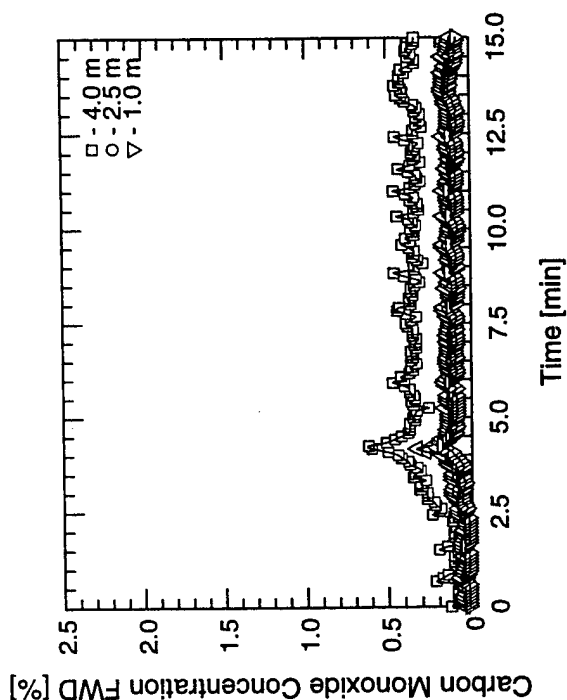
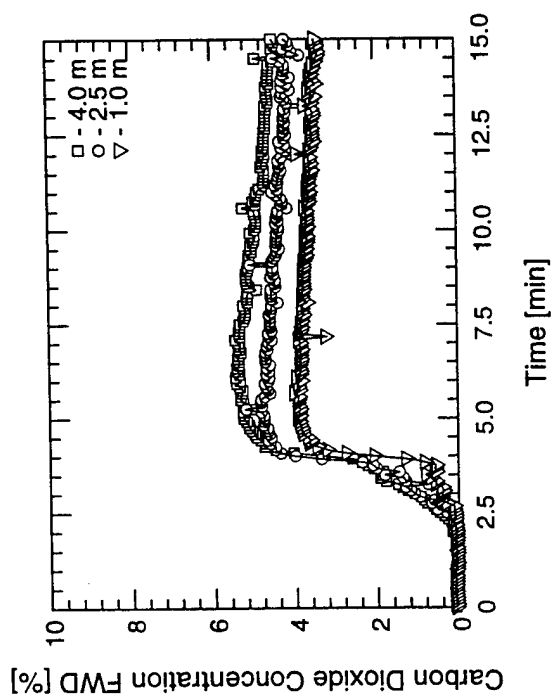
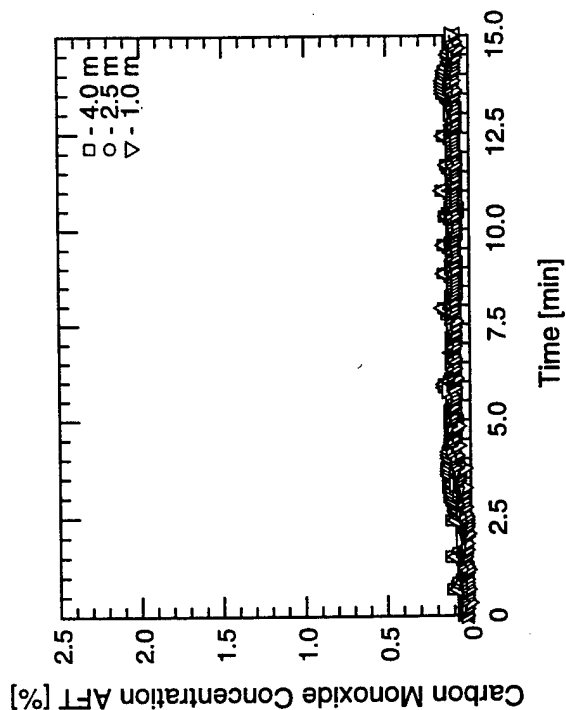
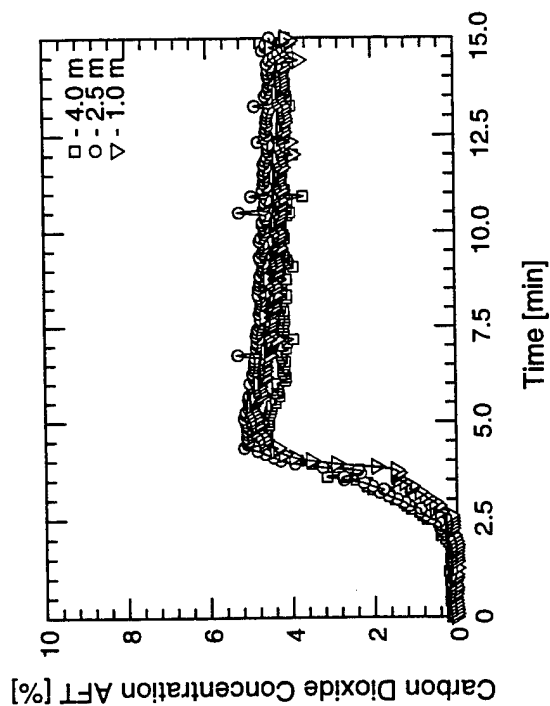


Test #6

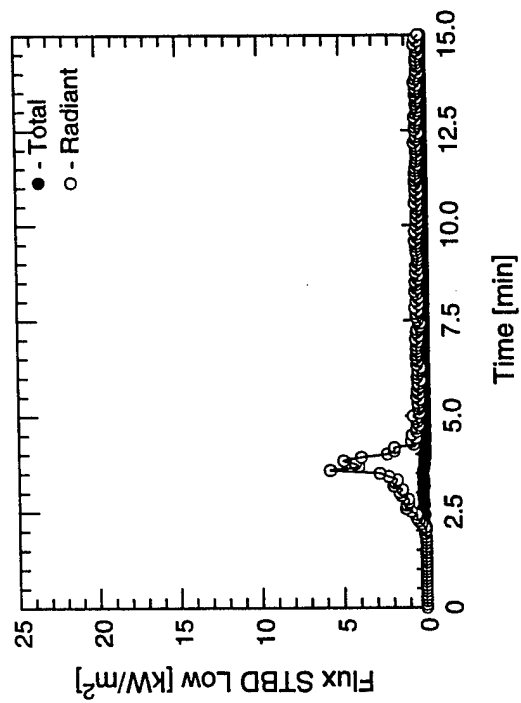
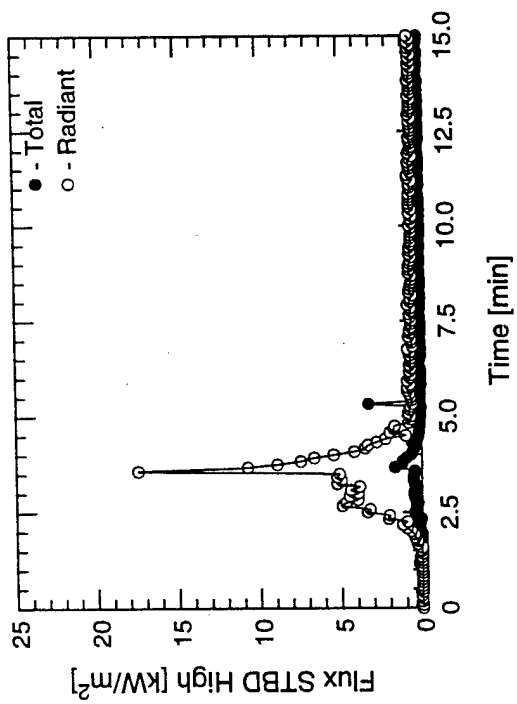
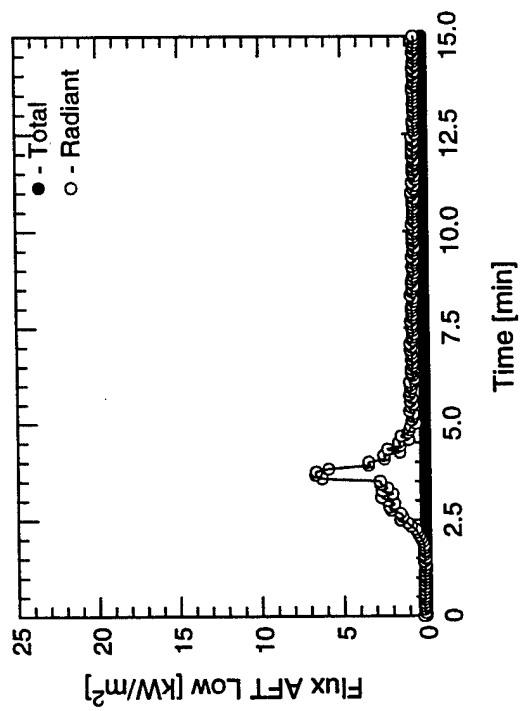
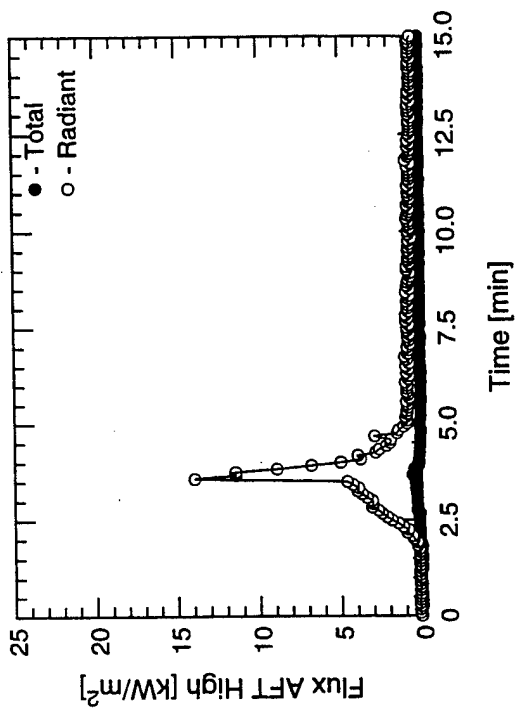


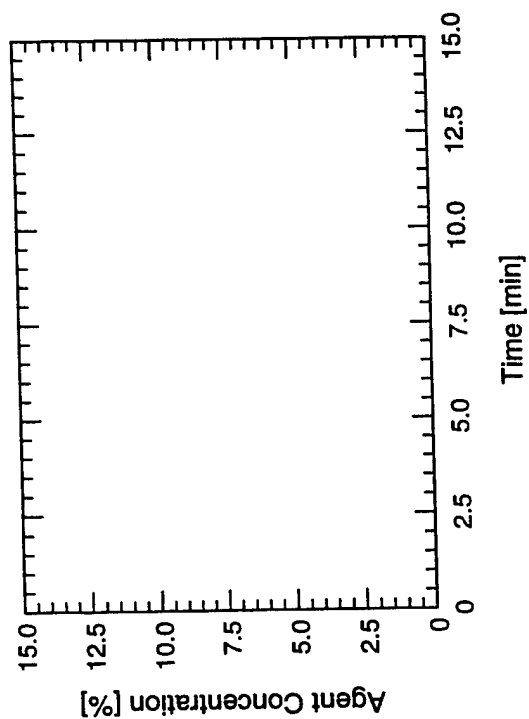
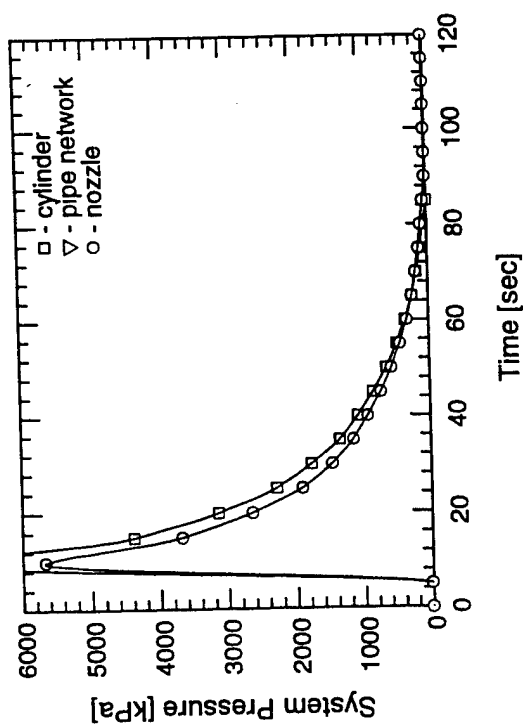
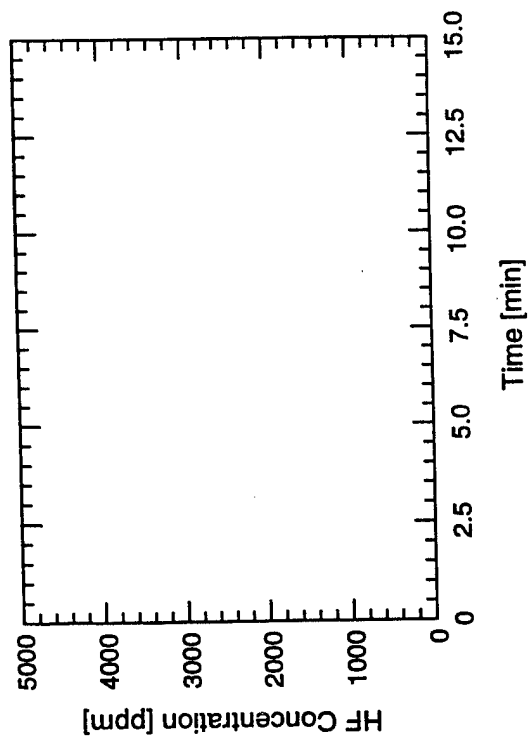
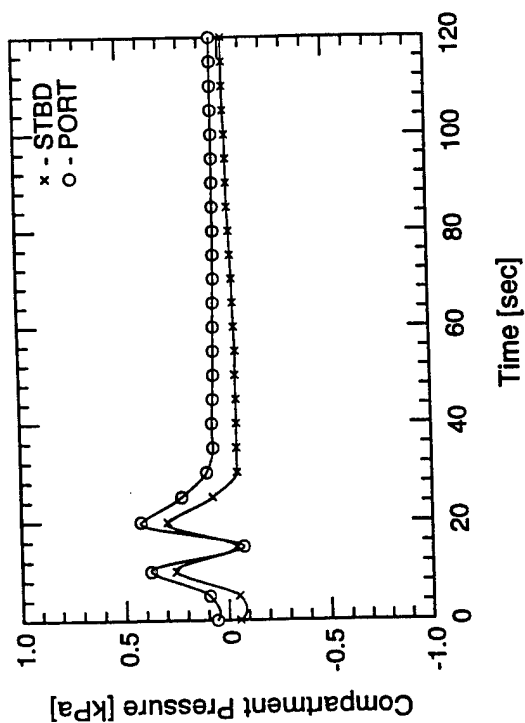
Test #7

Test #7

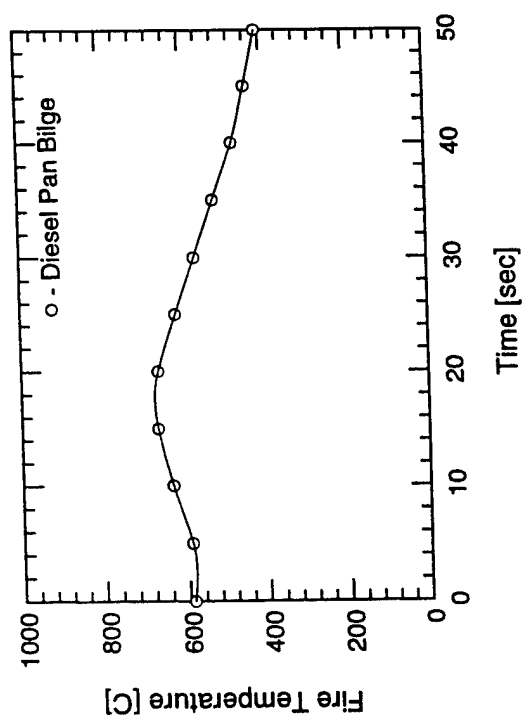


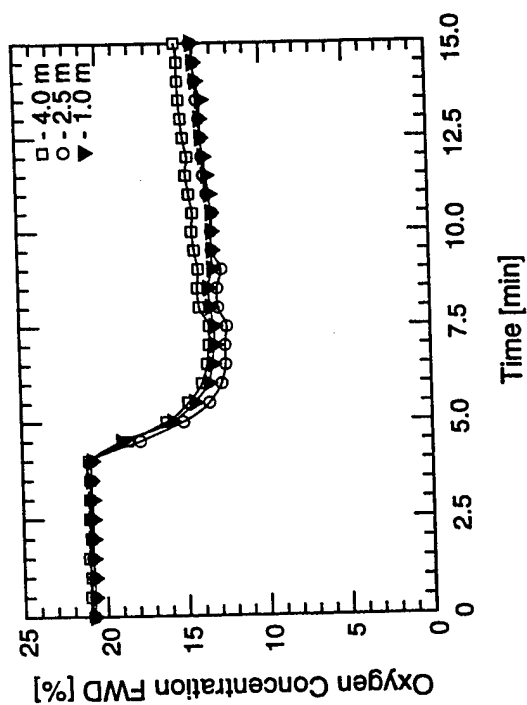
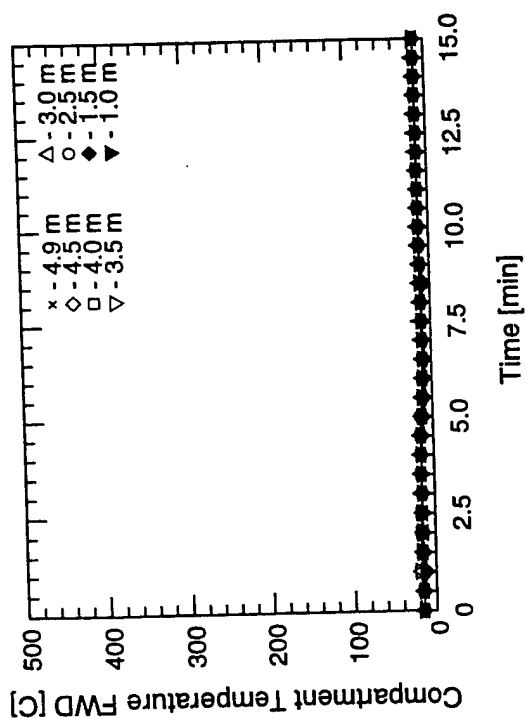
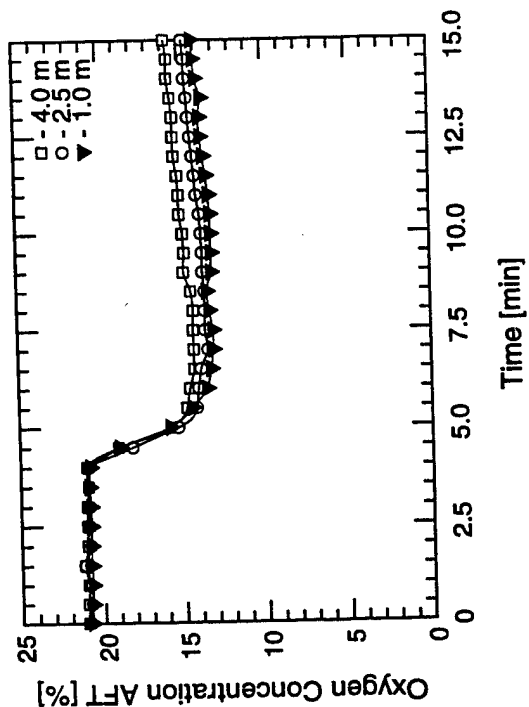
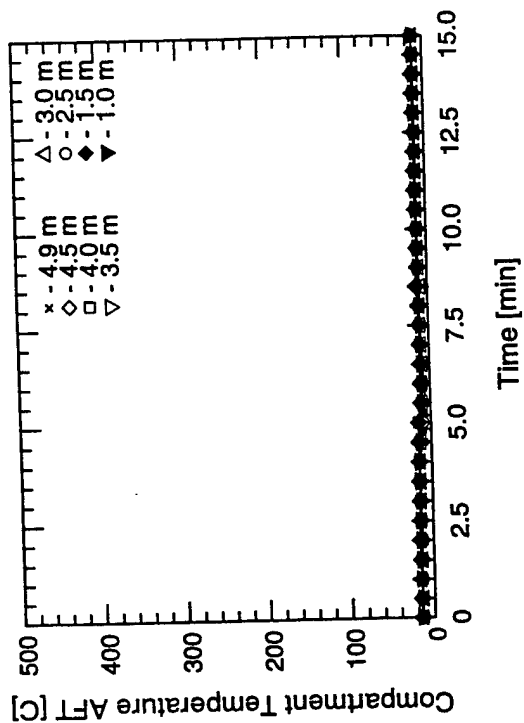
Test #7





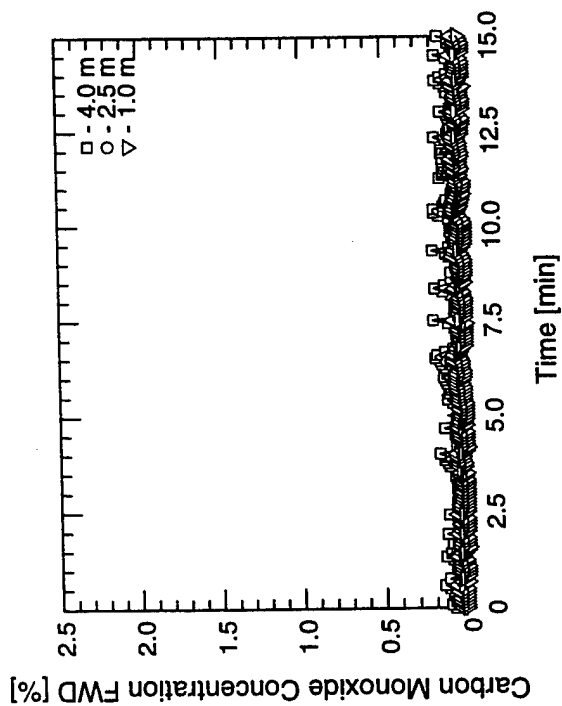
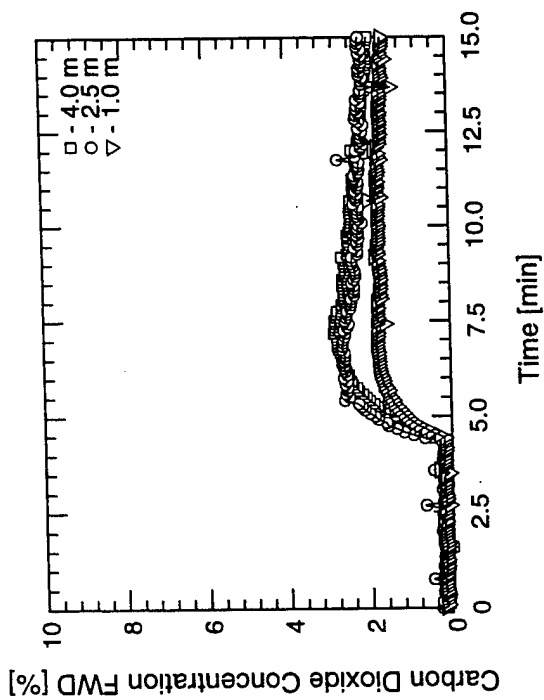
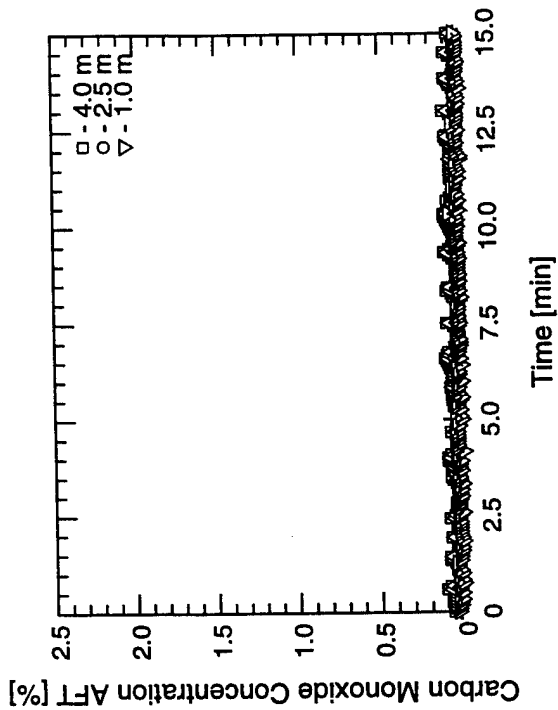
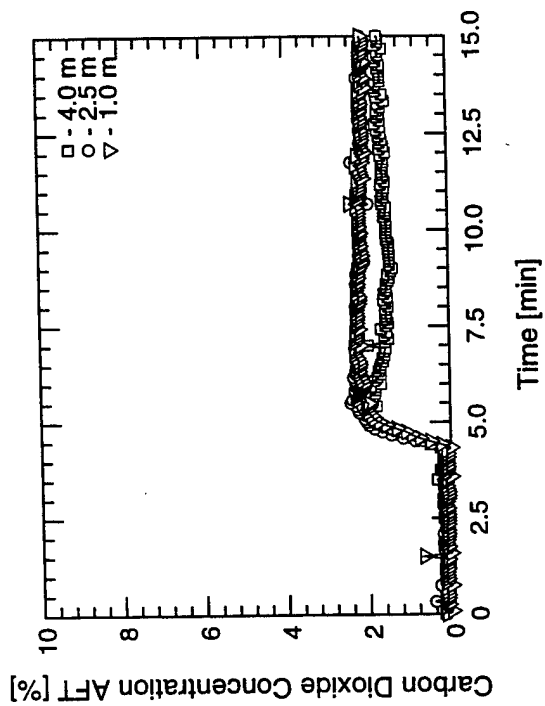
Test #7

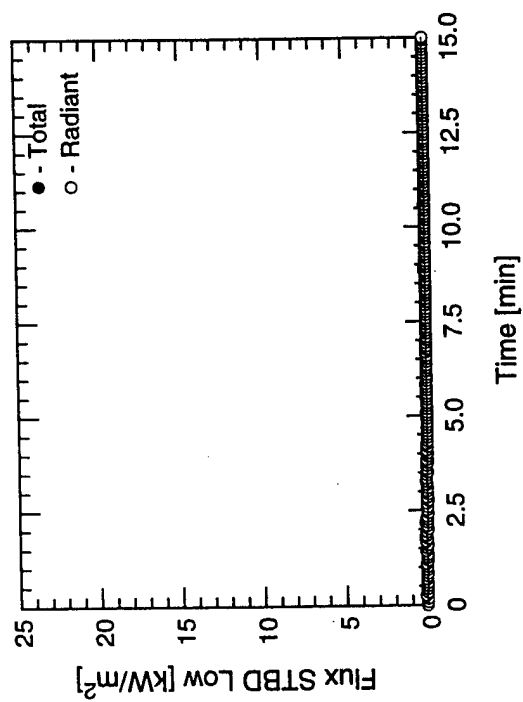
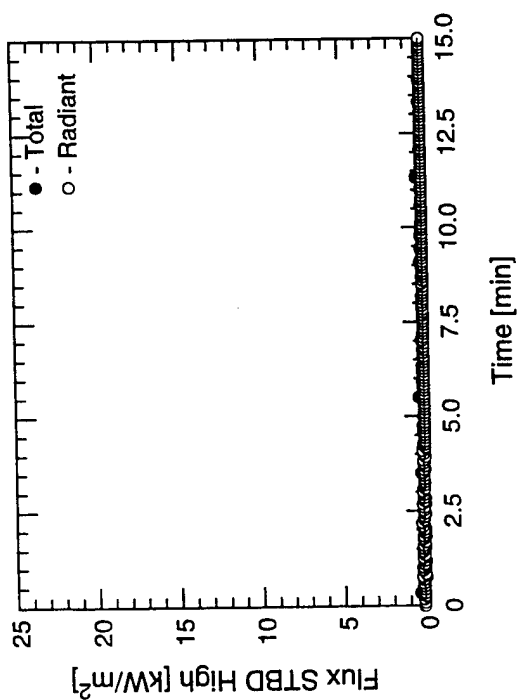
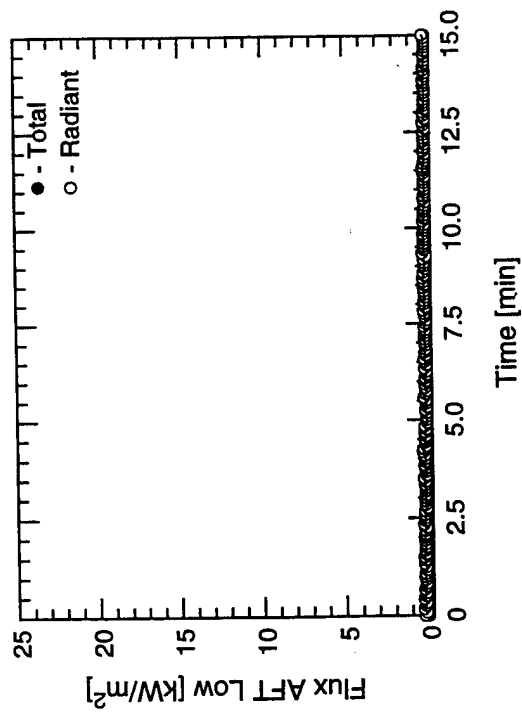
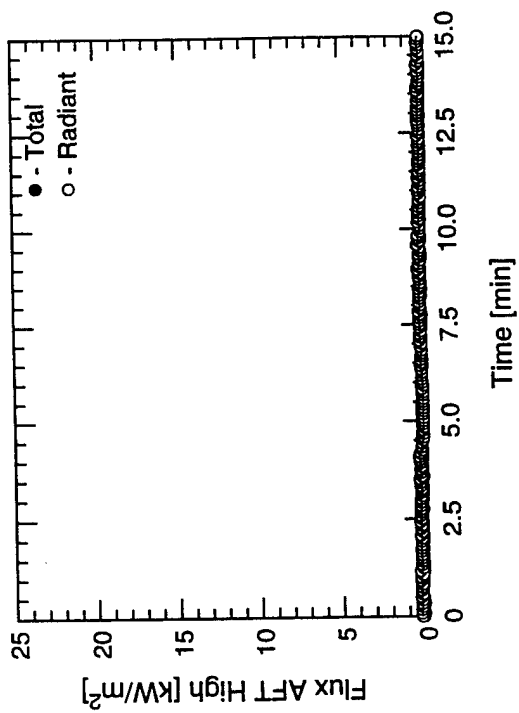




Test #8

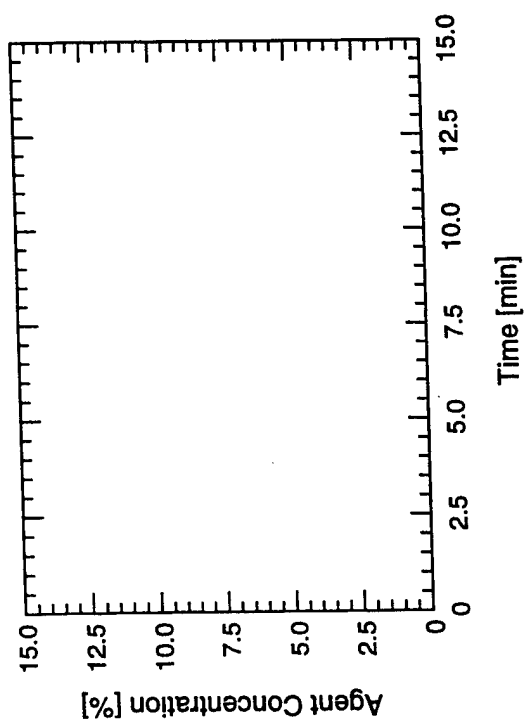
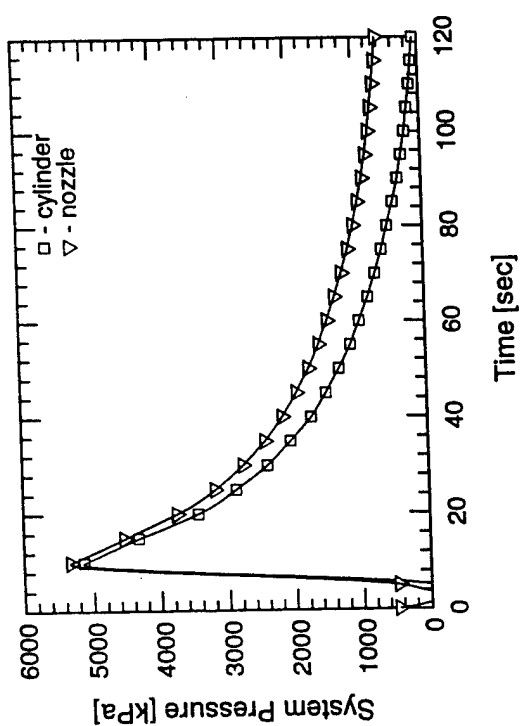
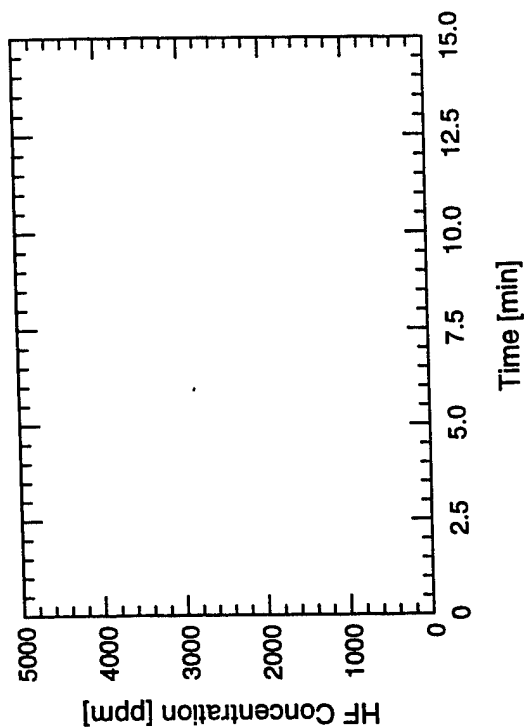
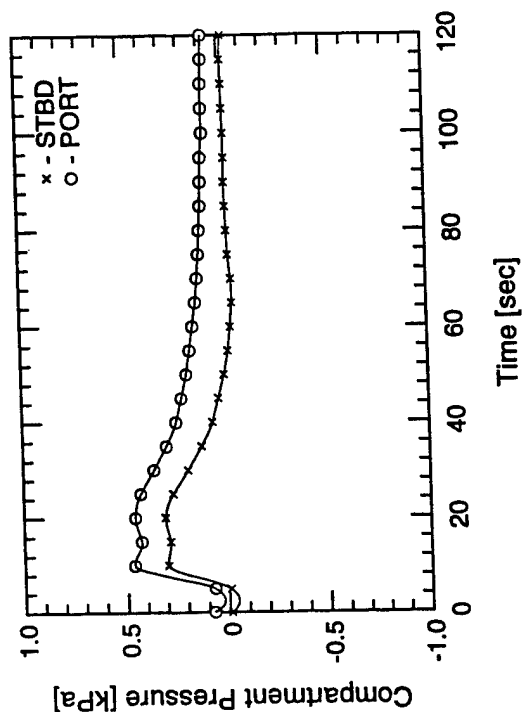
Test #8

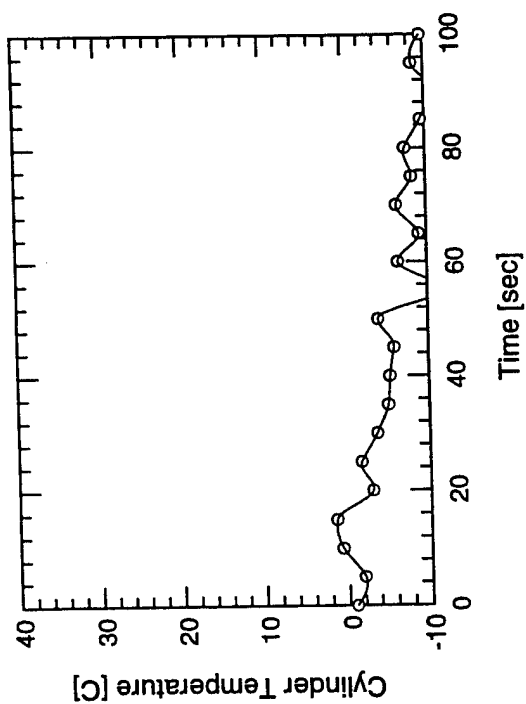
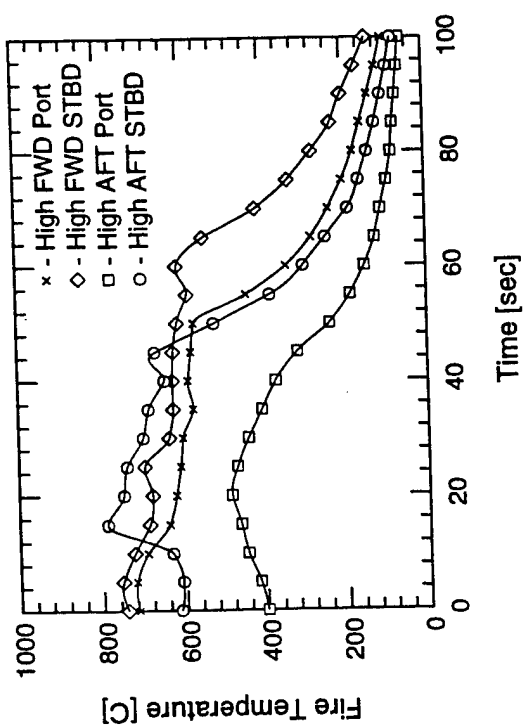
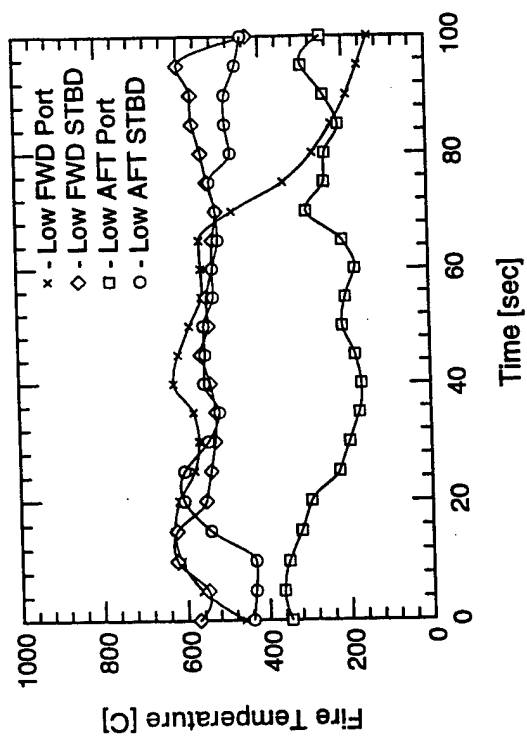




Test #8

Test #8

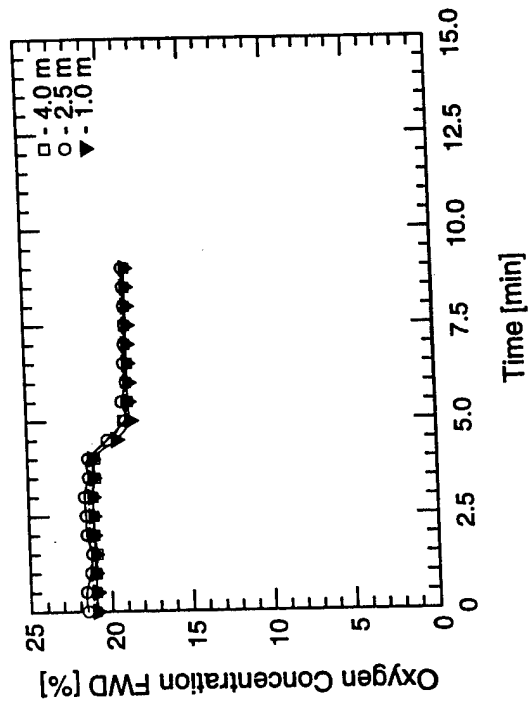
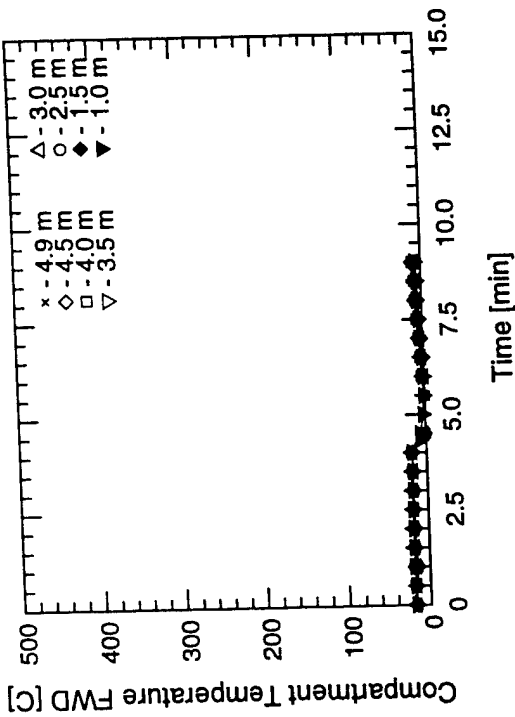
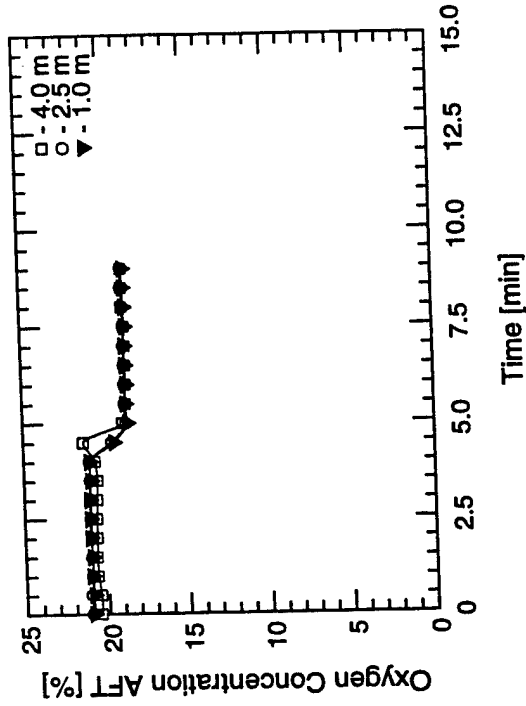
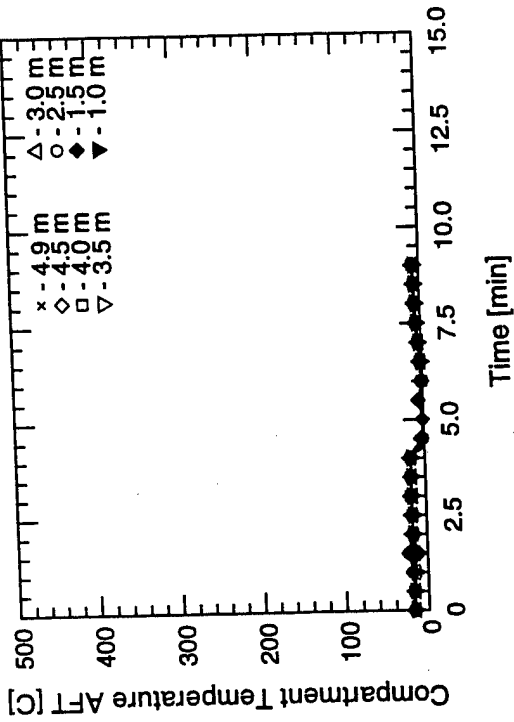




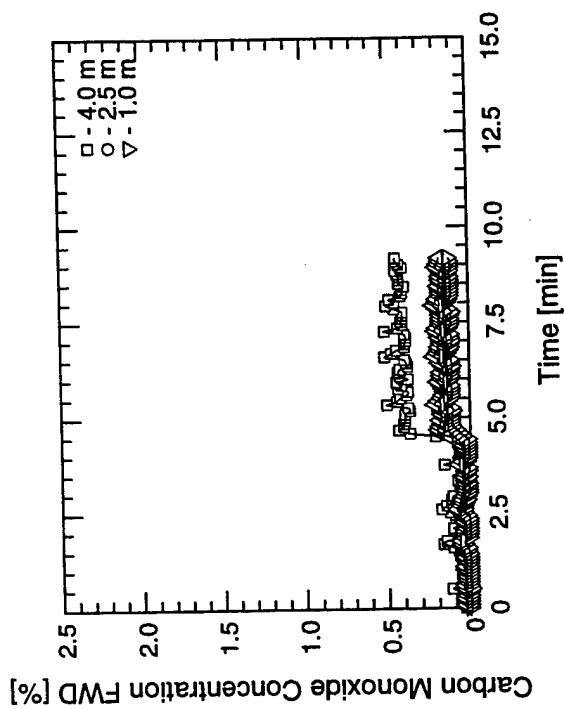
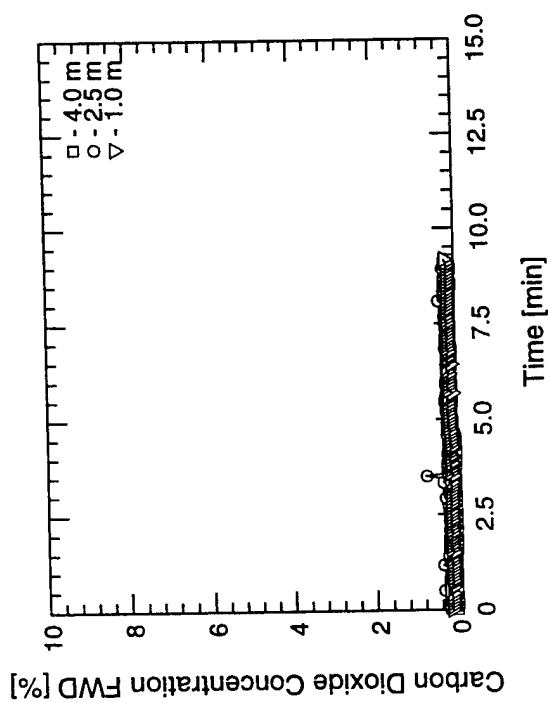
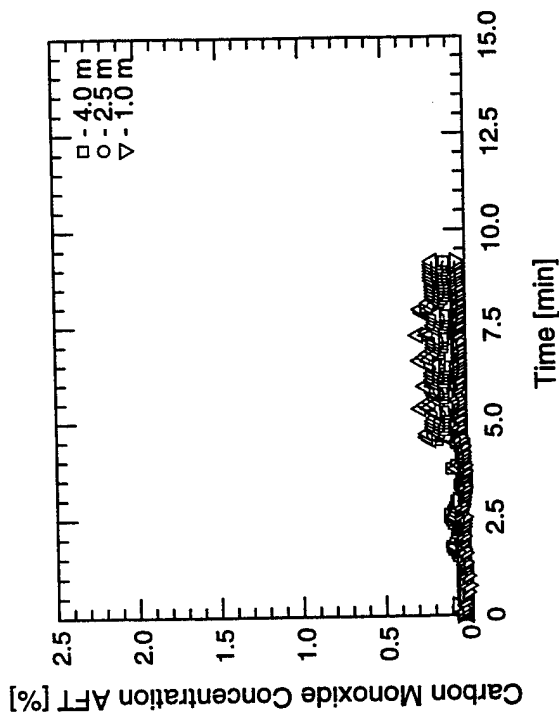
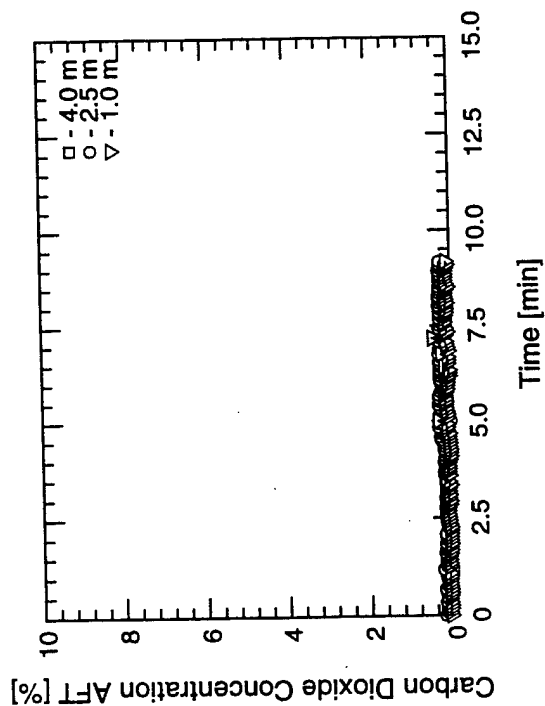
Test #8

Test #9

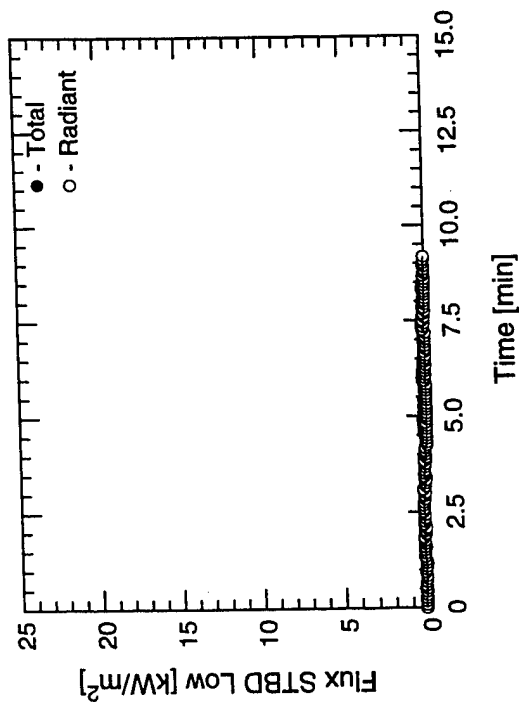
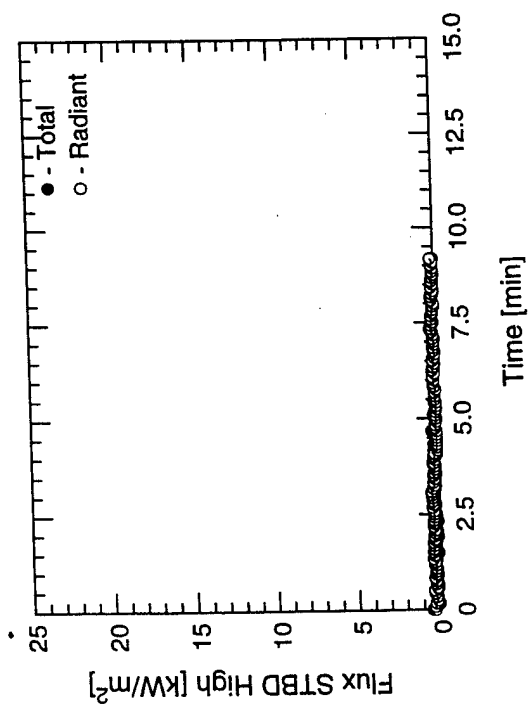
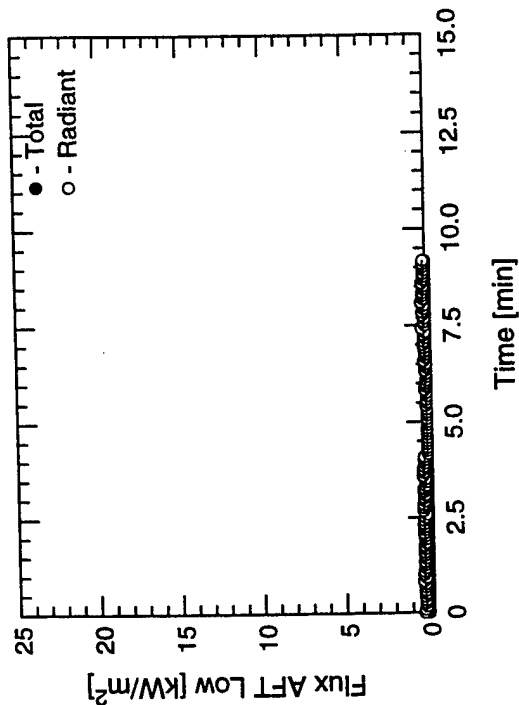
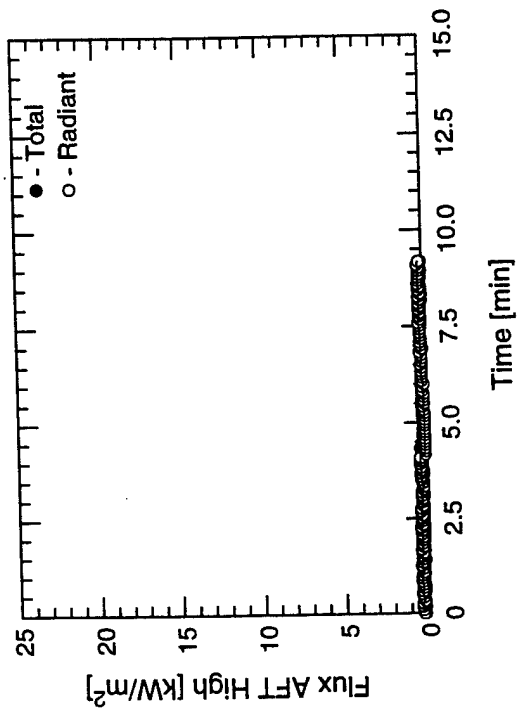
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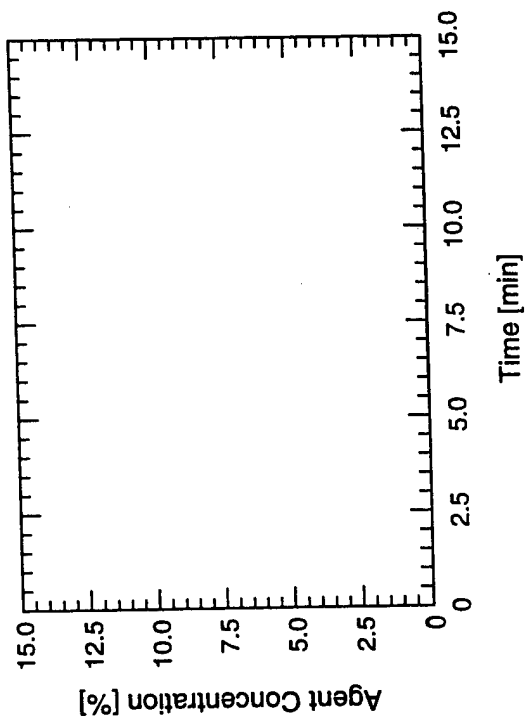
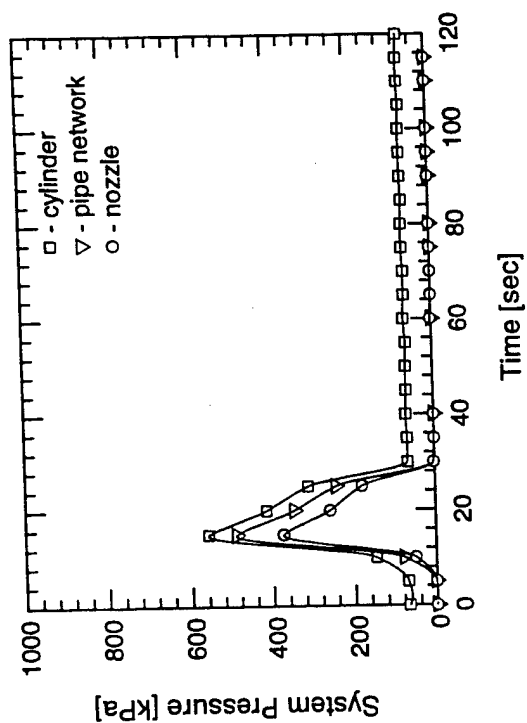
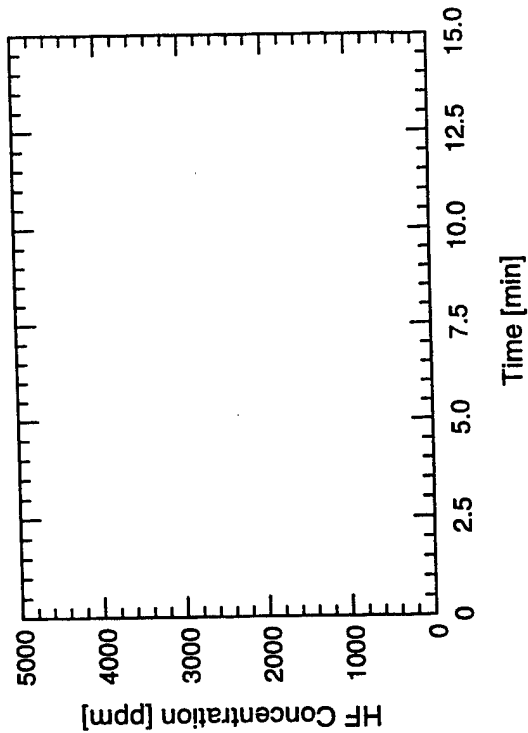
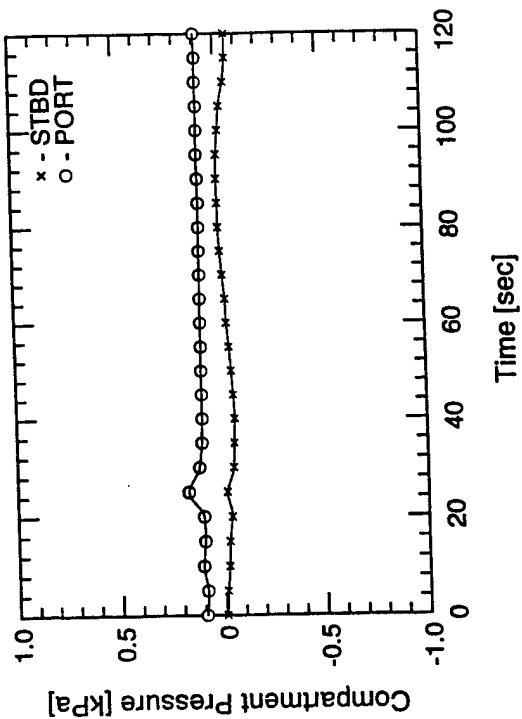


Test #9



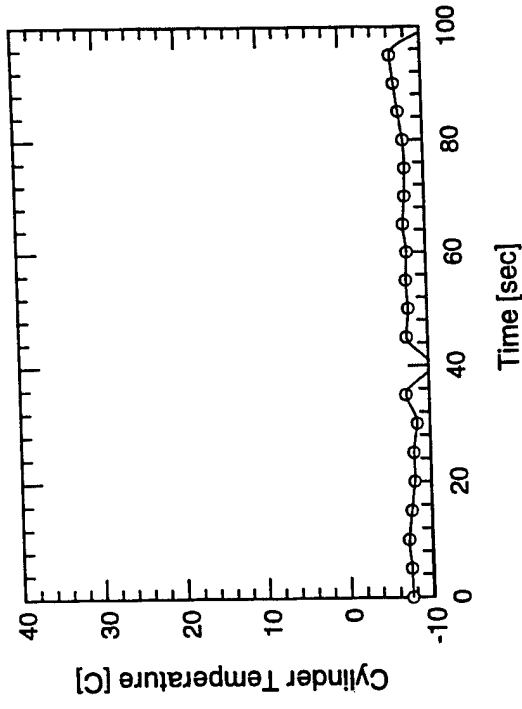
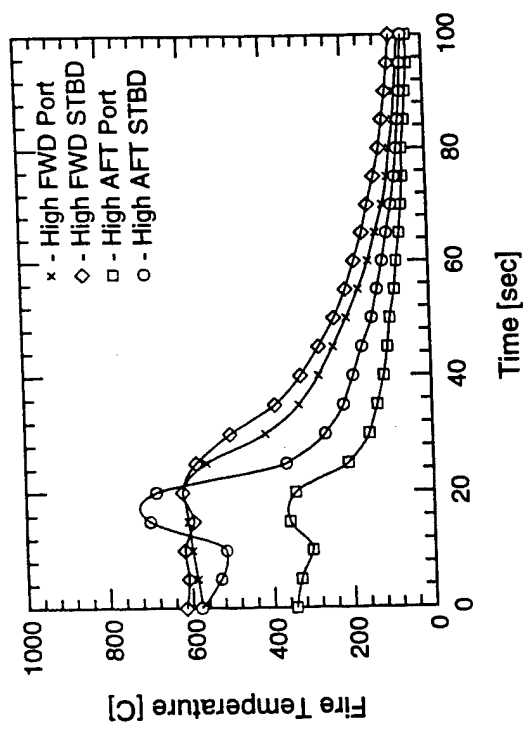
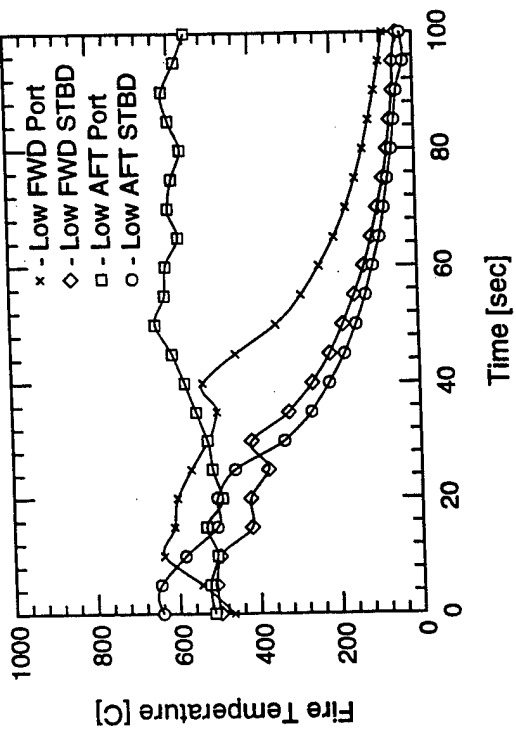
Test #9

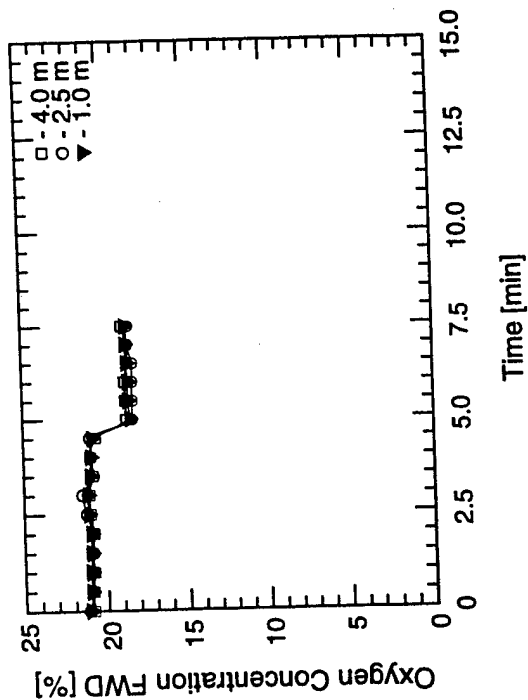
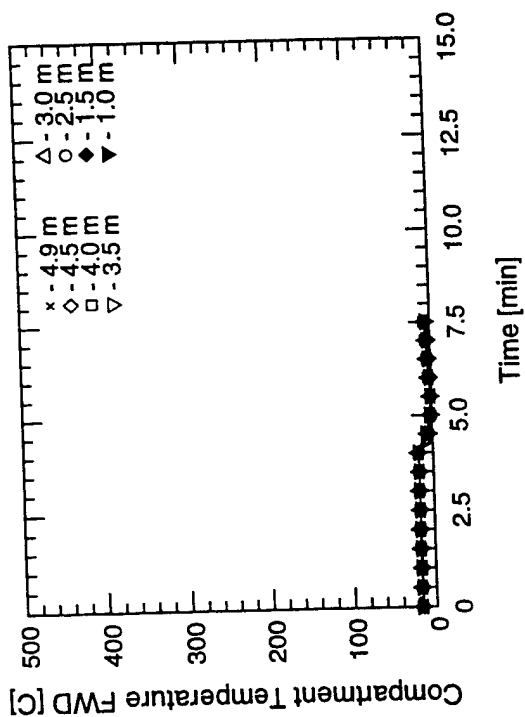
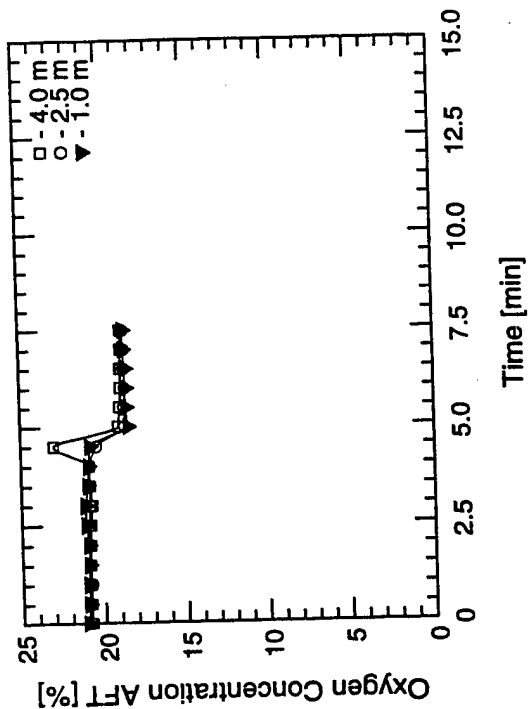
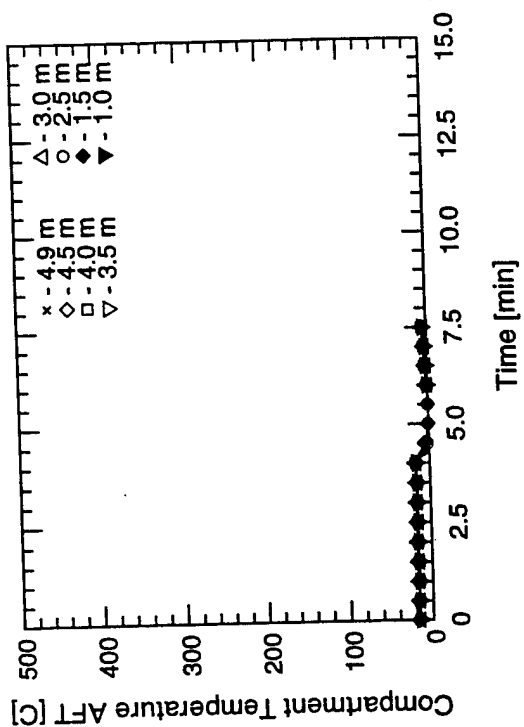




Test #9

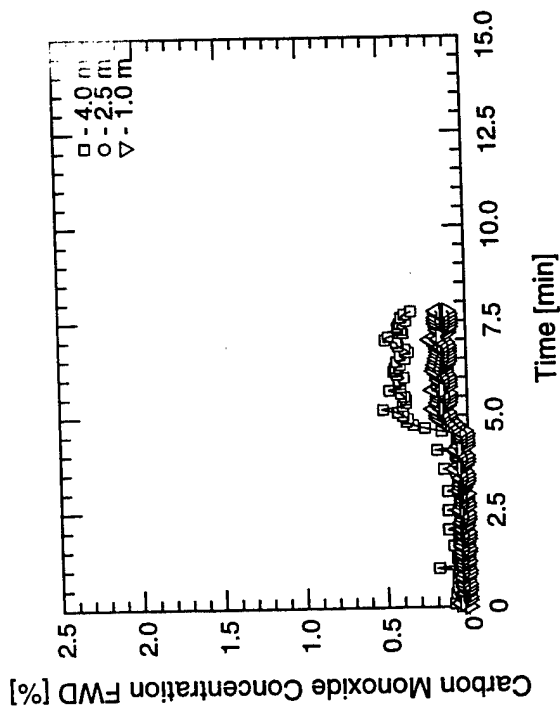
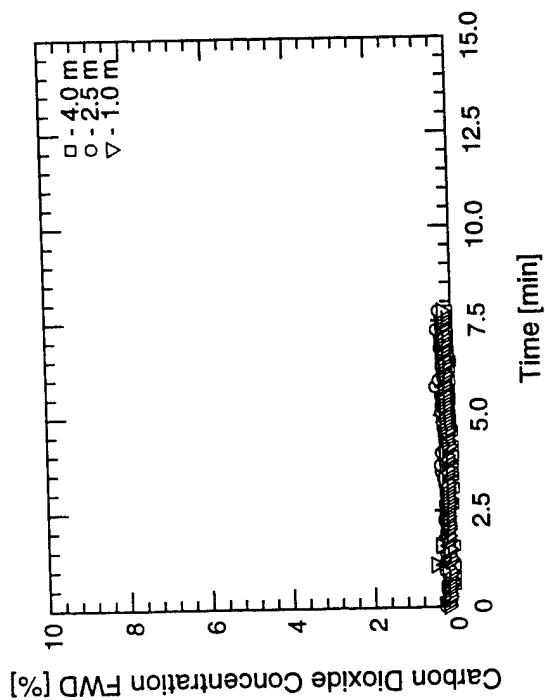
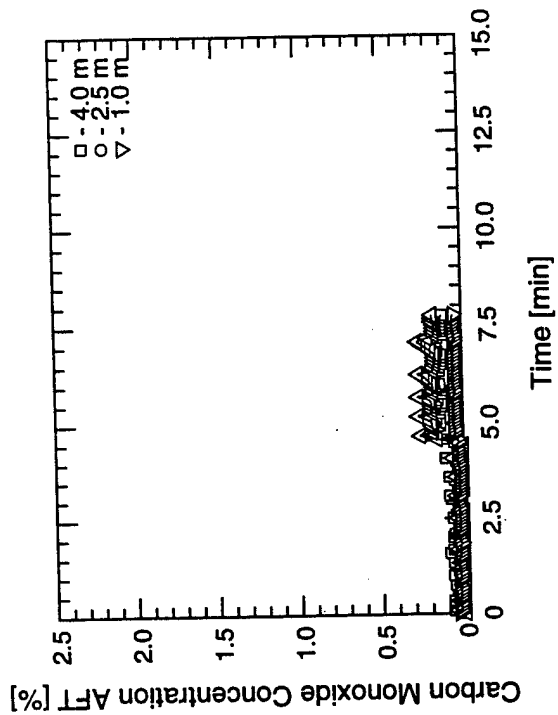
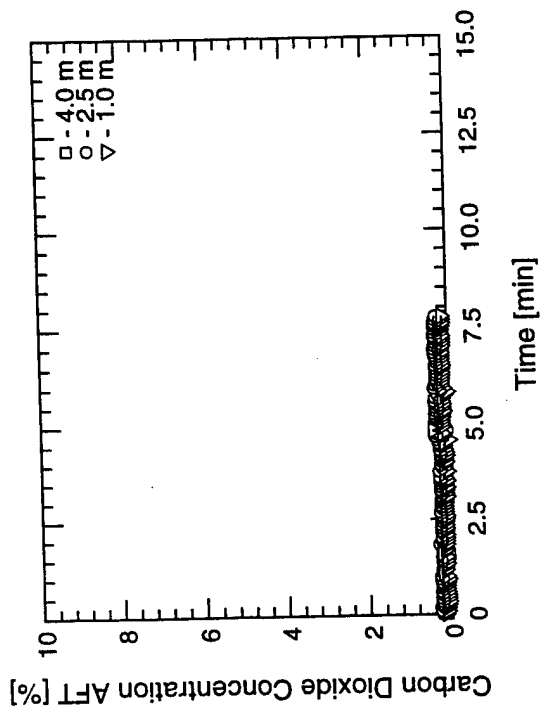
Test #9

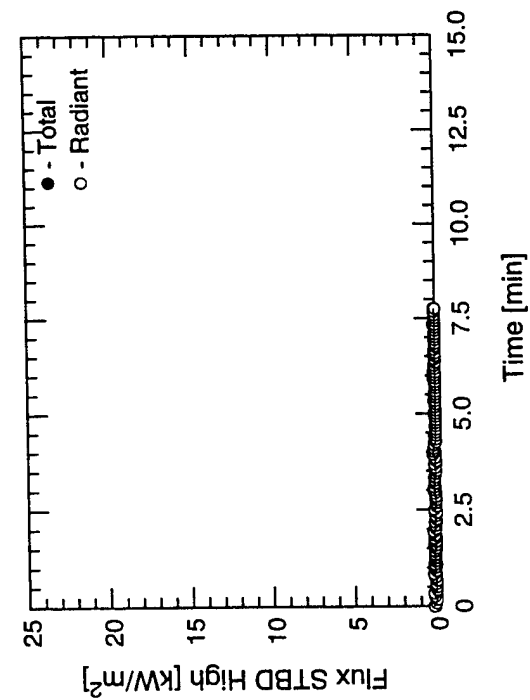




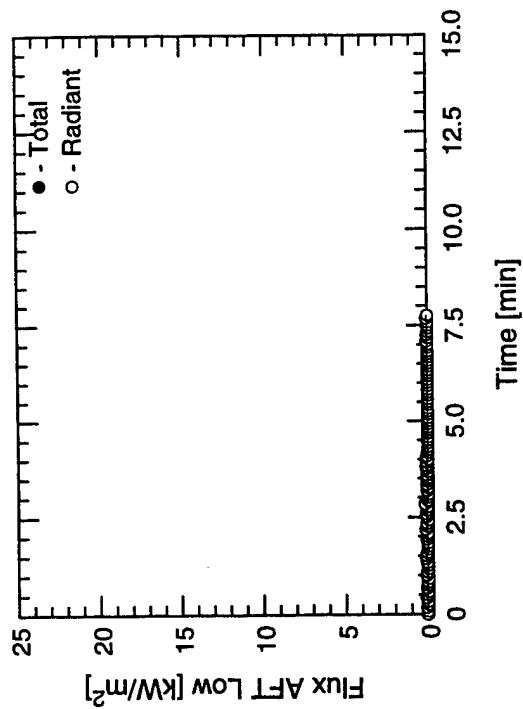
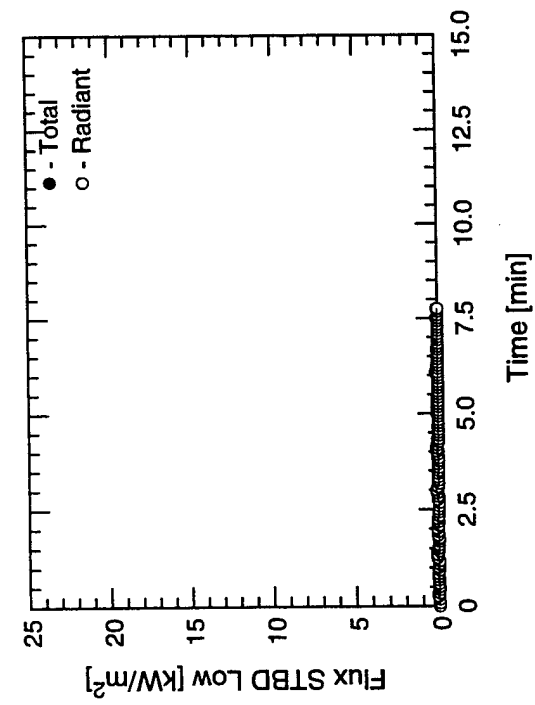
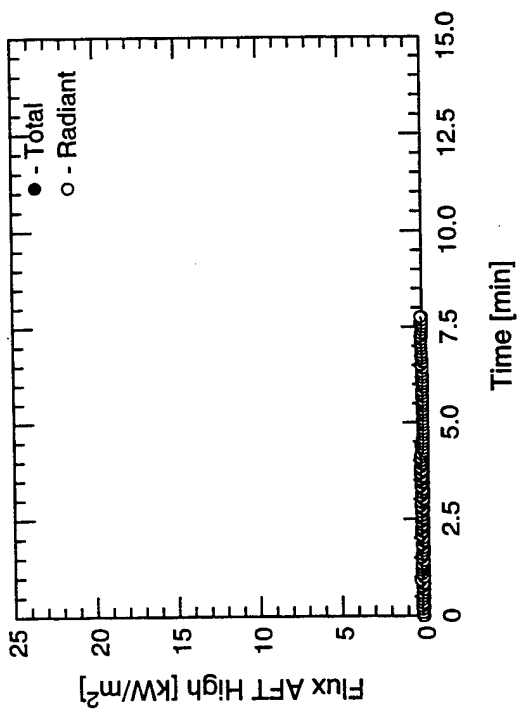
Test #10

Test #10



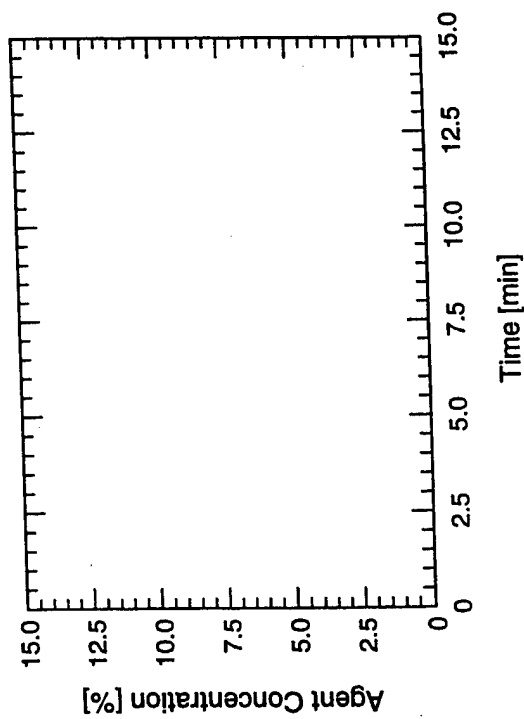
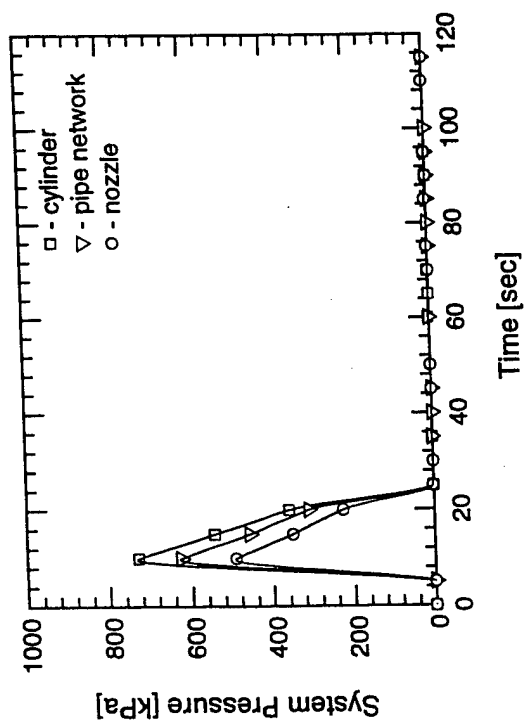
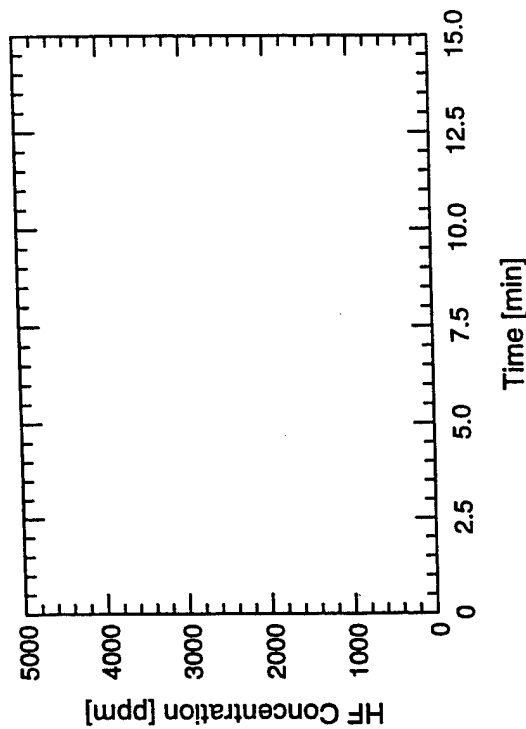
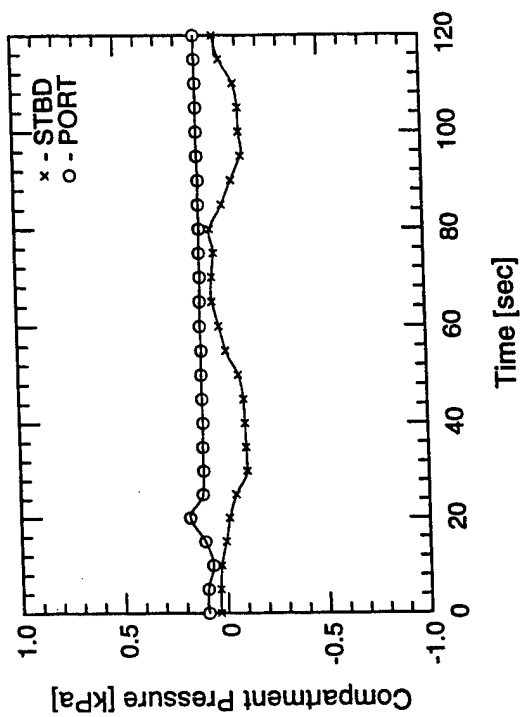


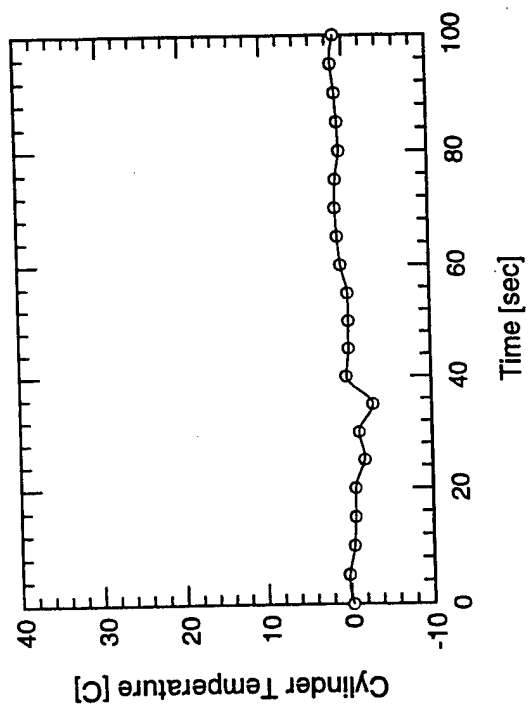
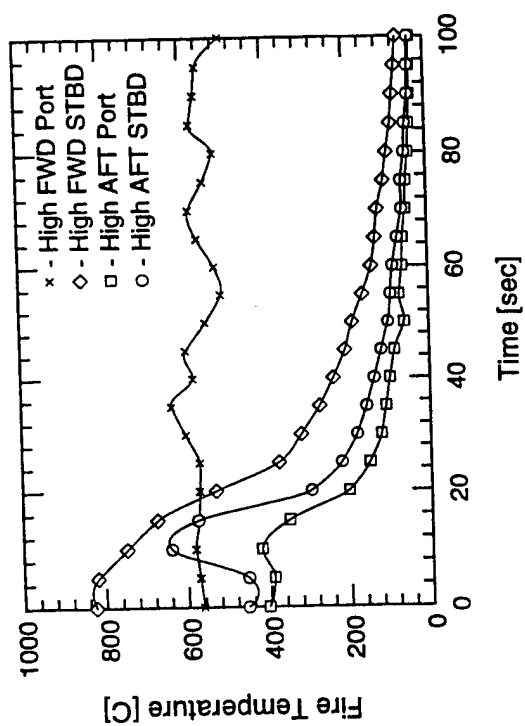
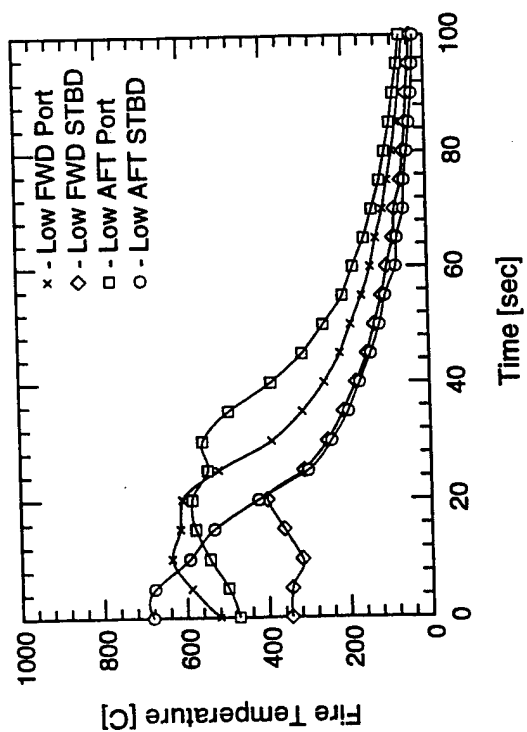
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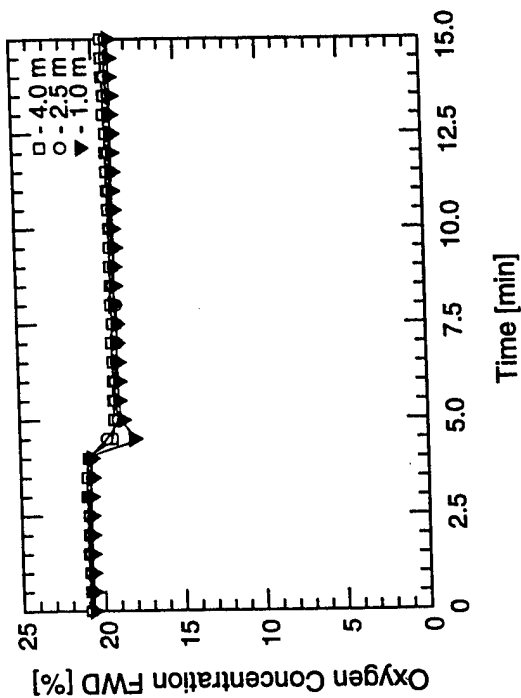
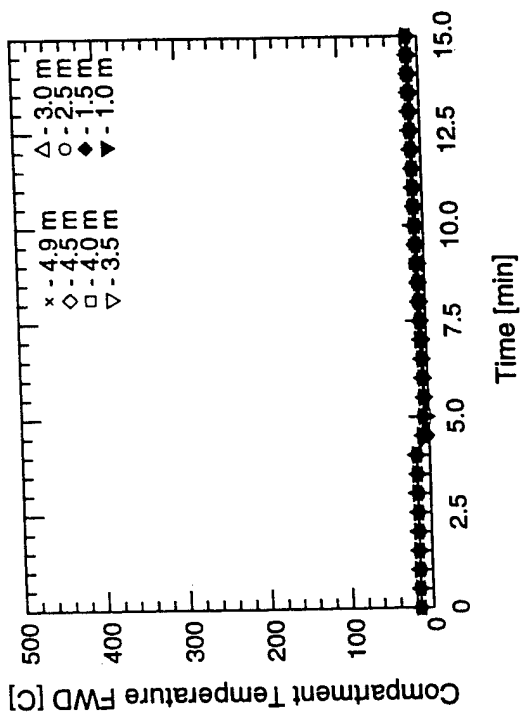
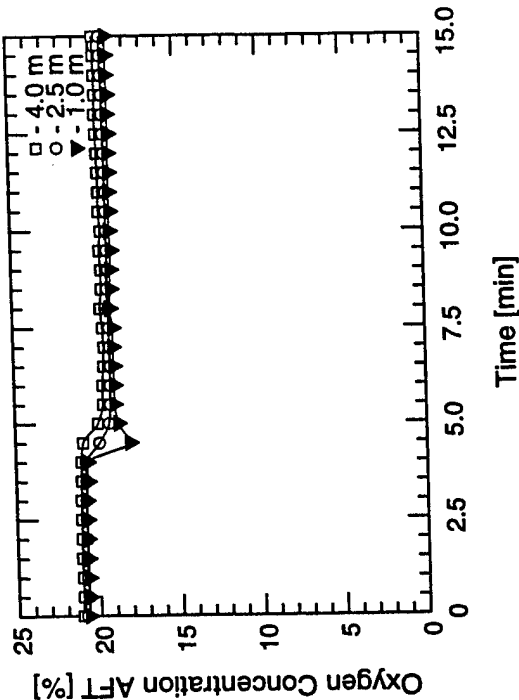
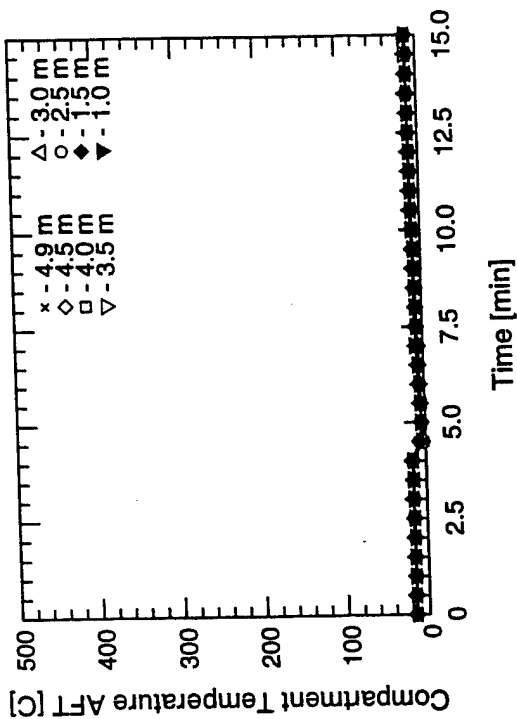
Test #10

Test #10

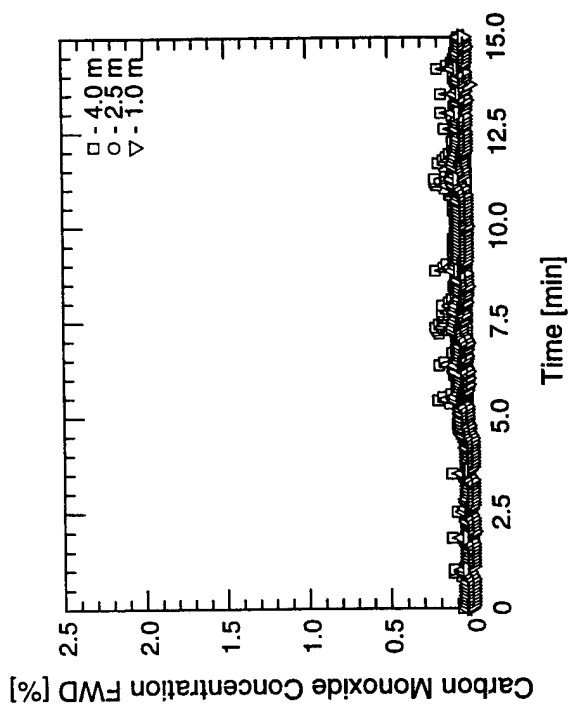
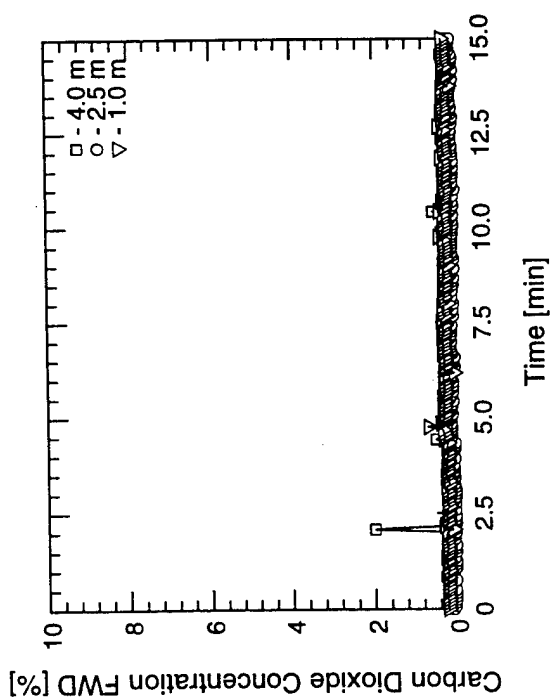
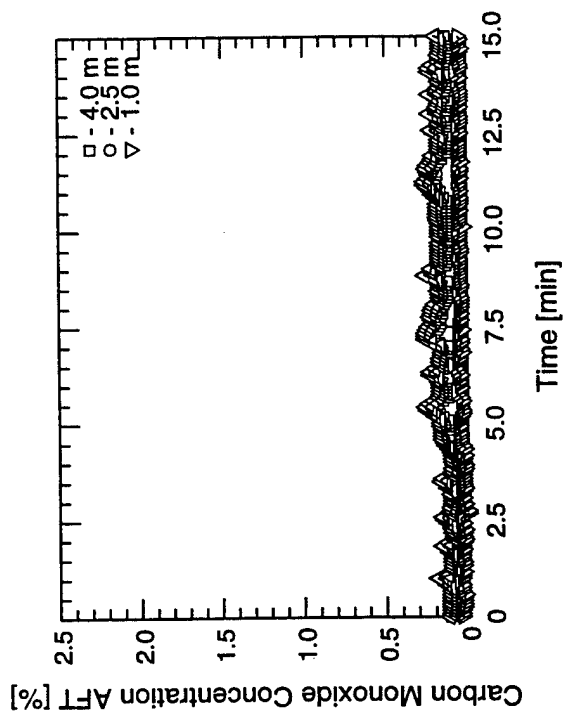
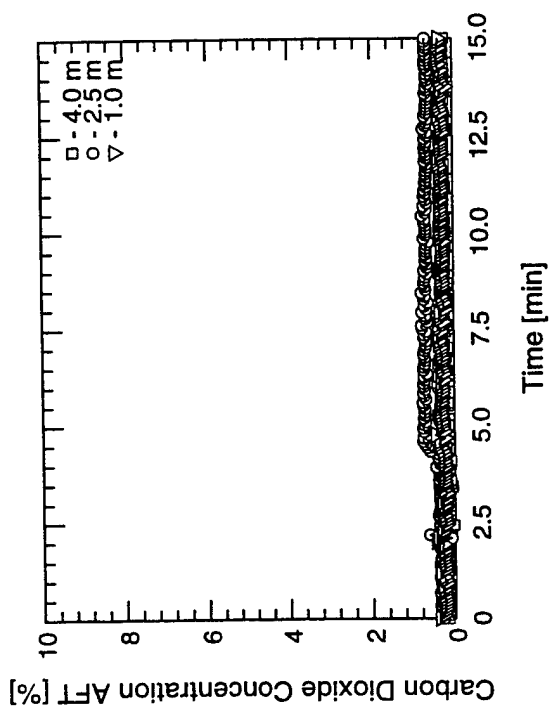




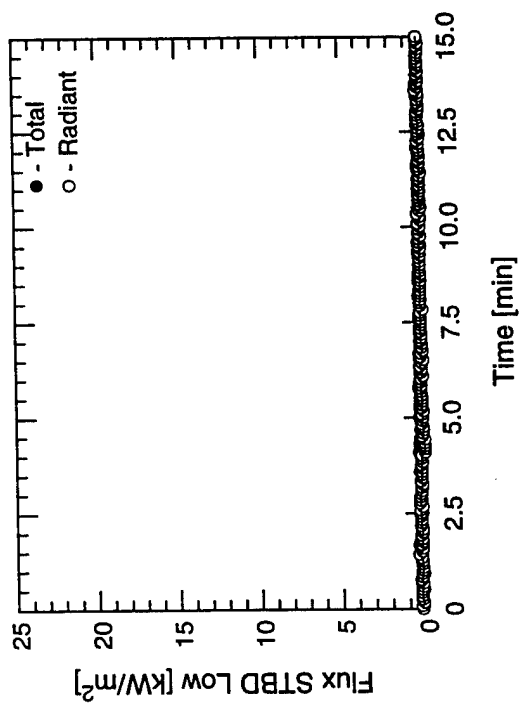
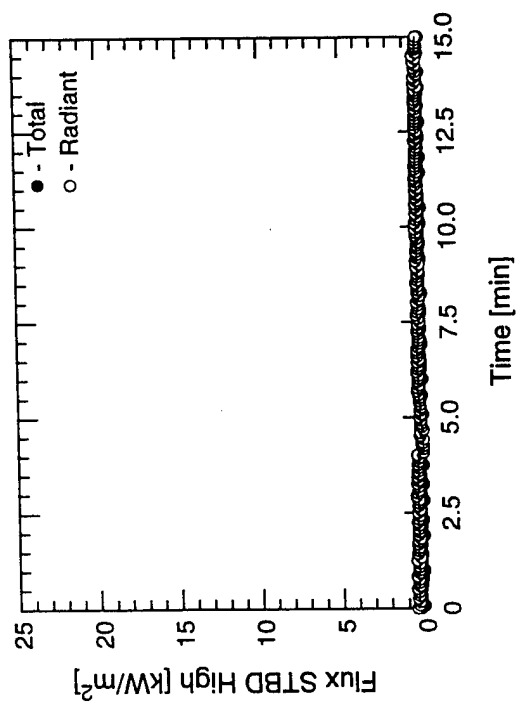
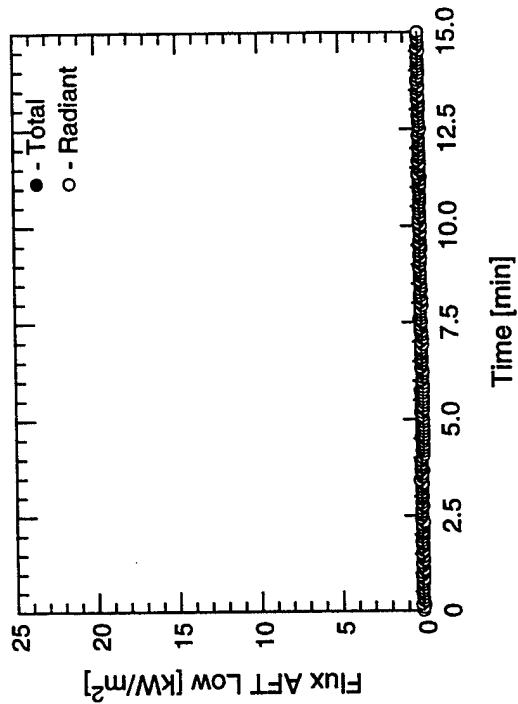
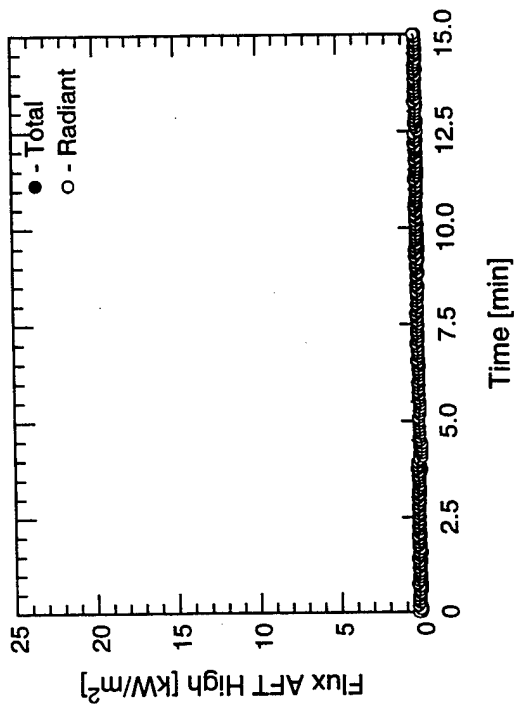
Test #10



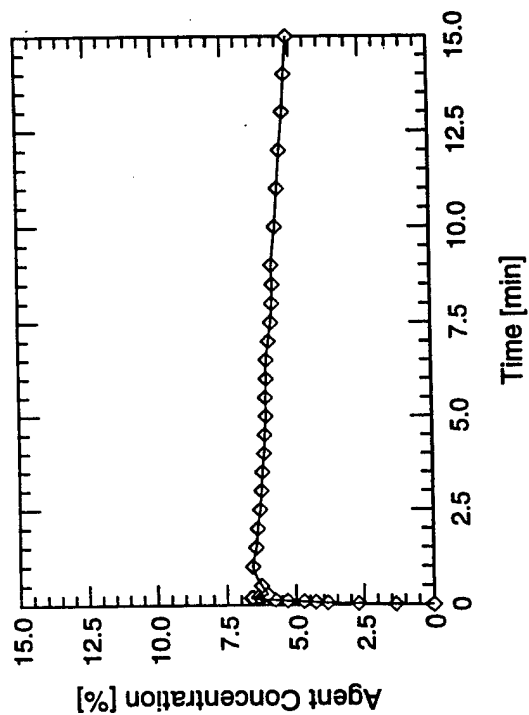
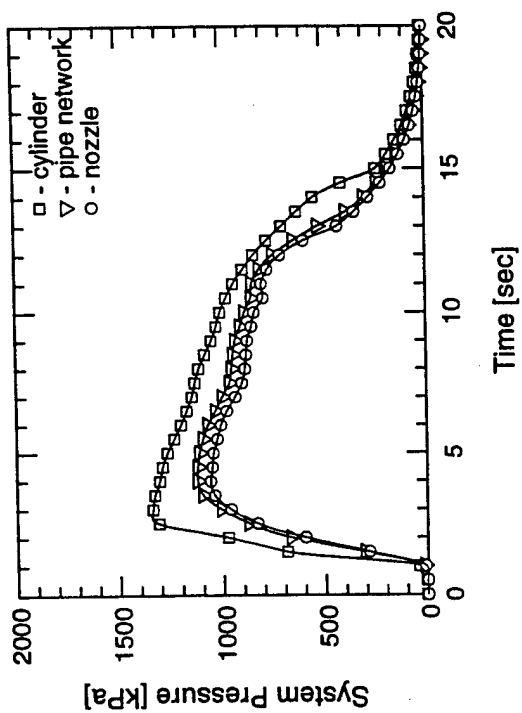
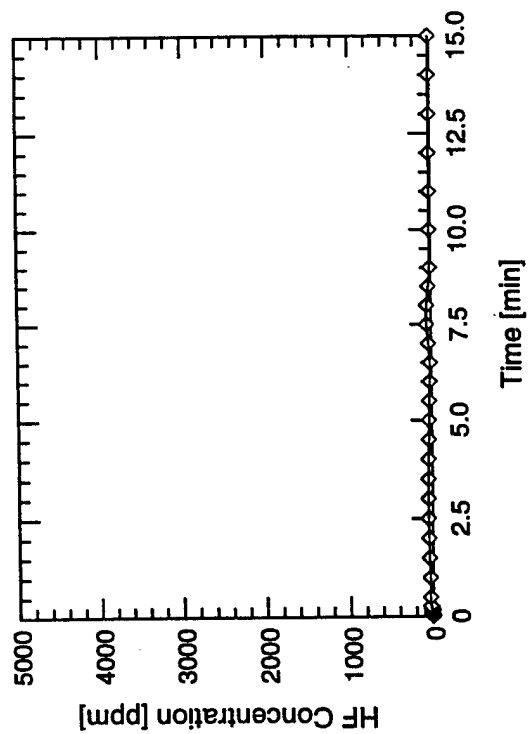
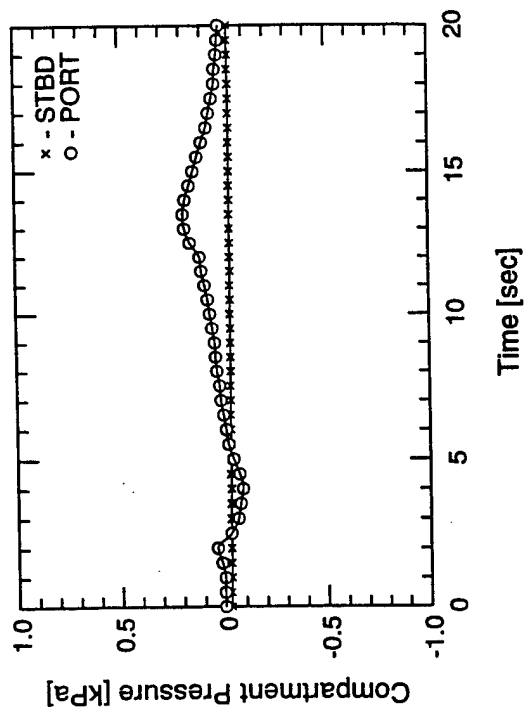
Test #11



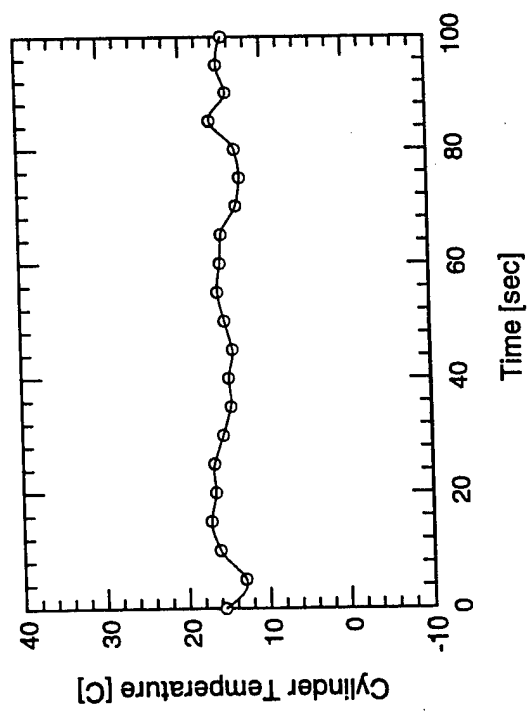
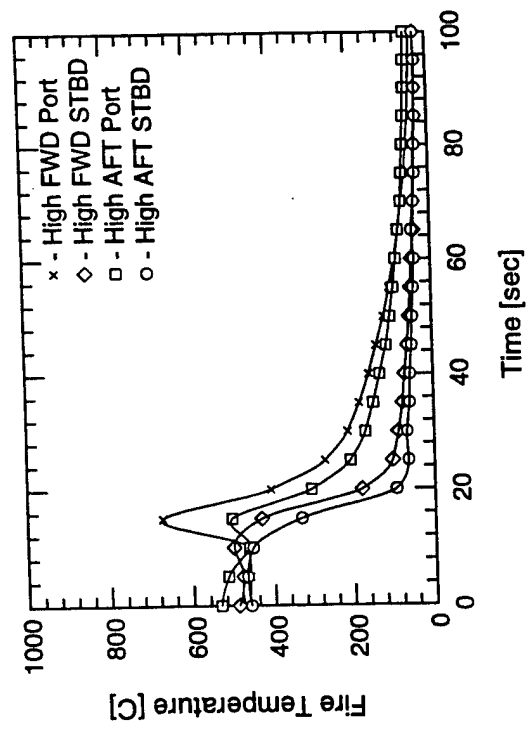
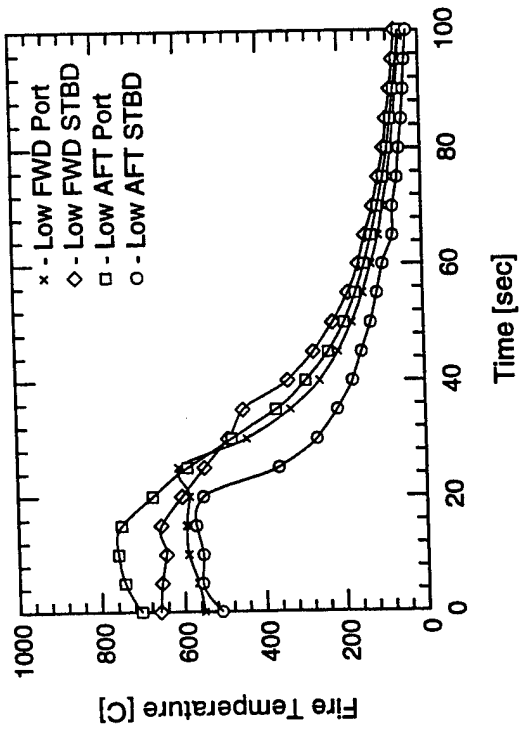
Test #11



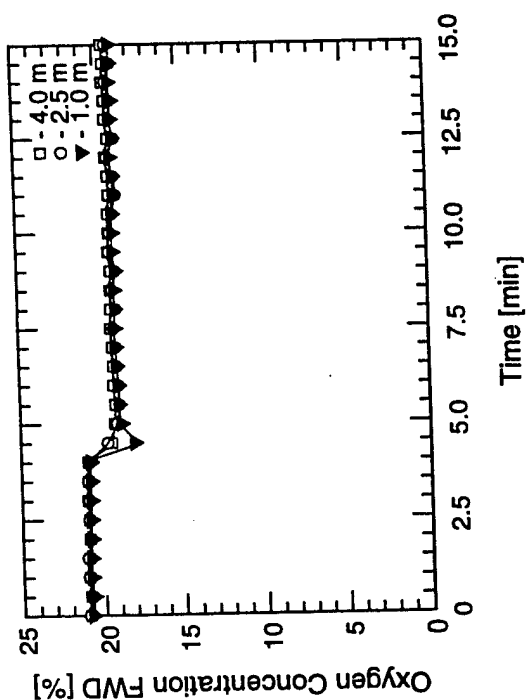
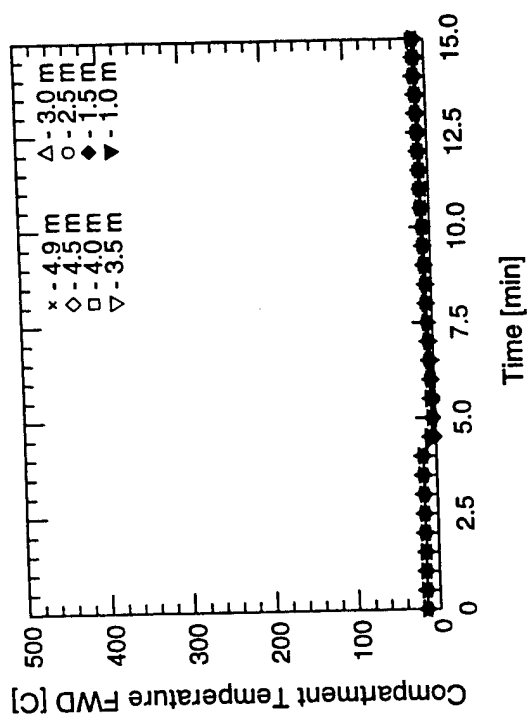
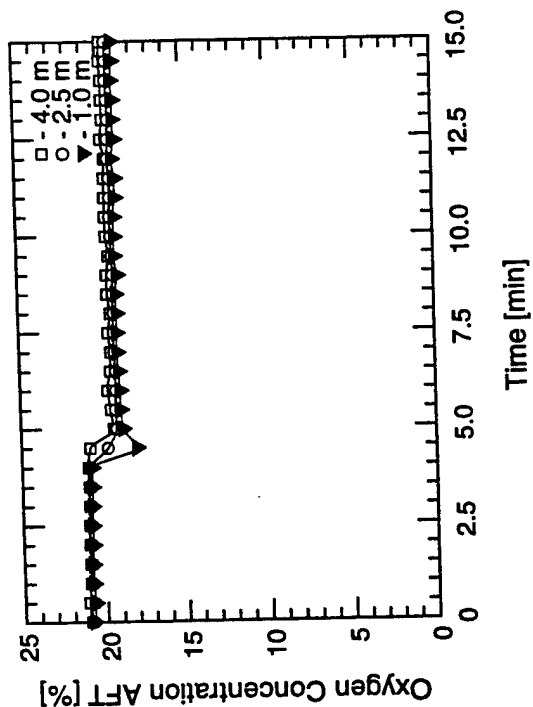
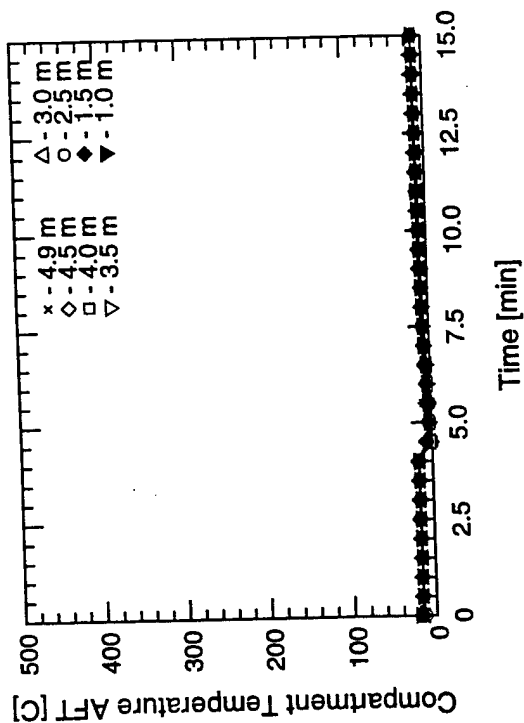
Test #11



Test #11



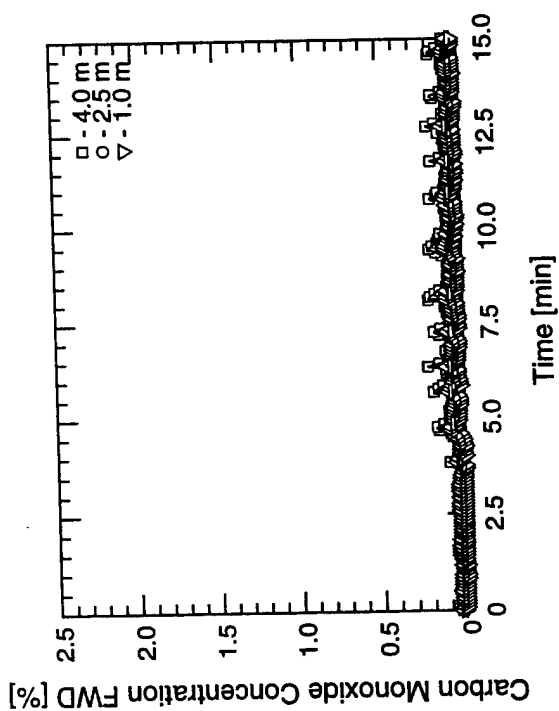
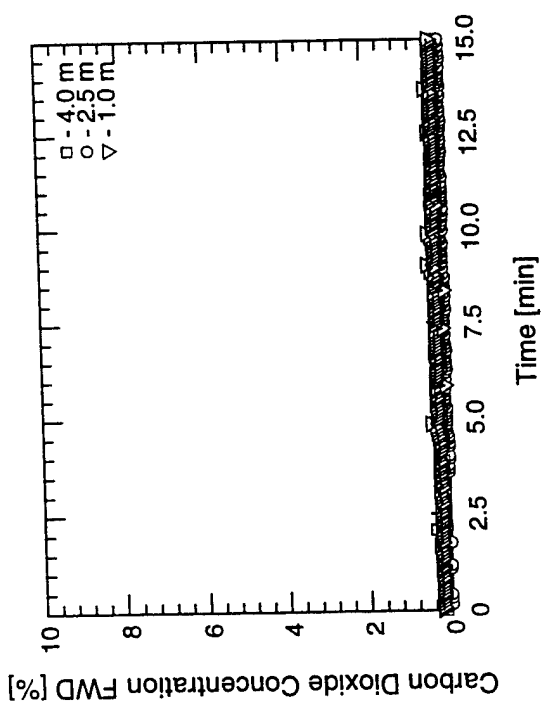
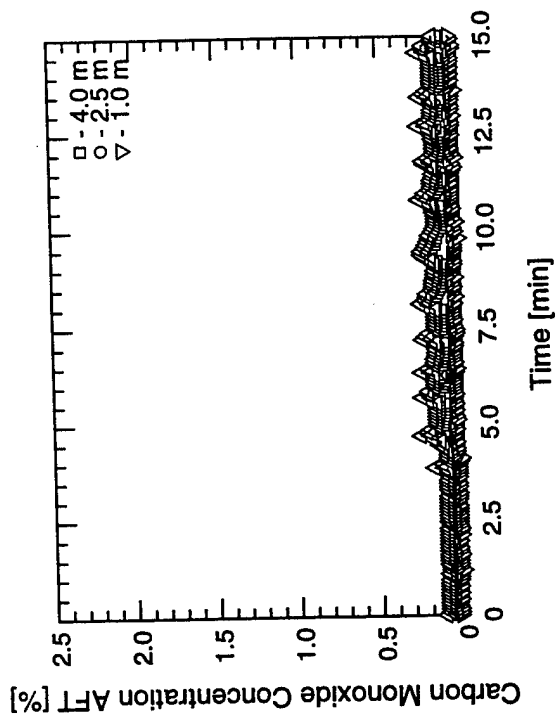
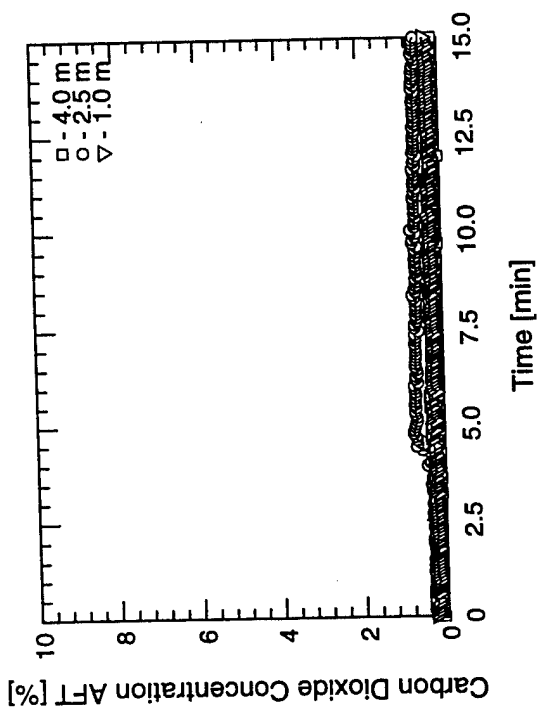
Test #11

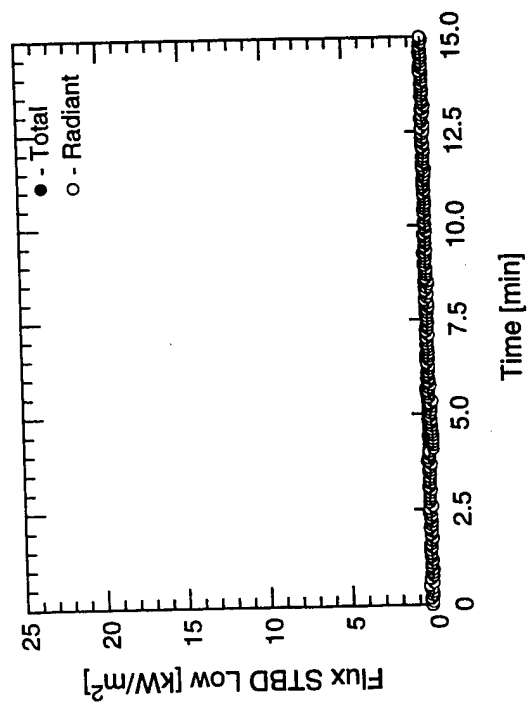
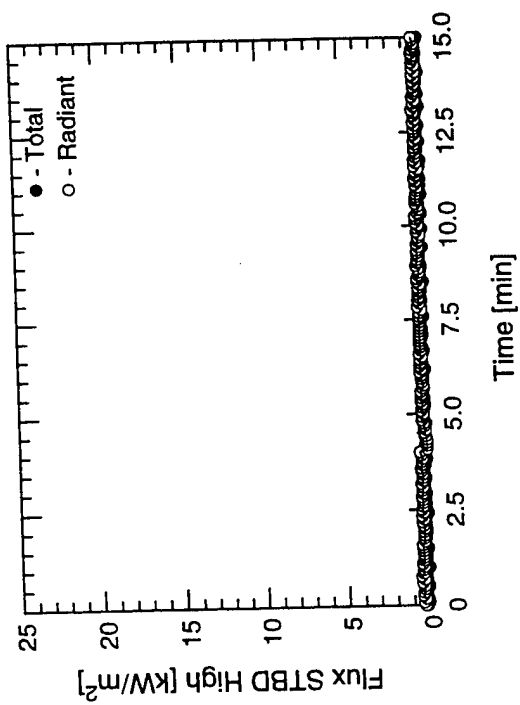
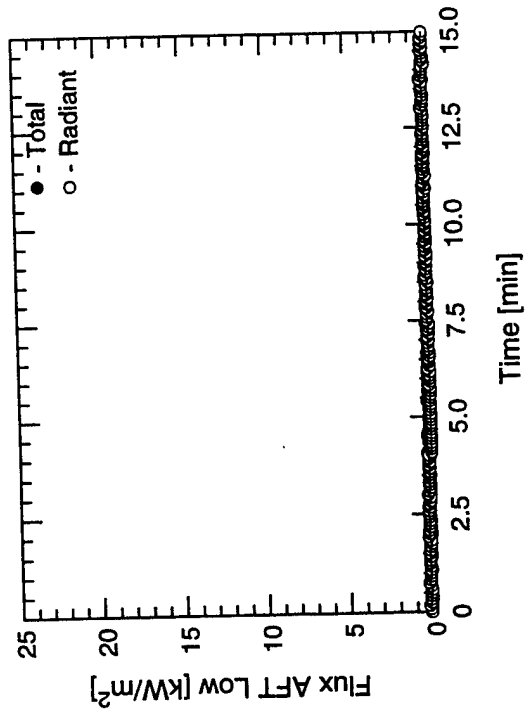
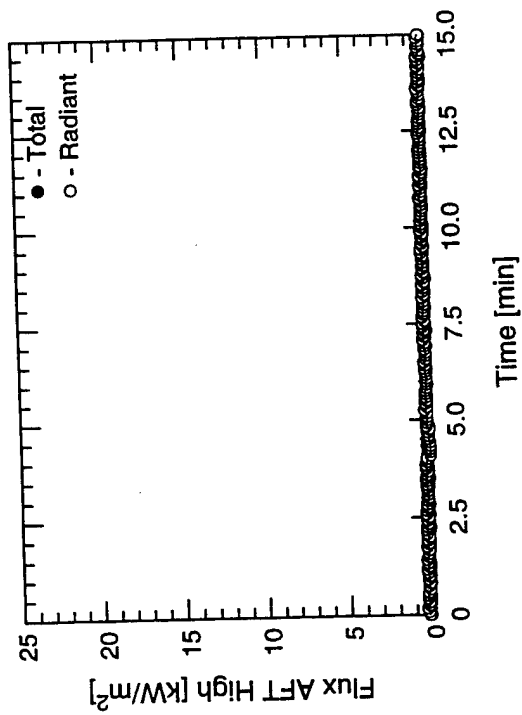


Test #12

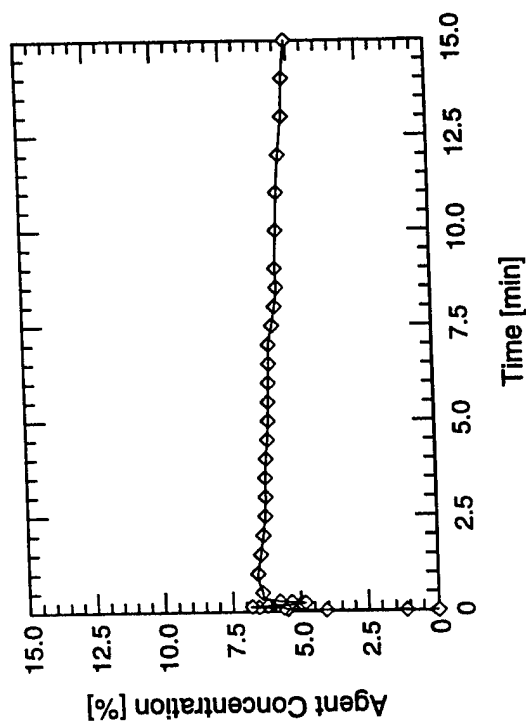
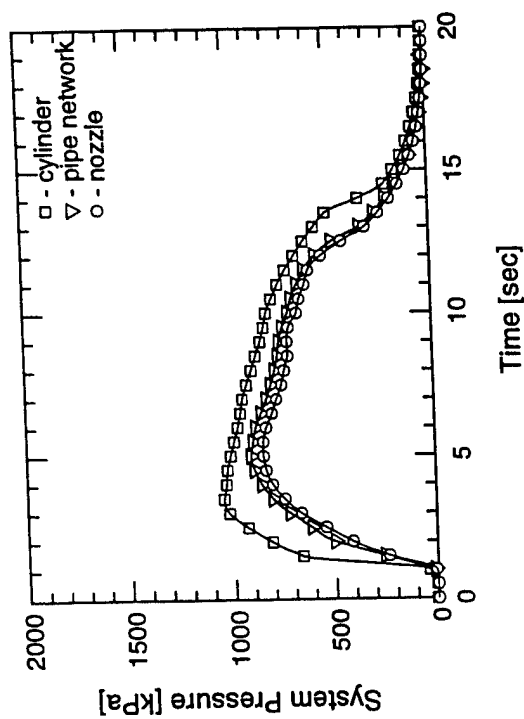
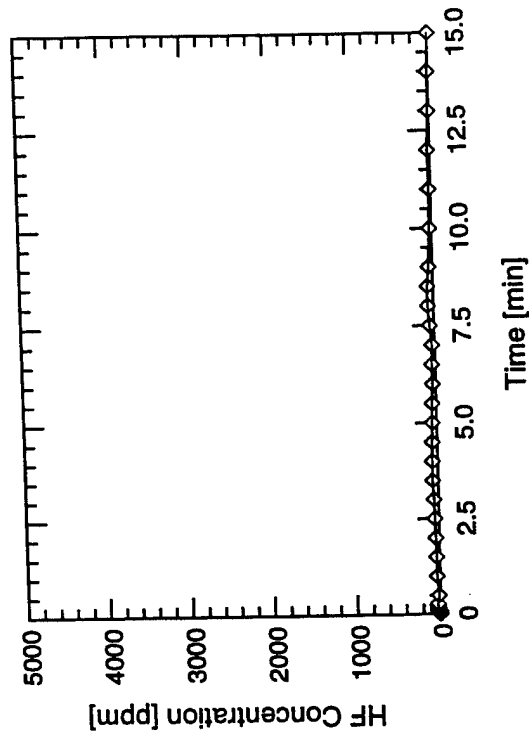
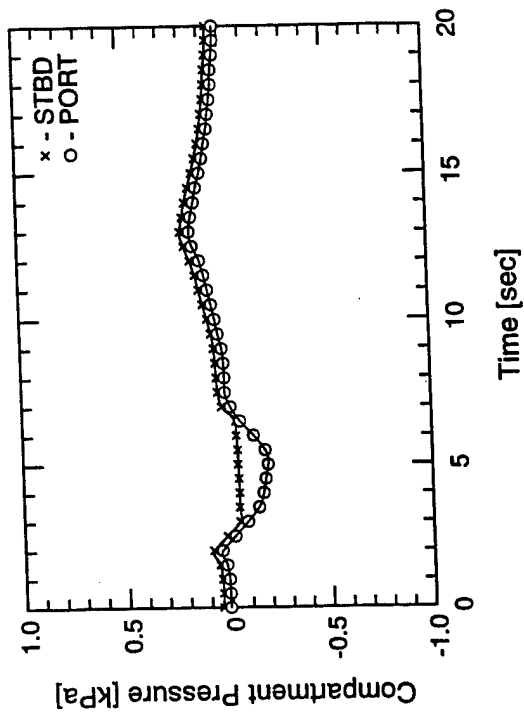
Test #12

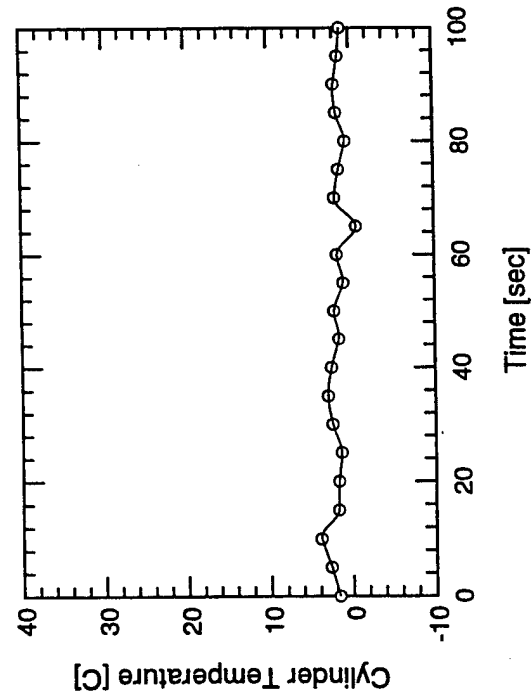
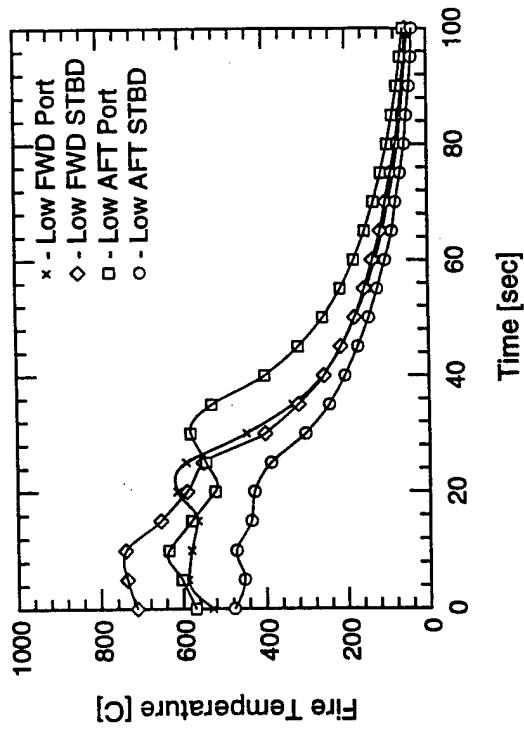
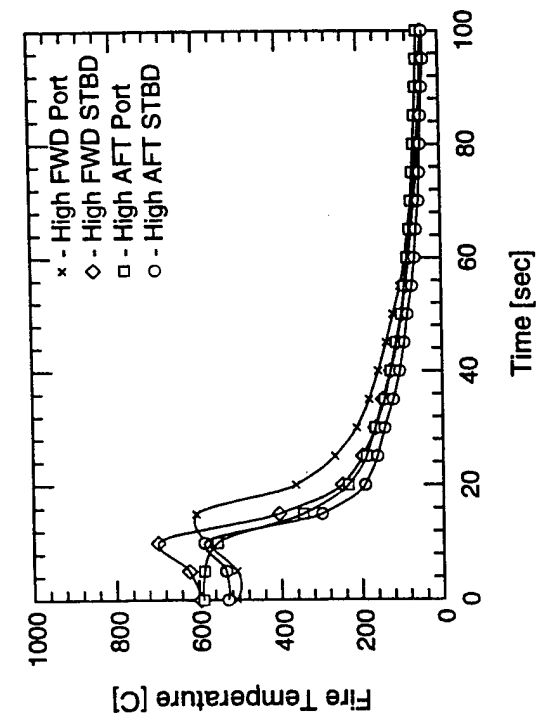
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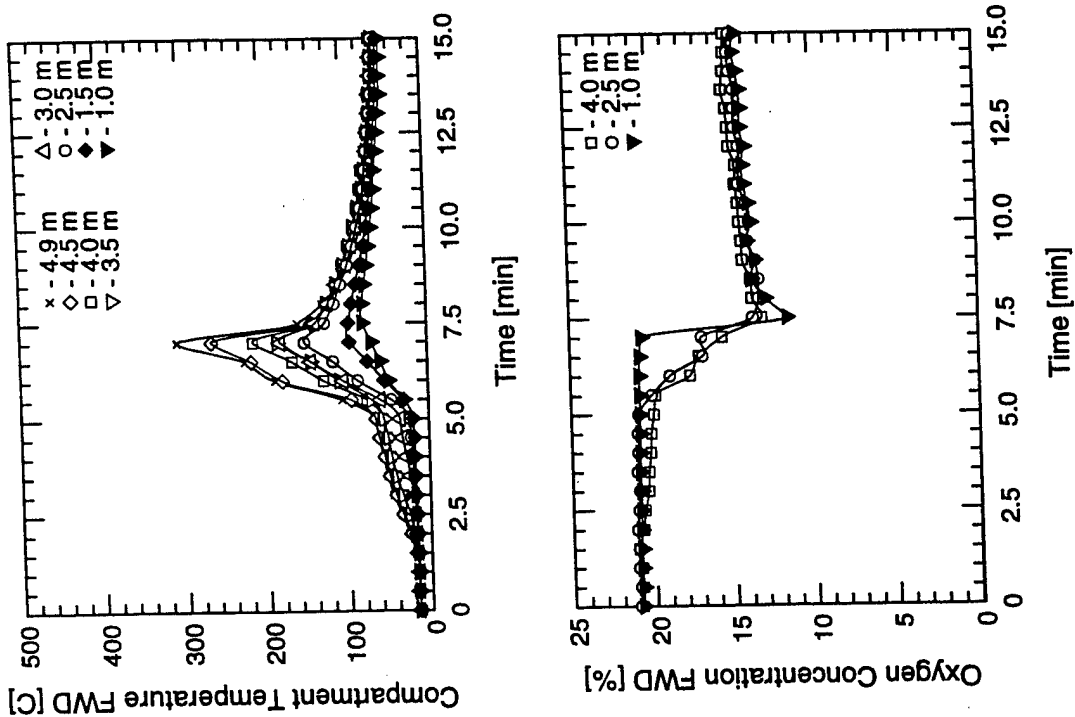
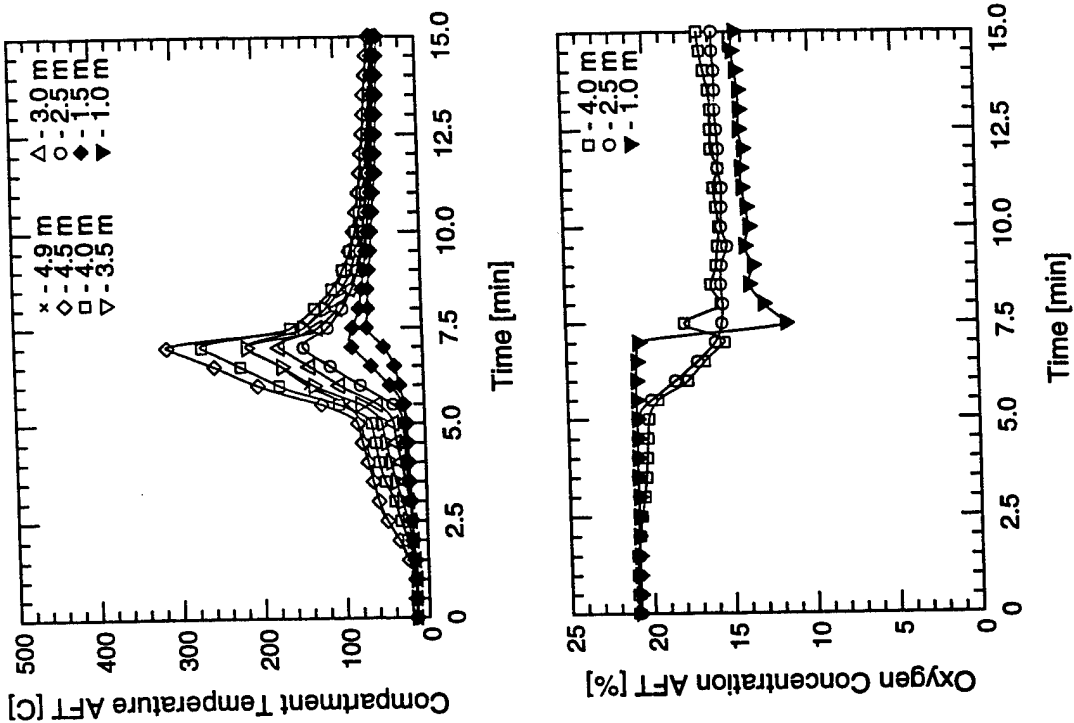
Test #12



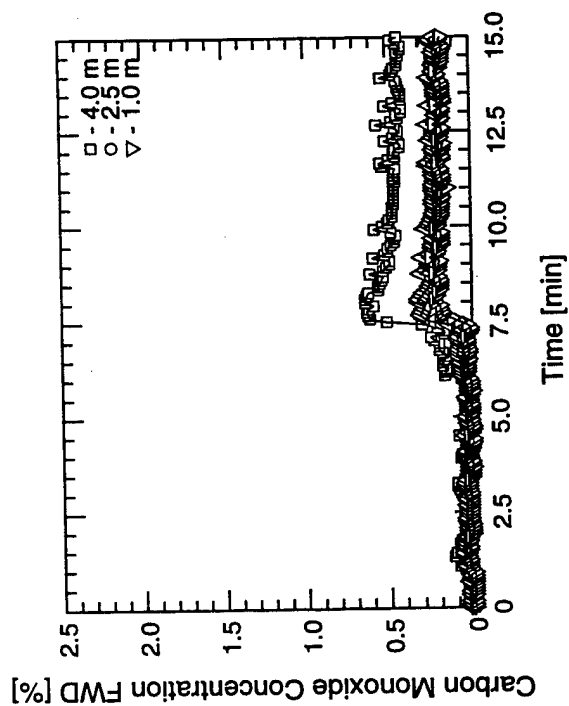
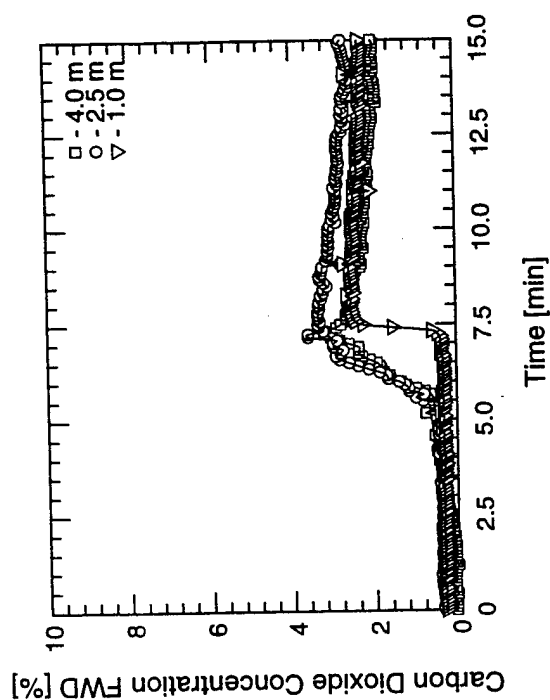
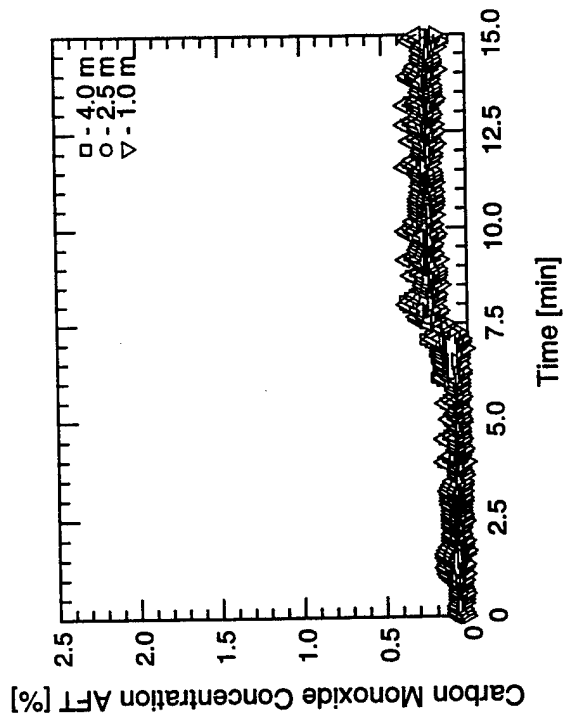
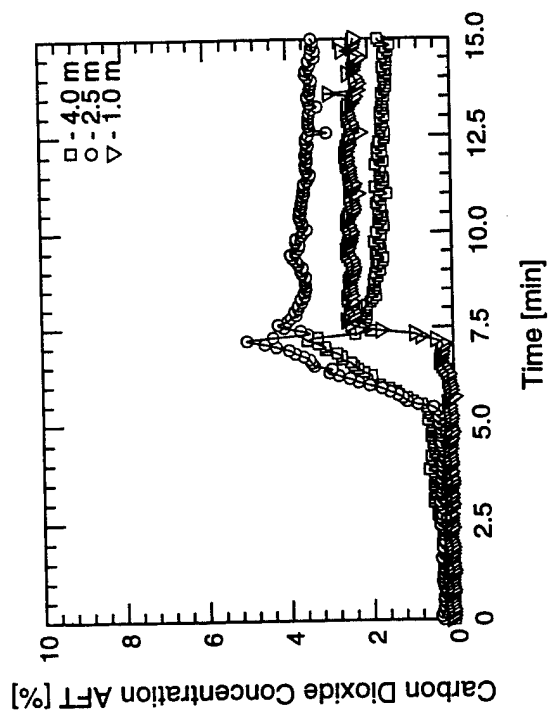


Test #12

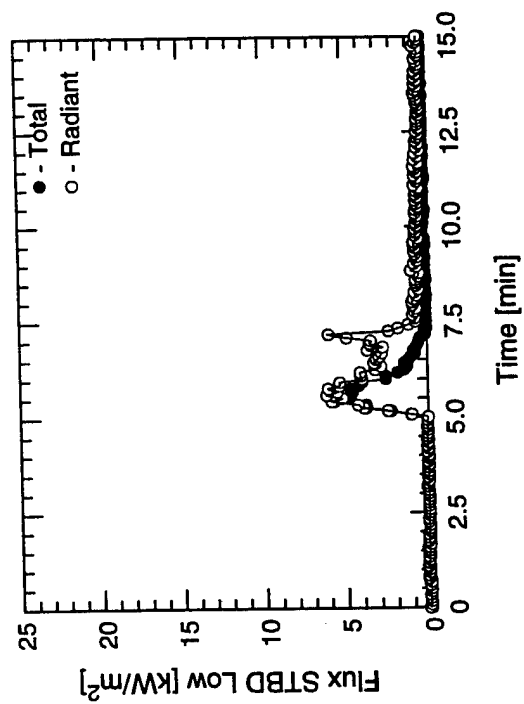
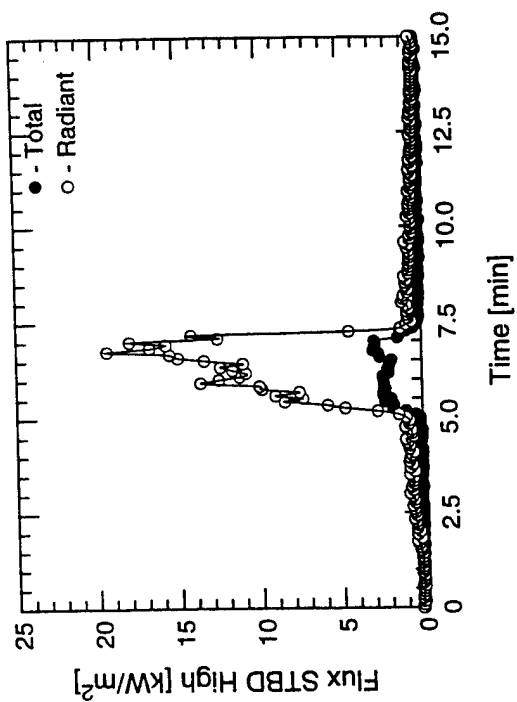
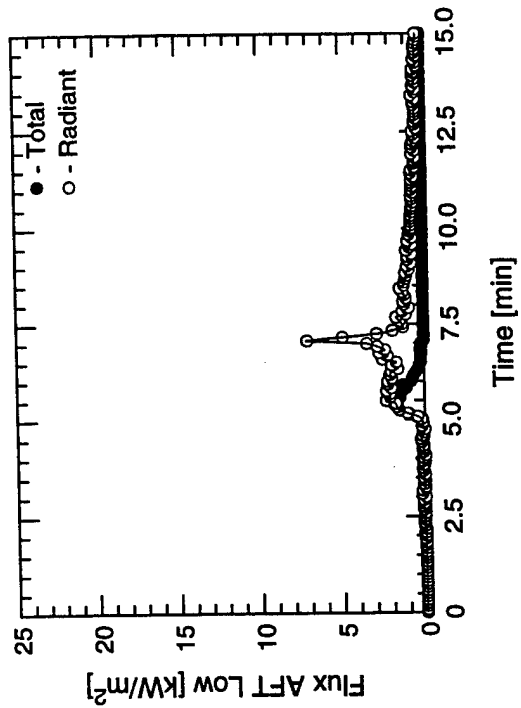
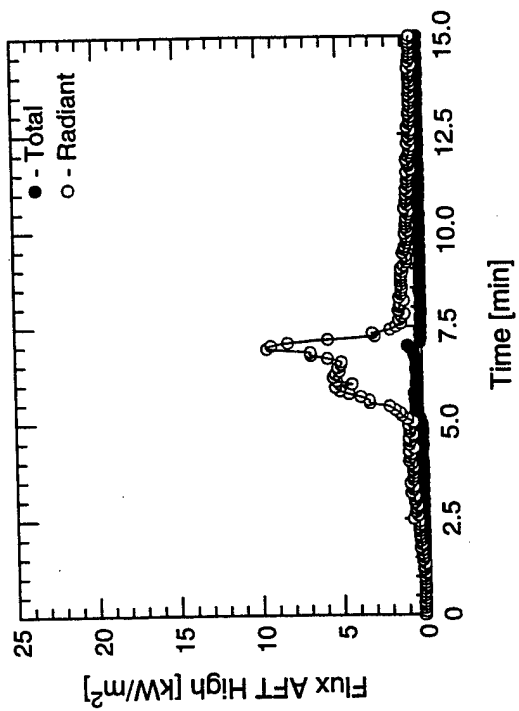
Test #13

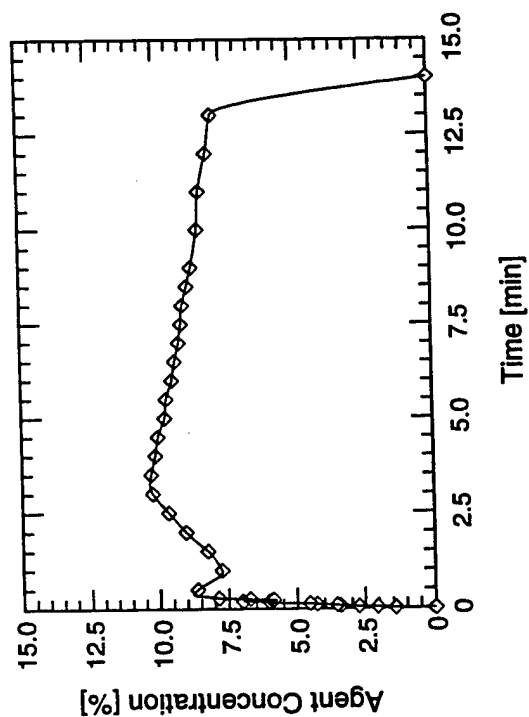
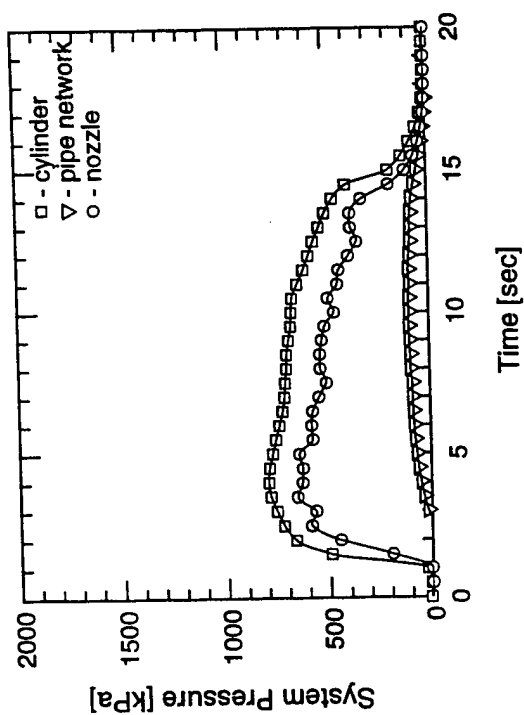
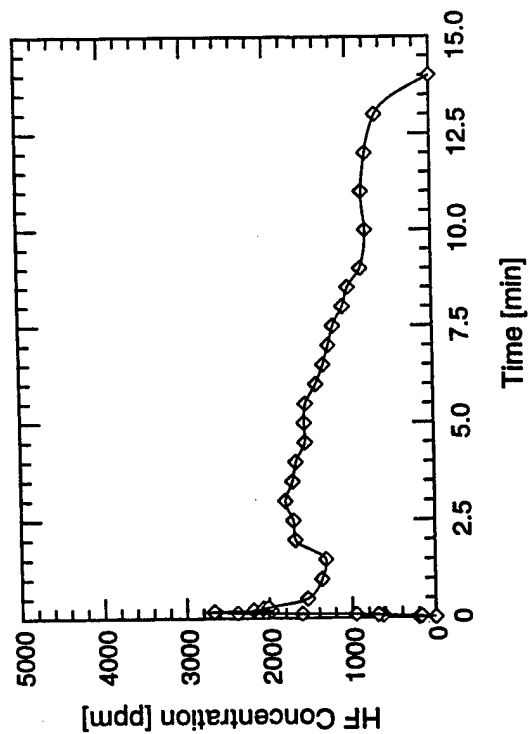
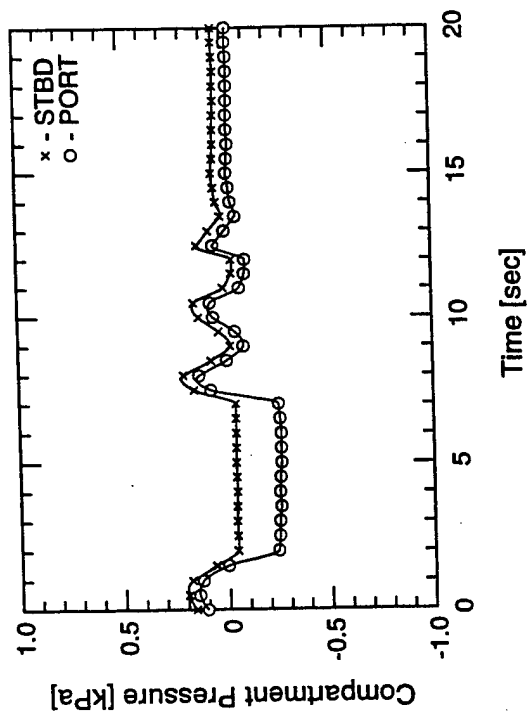


Test #13



Test #13

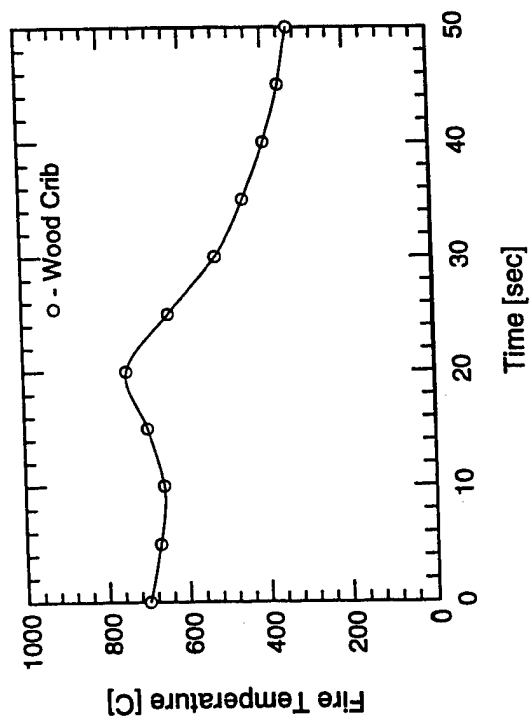
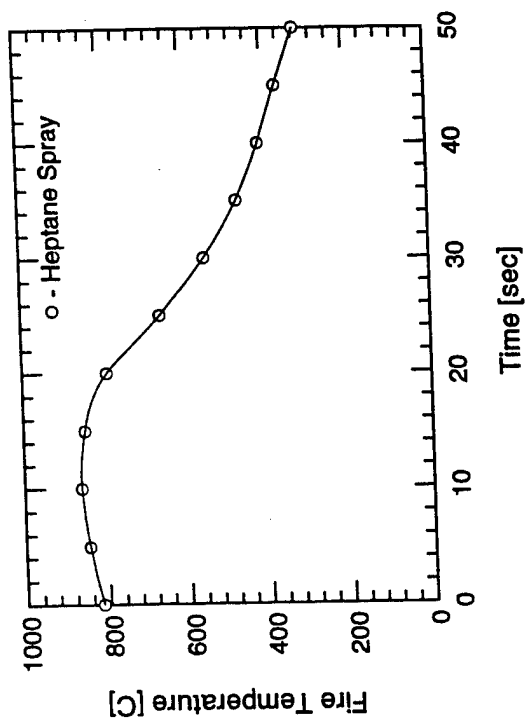
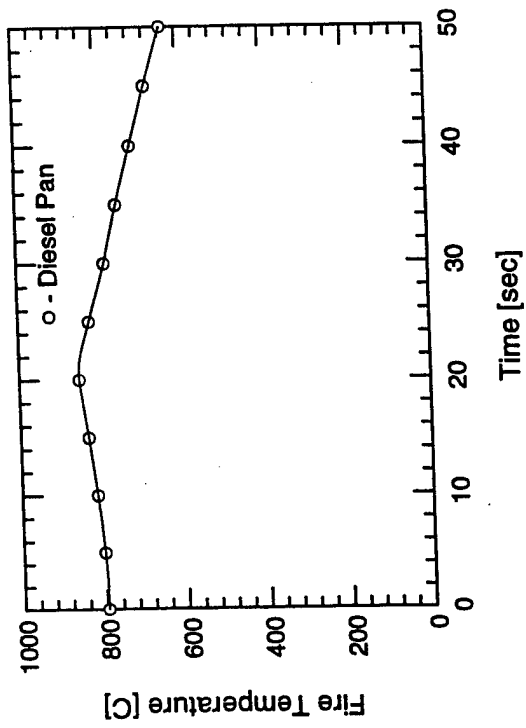


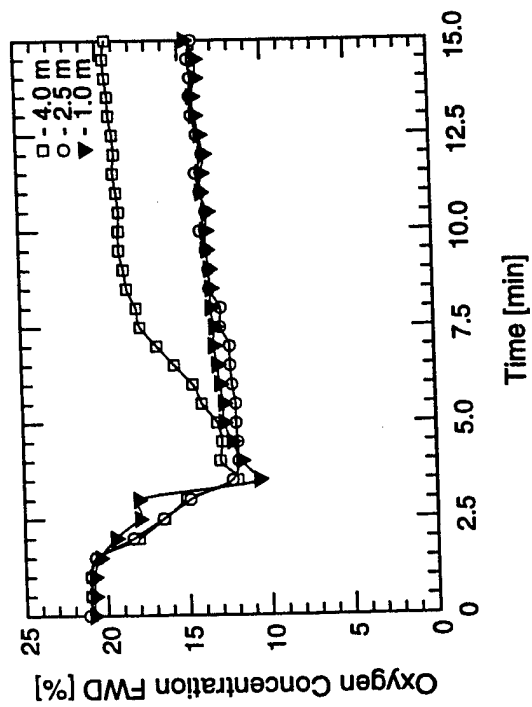
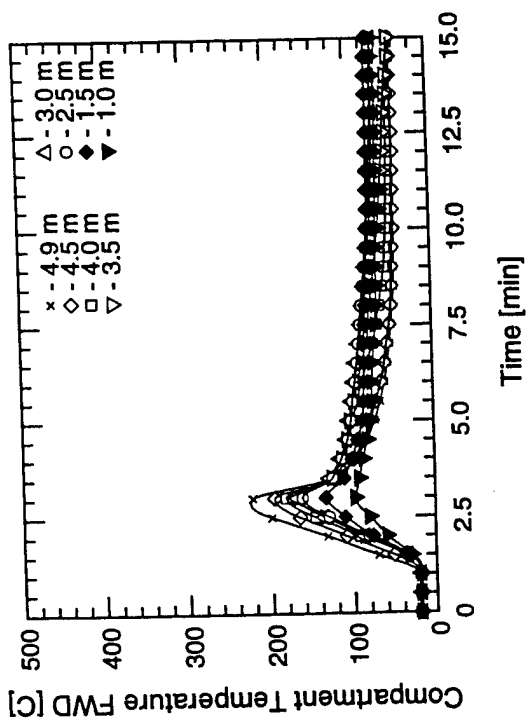
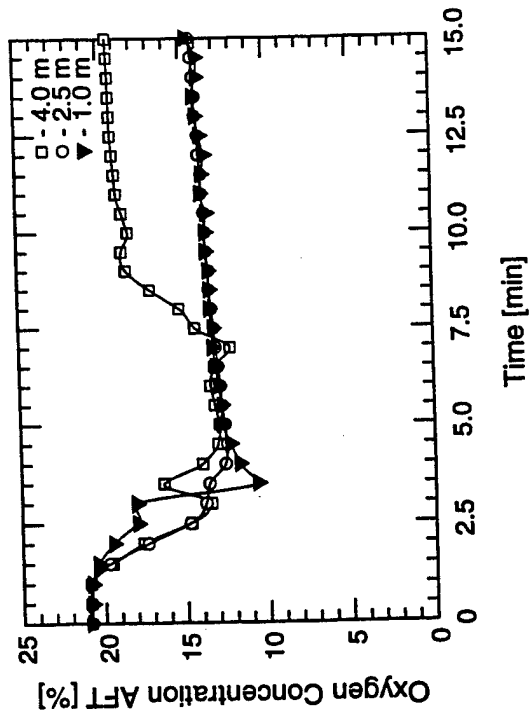
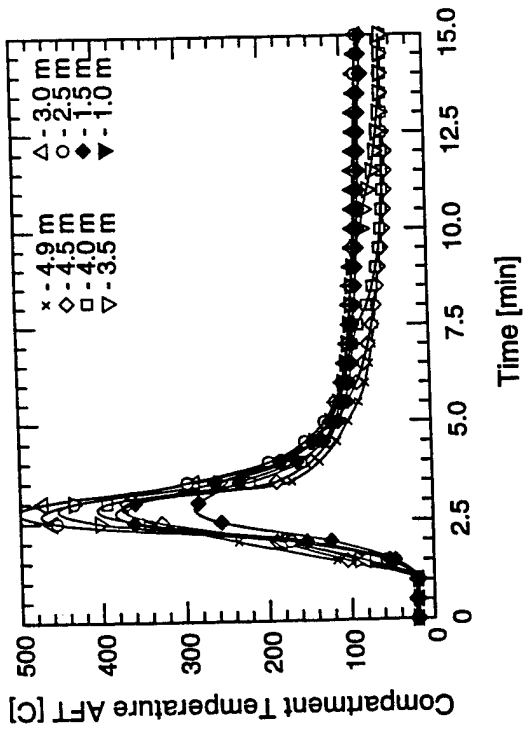


Test #13

Test #13

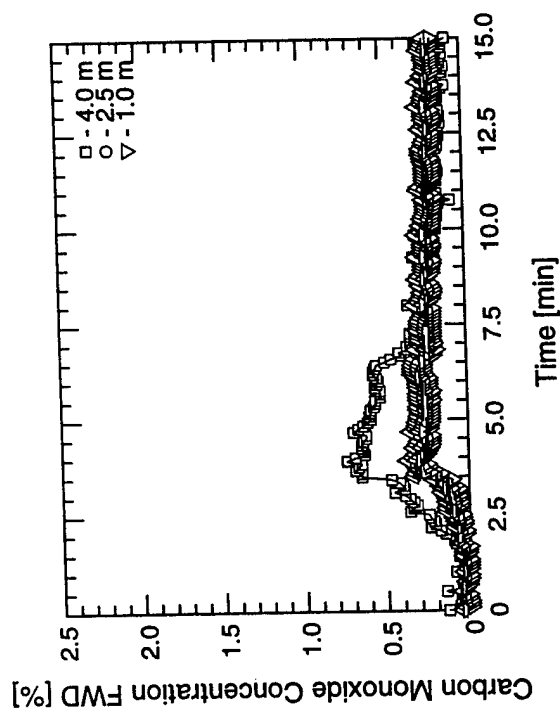
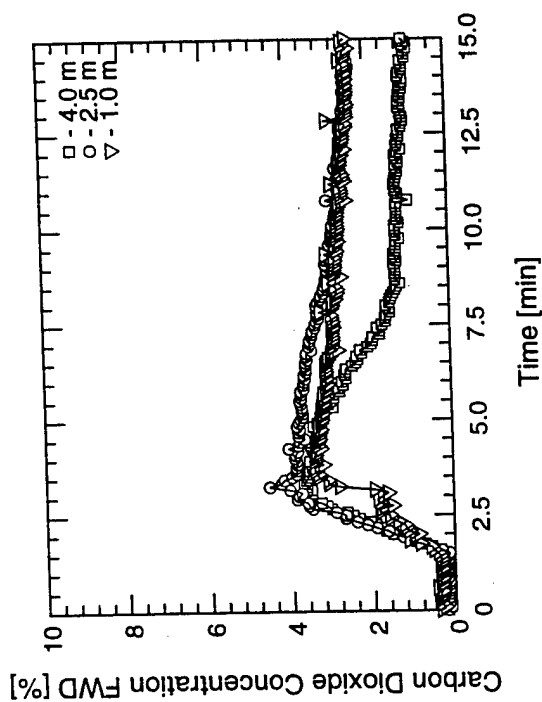
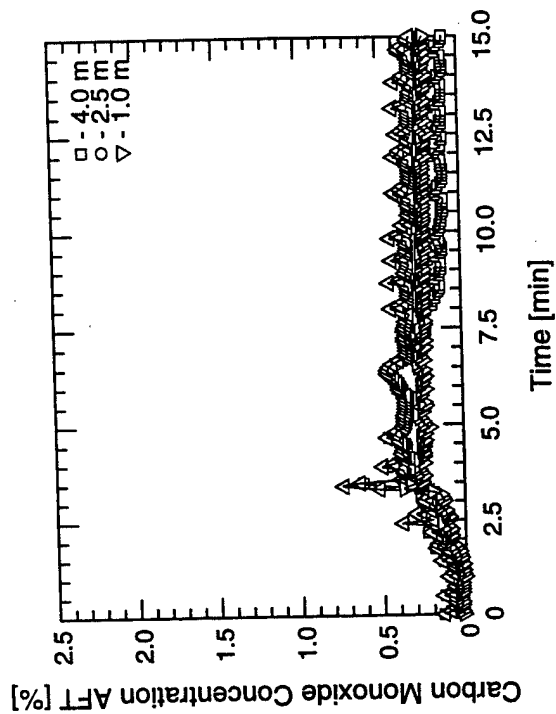
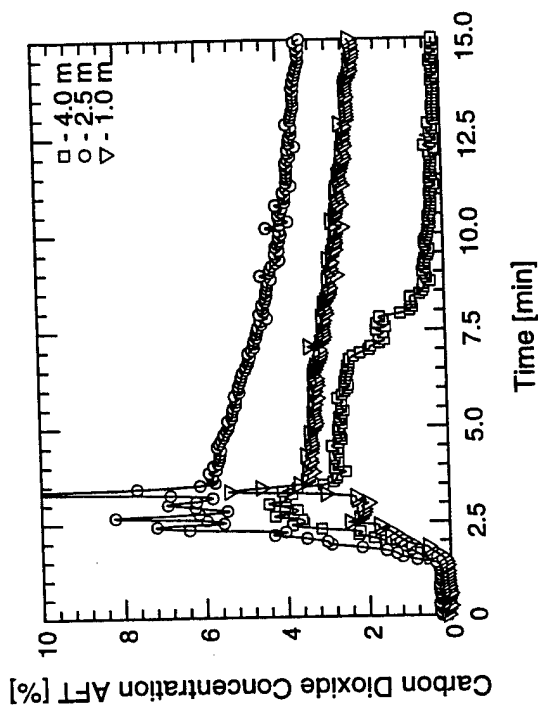
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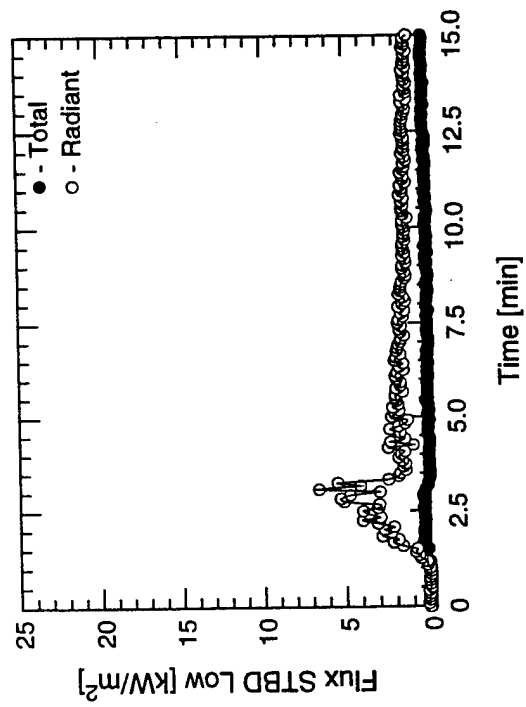
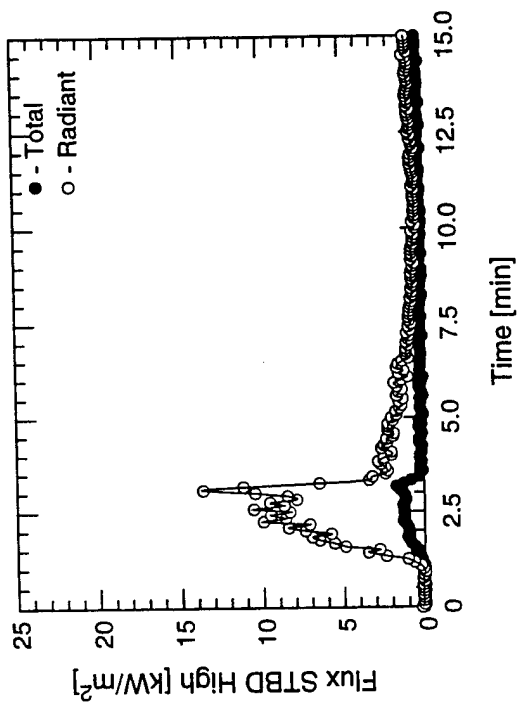
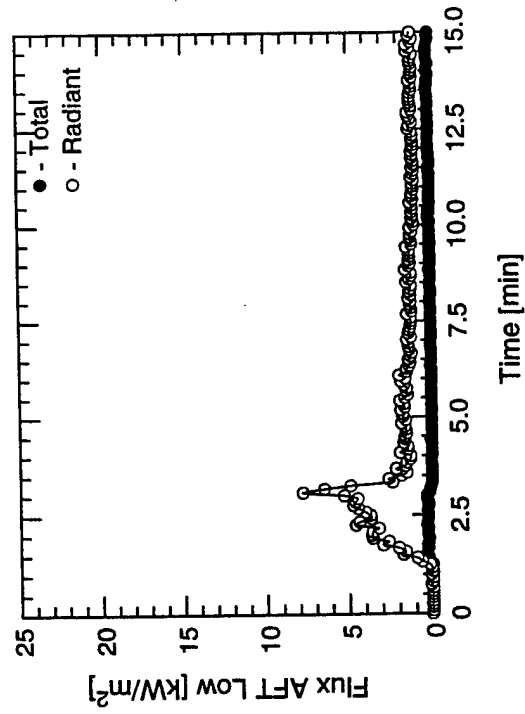
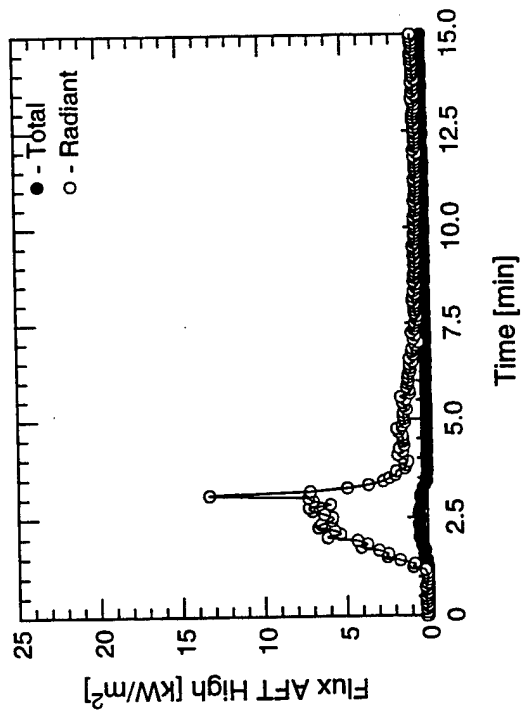




Test #14

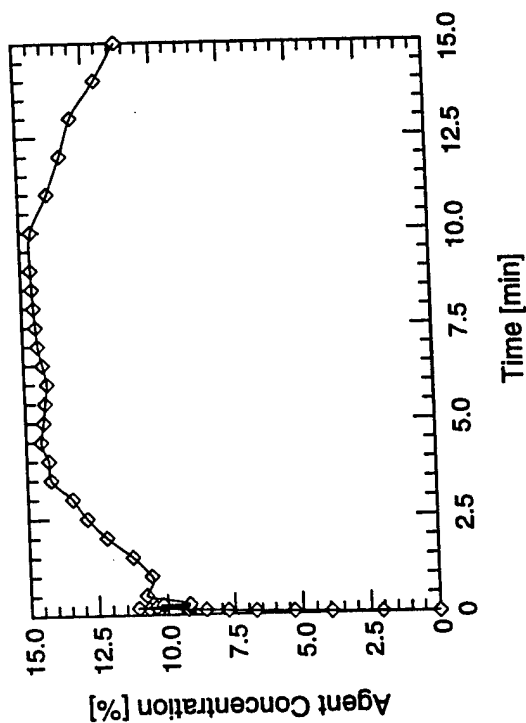
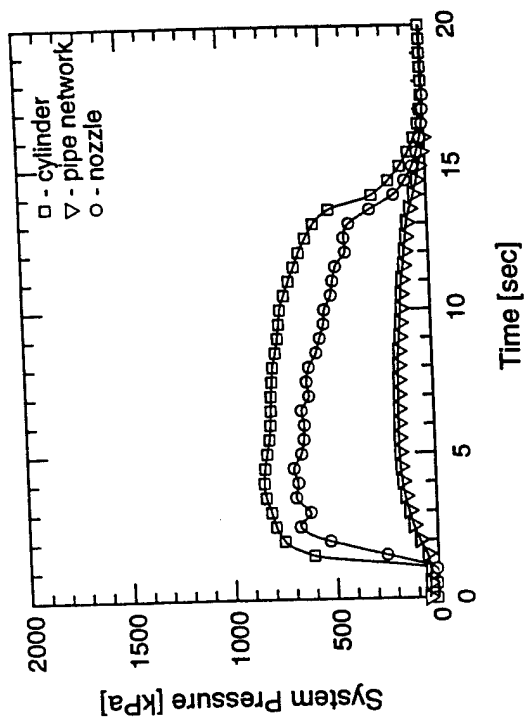
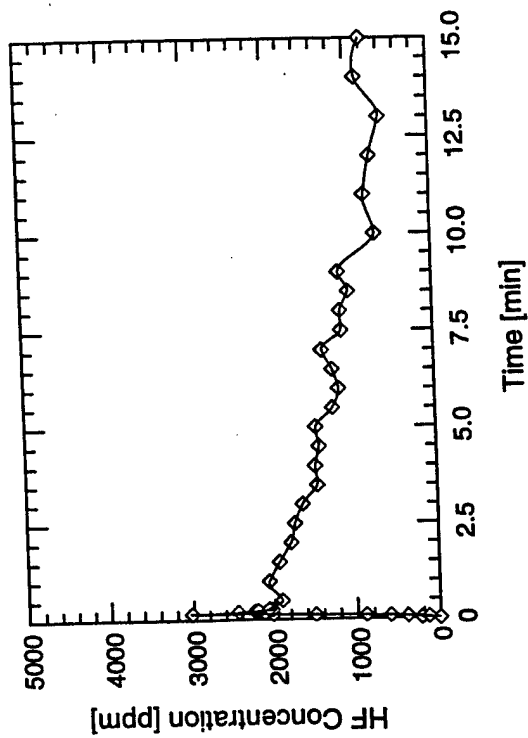
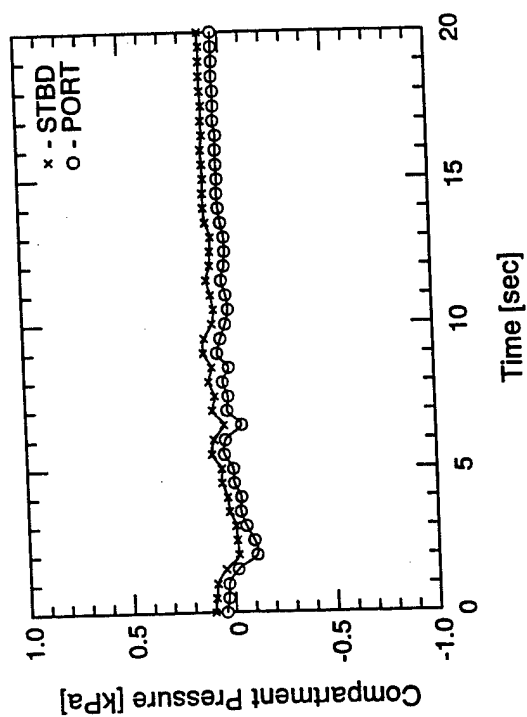
Test #14

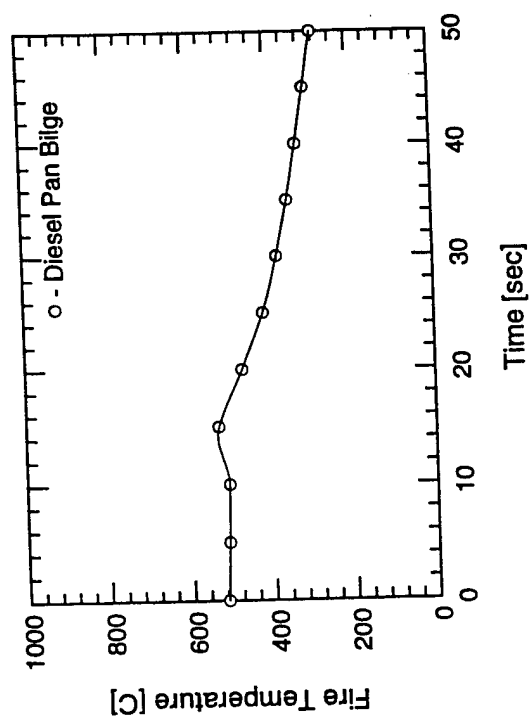


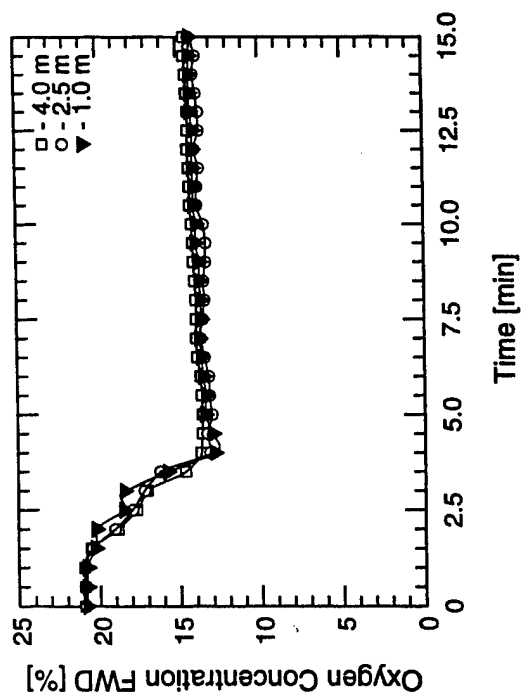
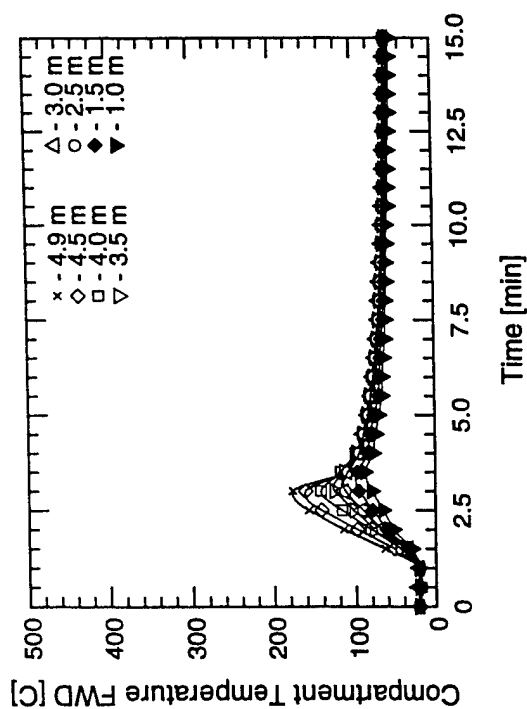
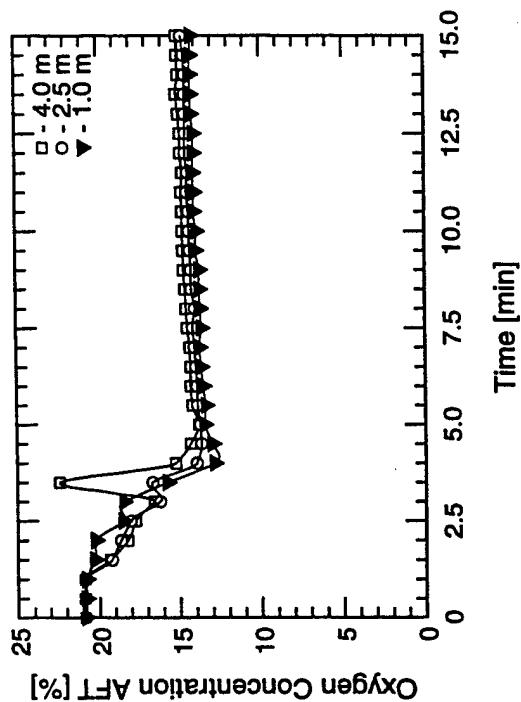
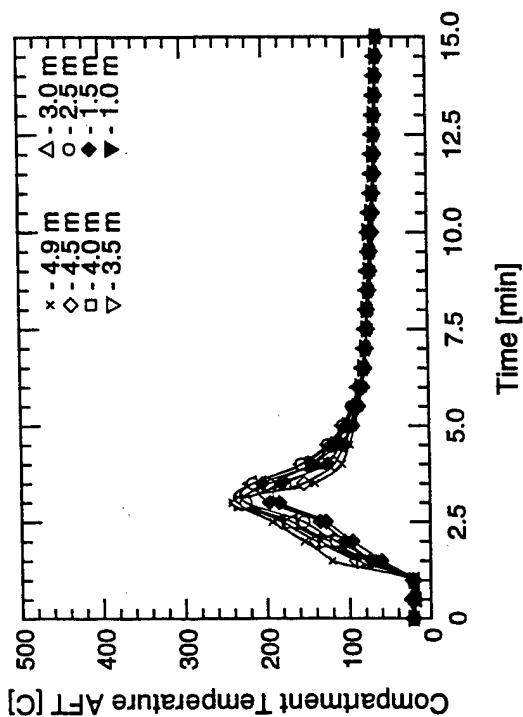


Test #14

Test #14

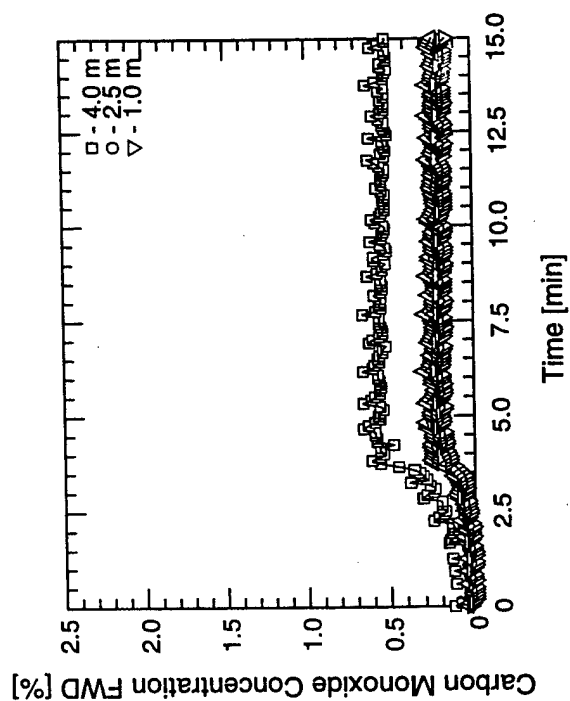
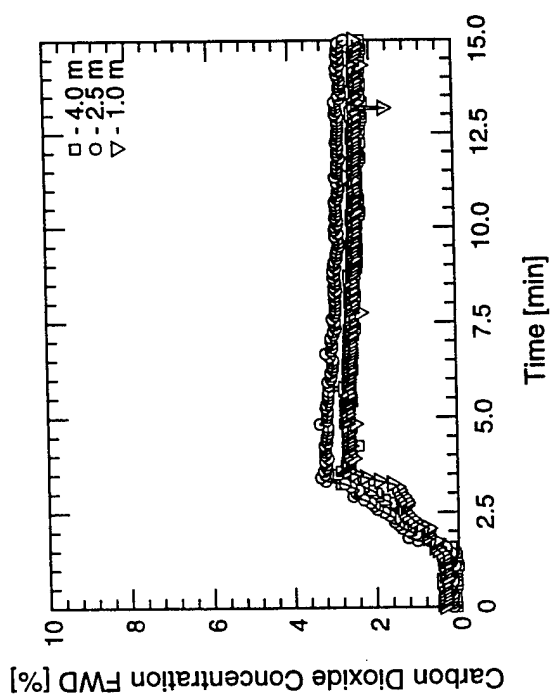
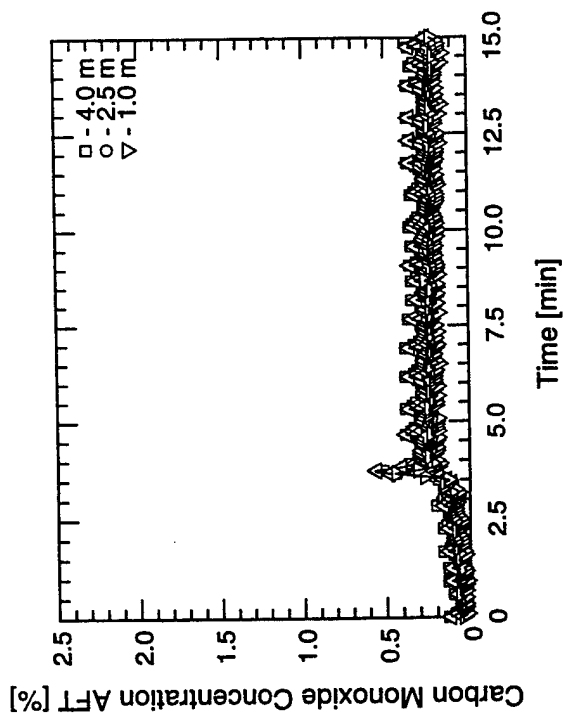
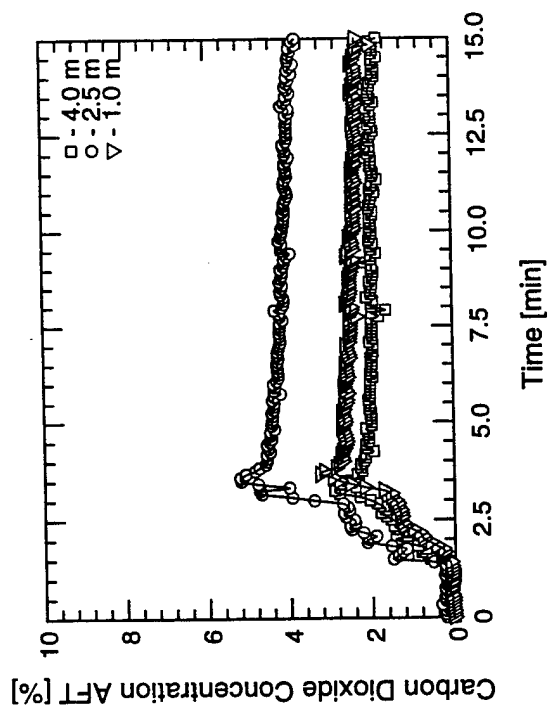




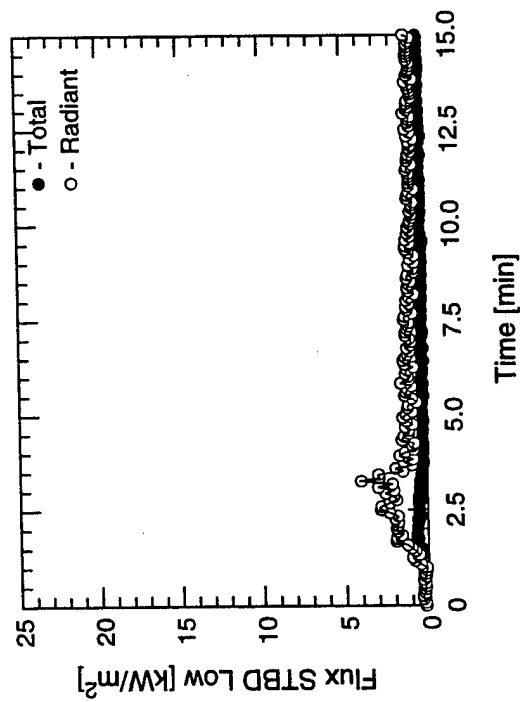
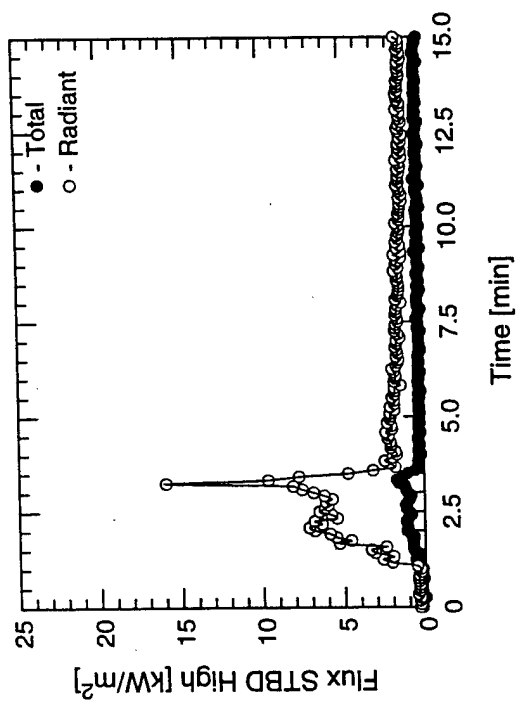
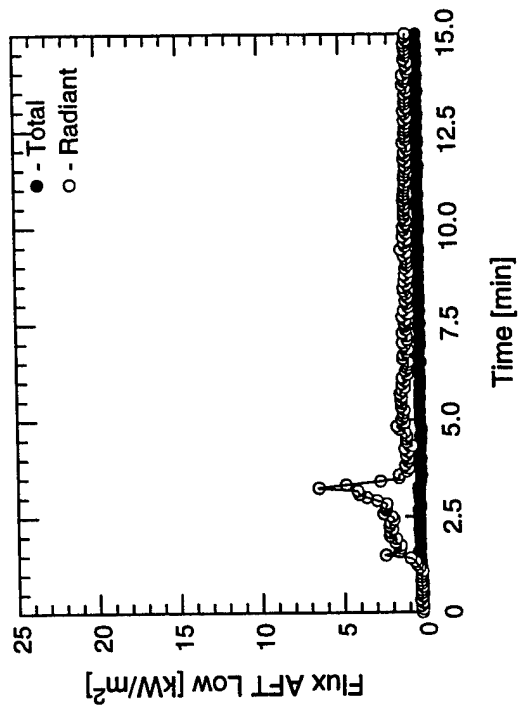
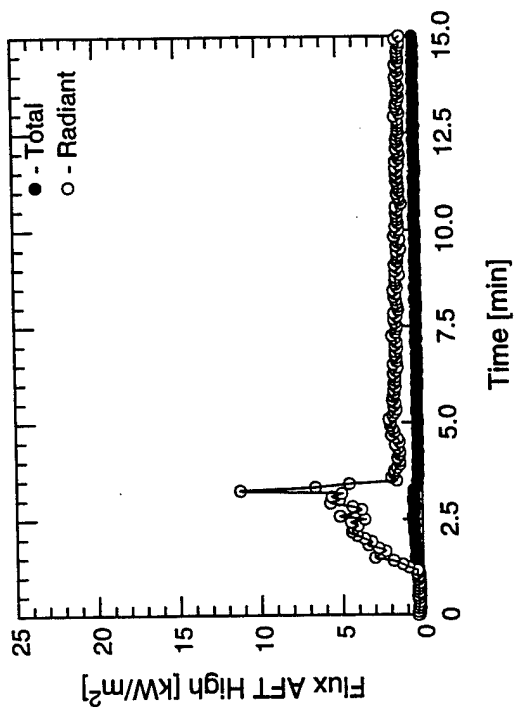


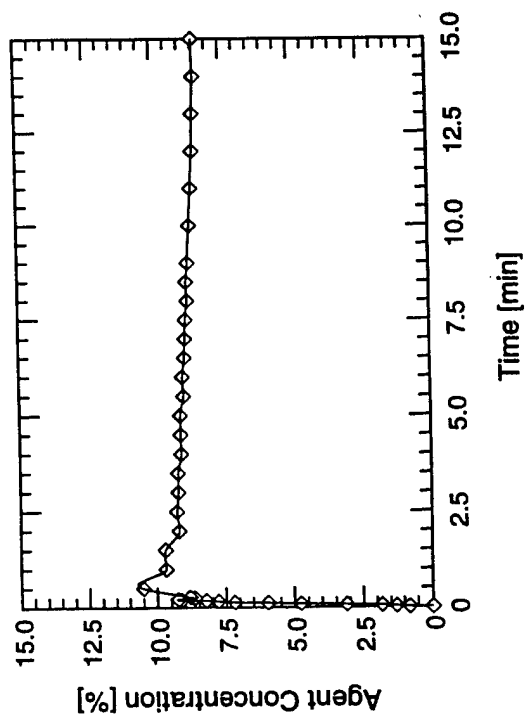
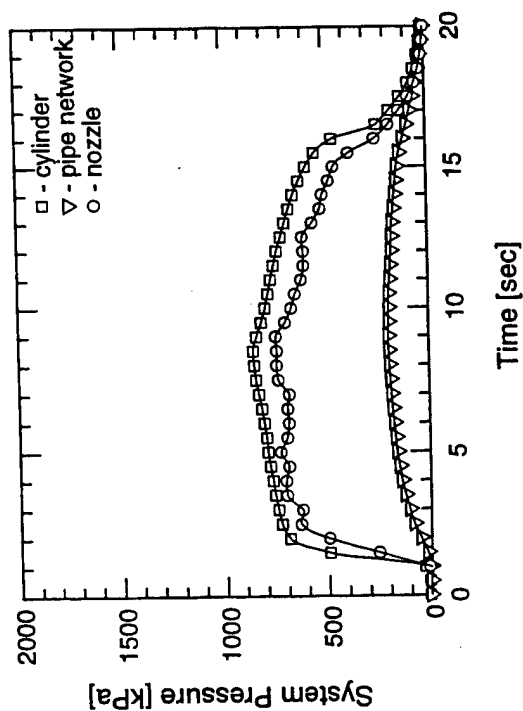
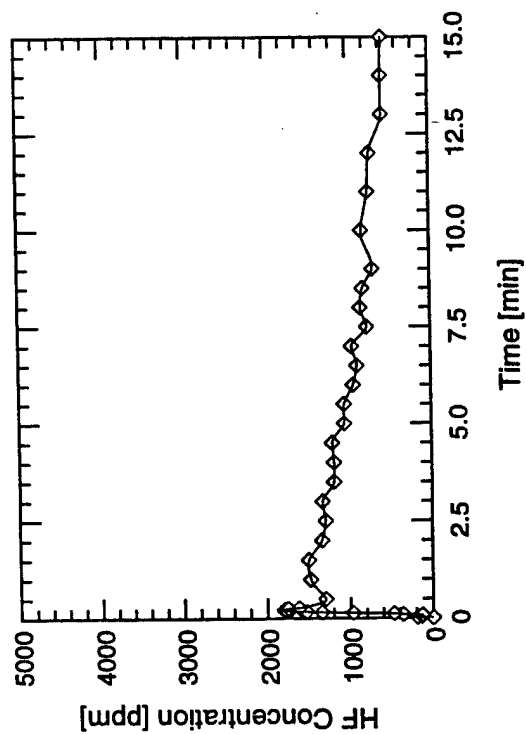
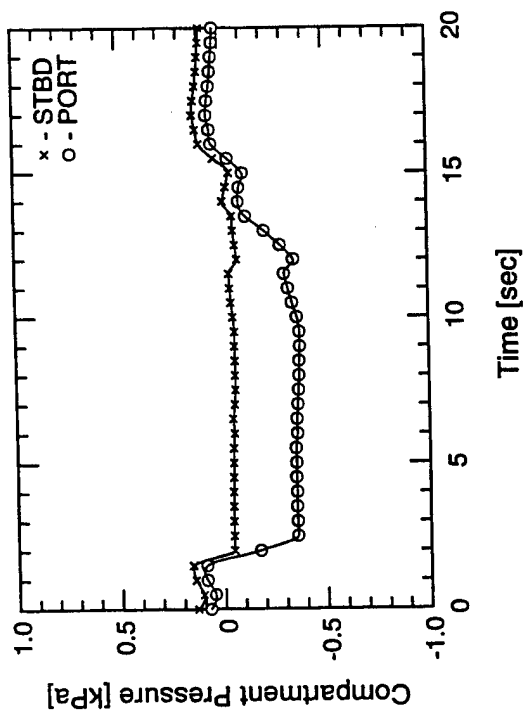
Test #15

Test #15

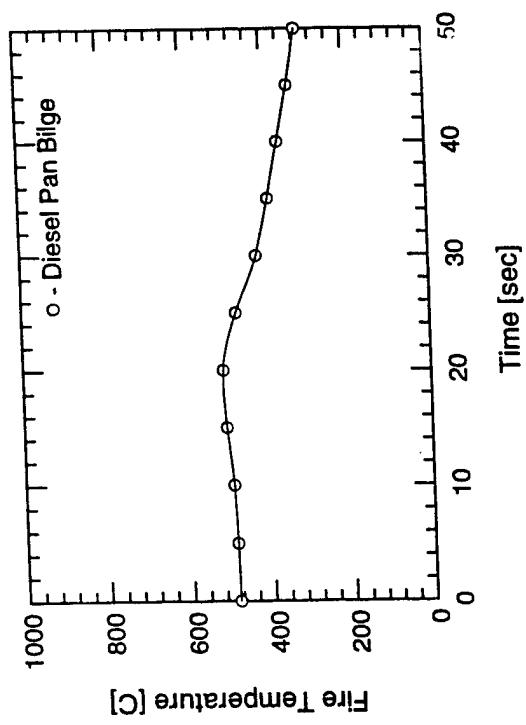


Test #15



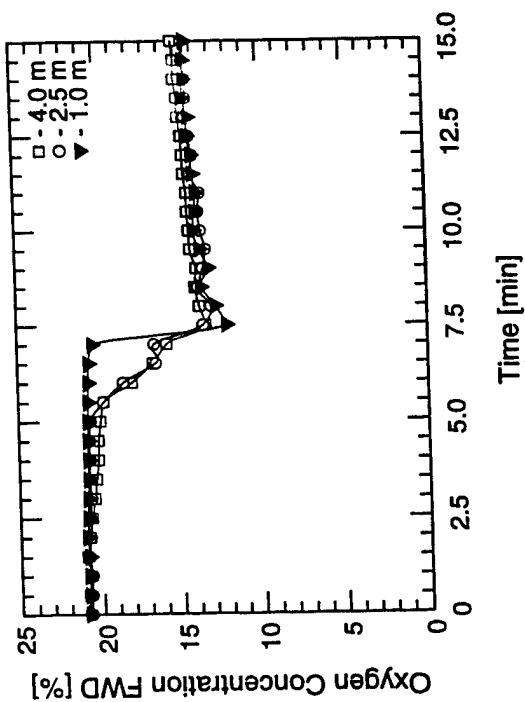
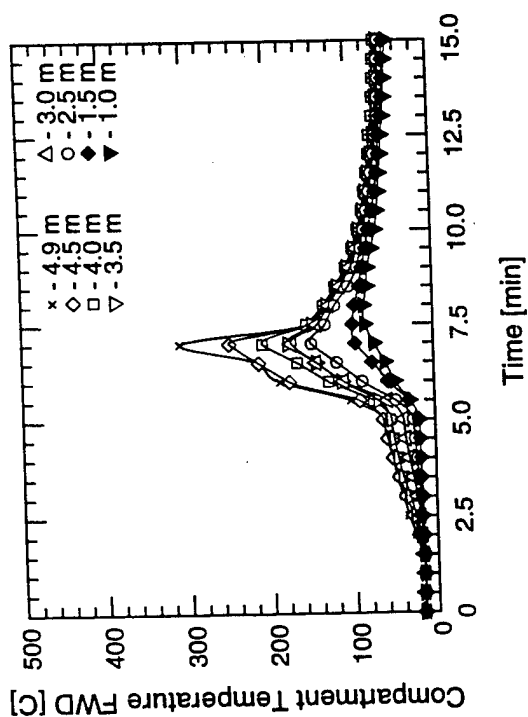
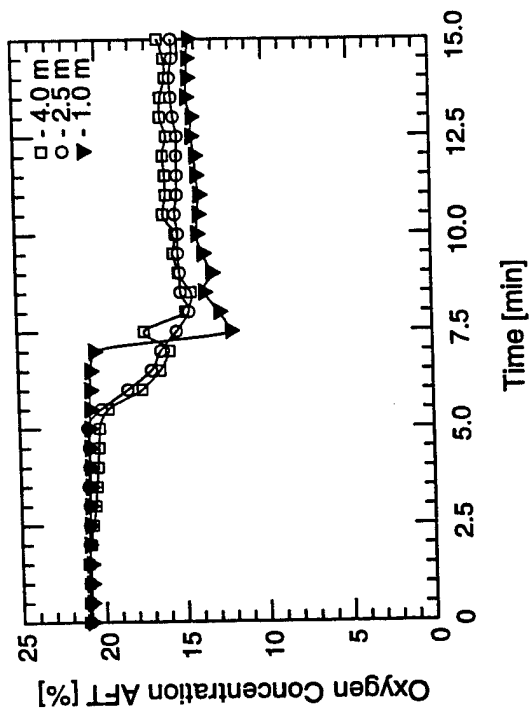
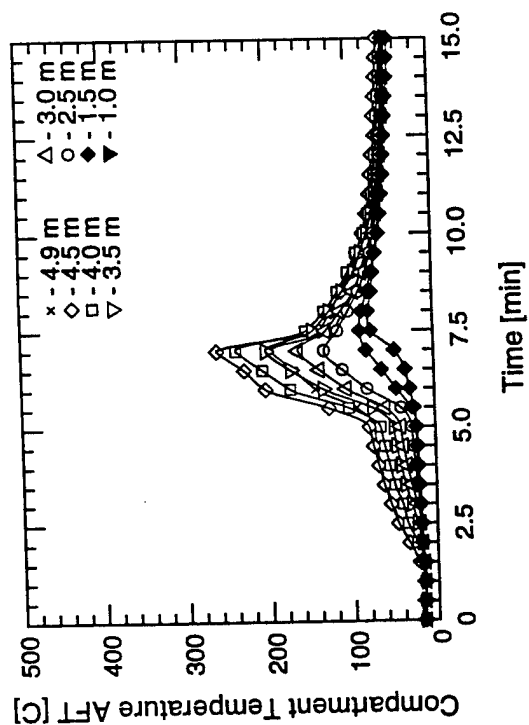


Test #15



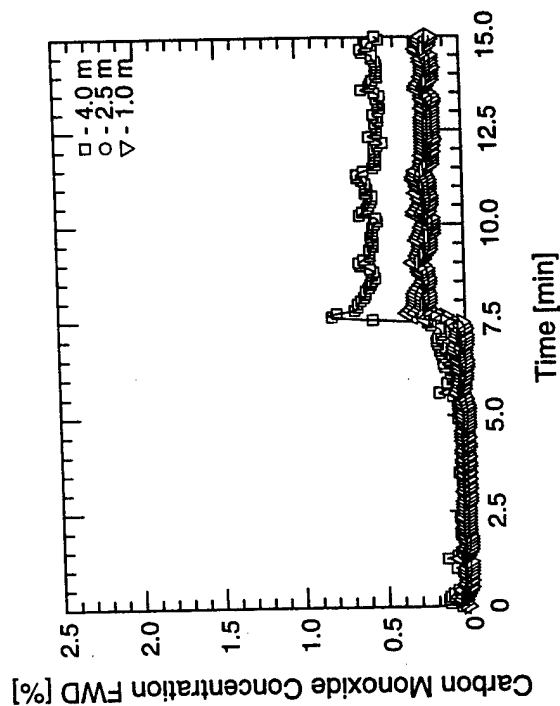
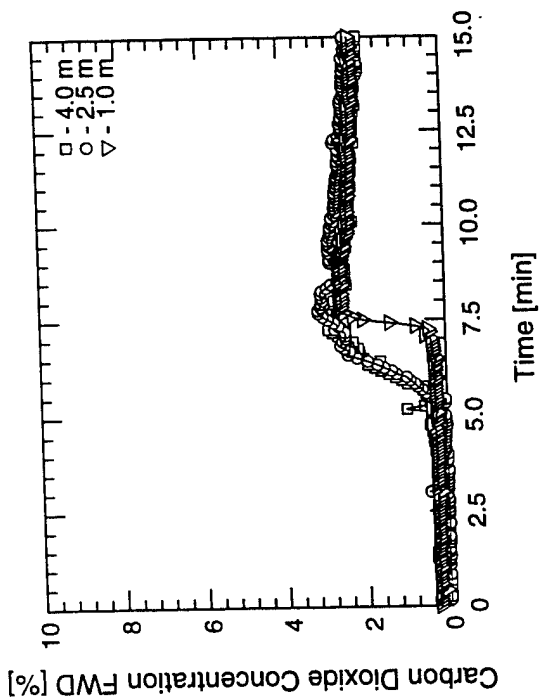
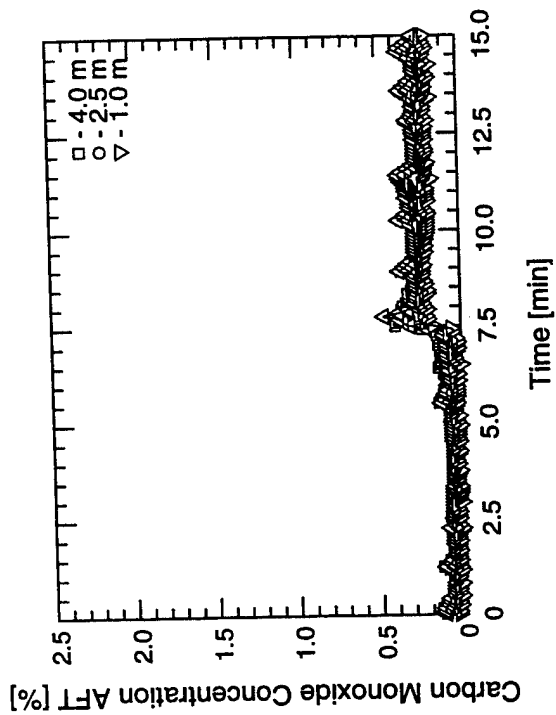
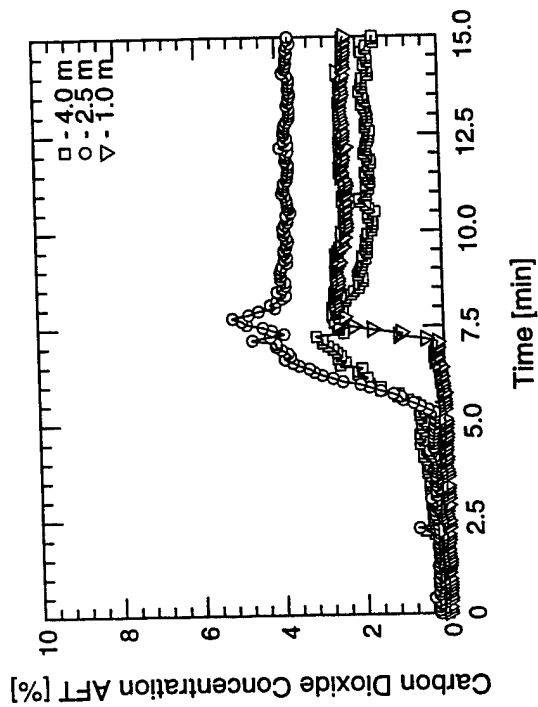
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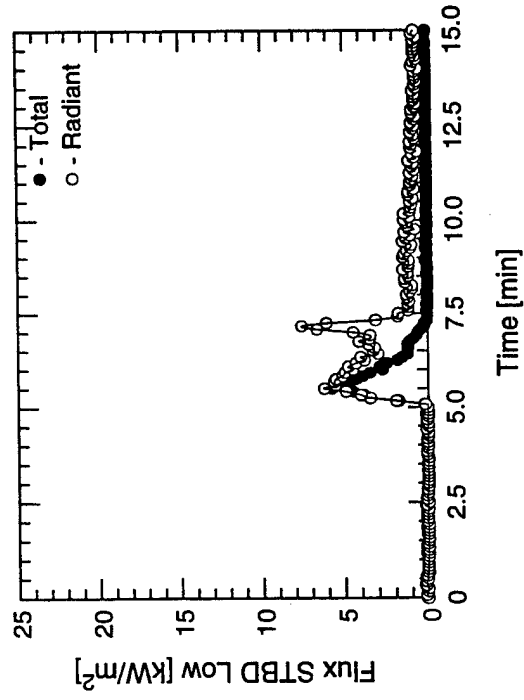
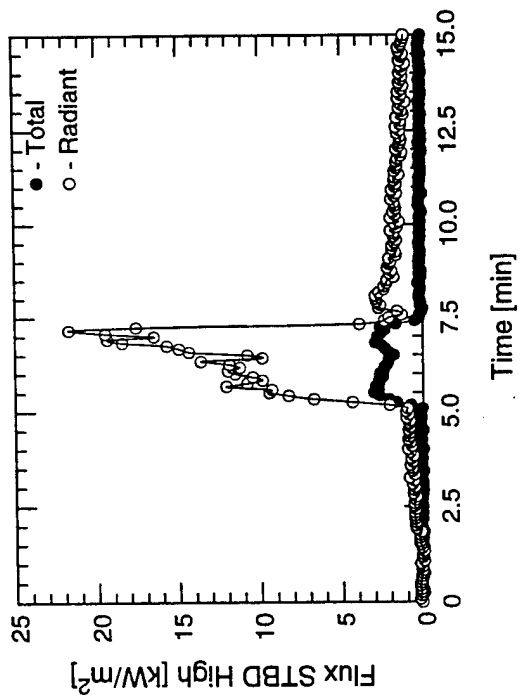
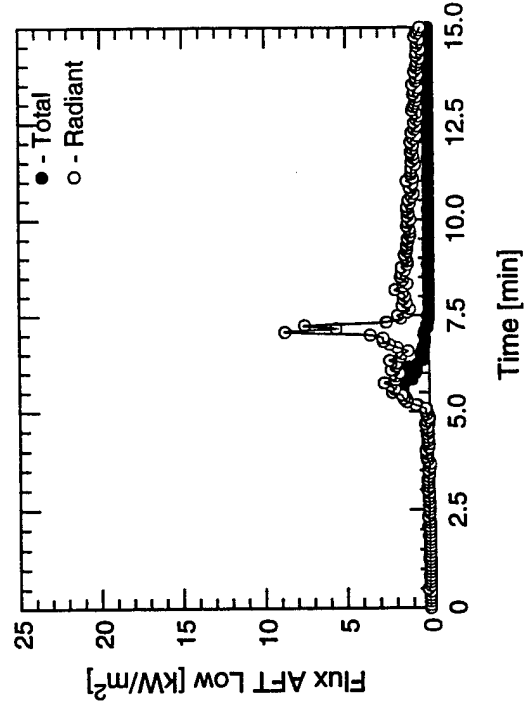
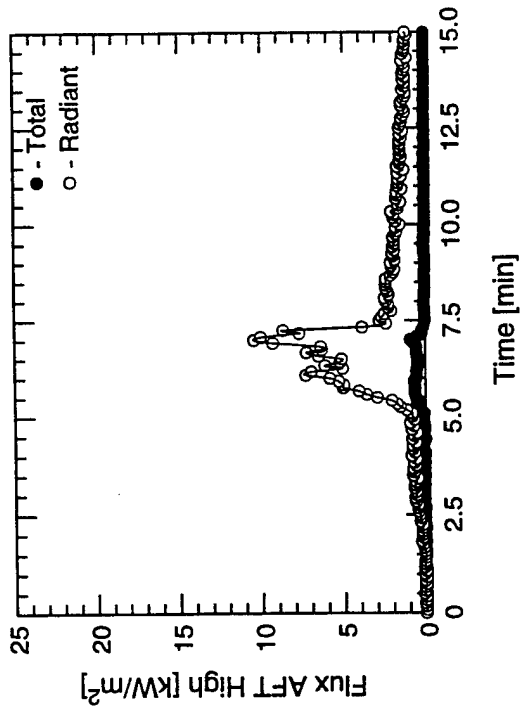
Test #15



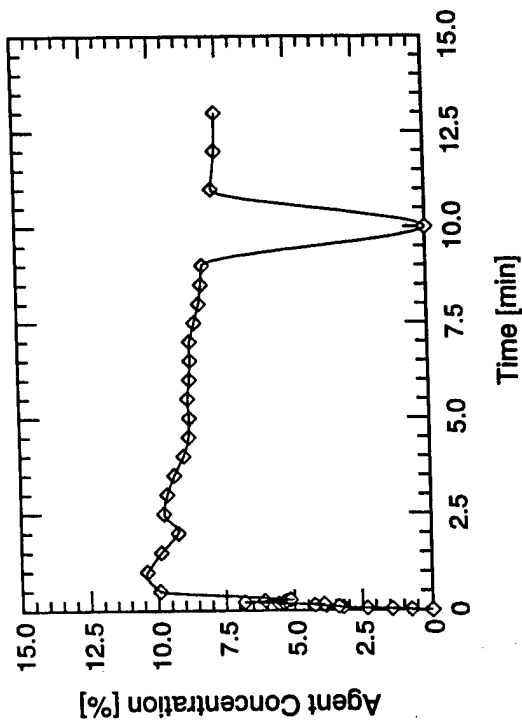
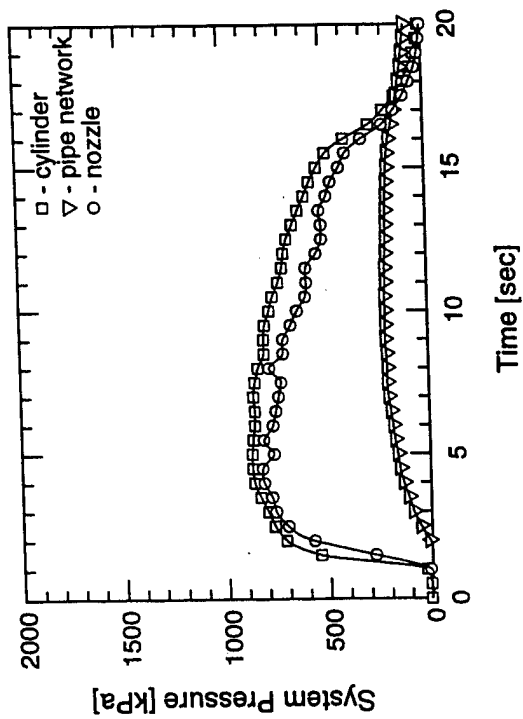
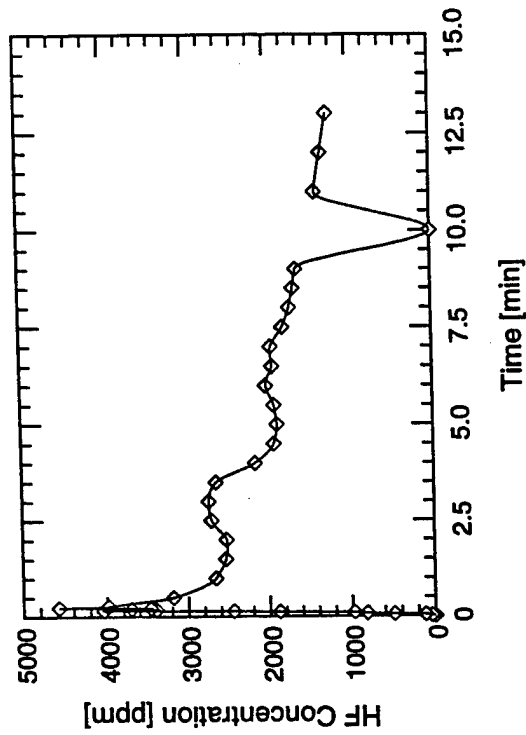
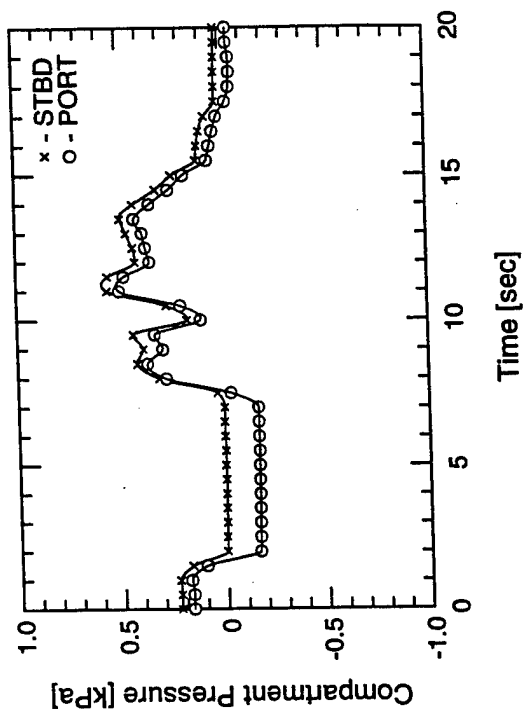
Test #16

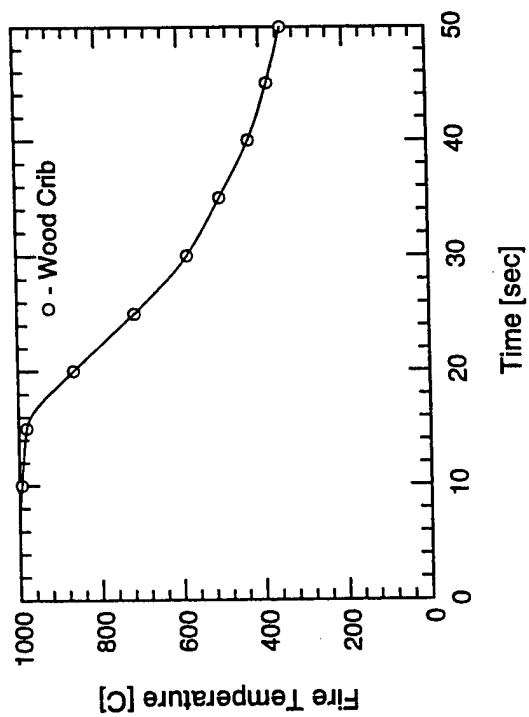
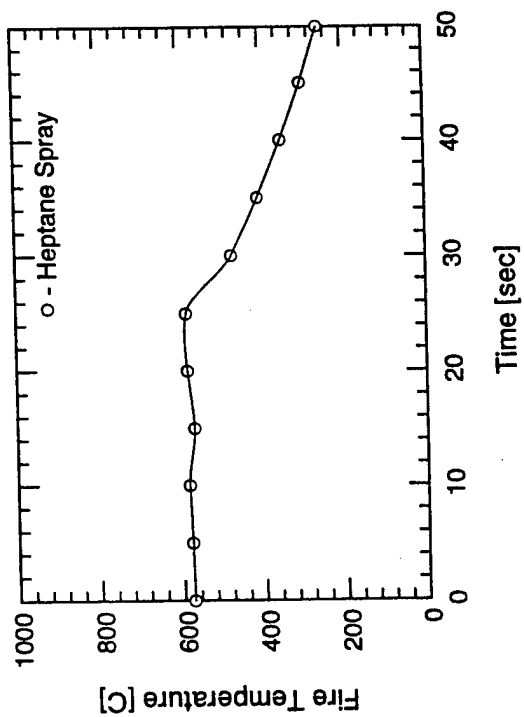
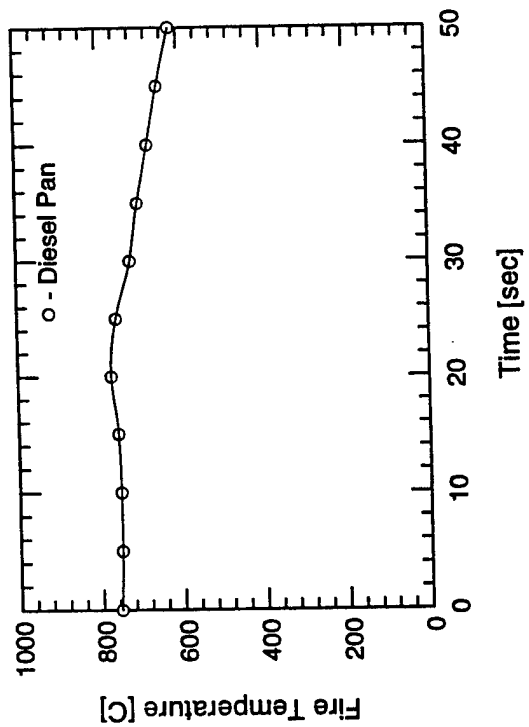
Test #16



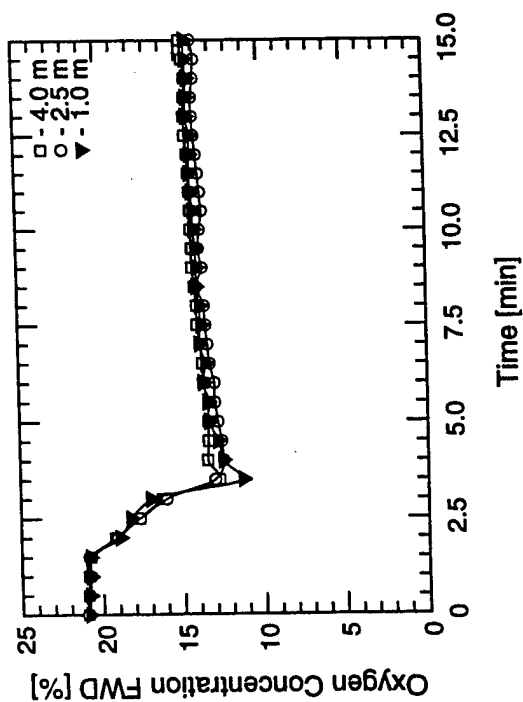
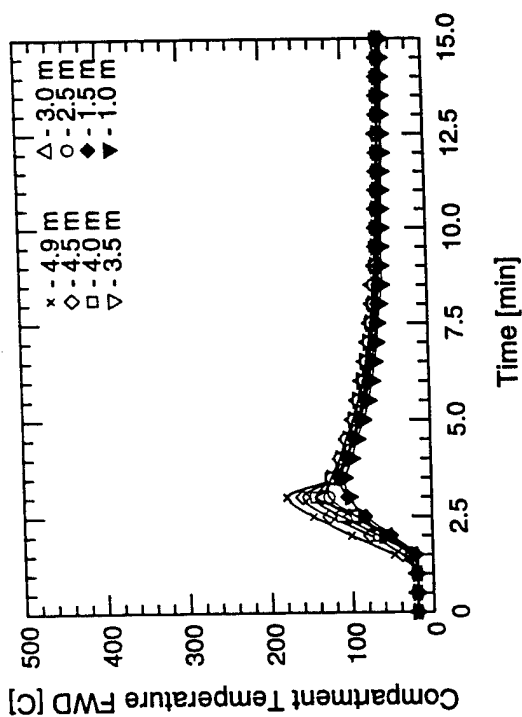
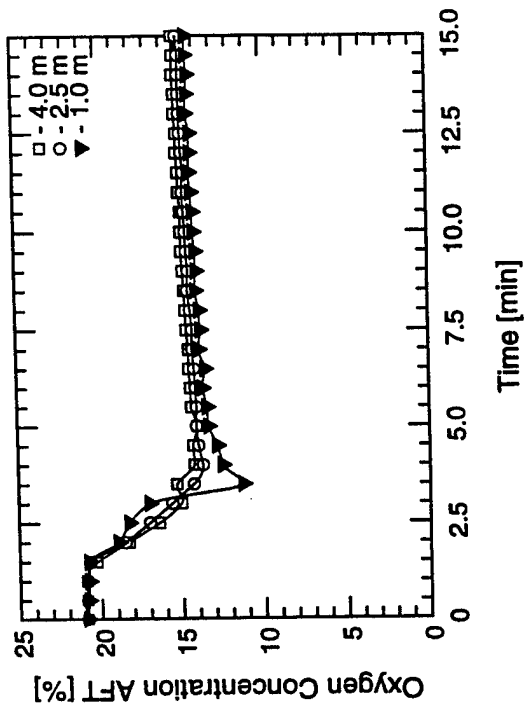
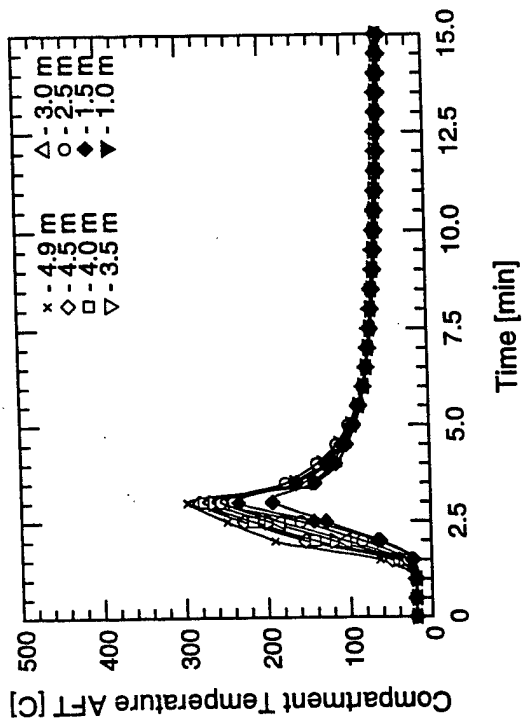


Test #16

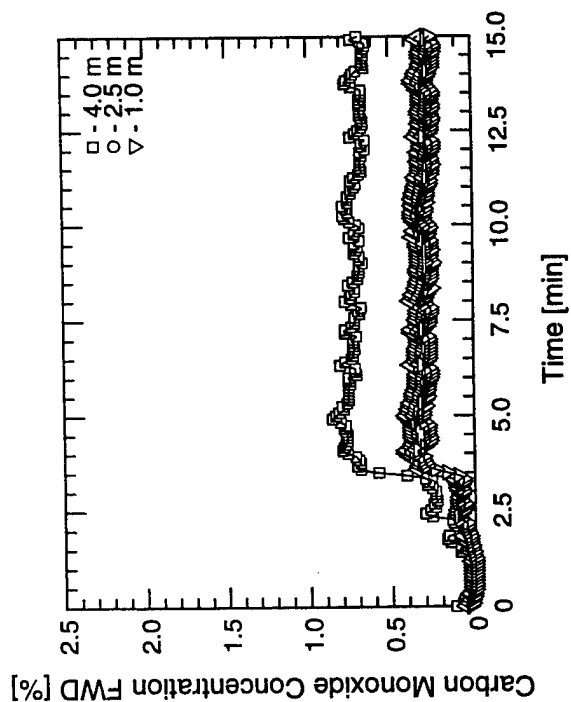
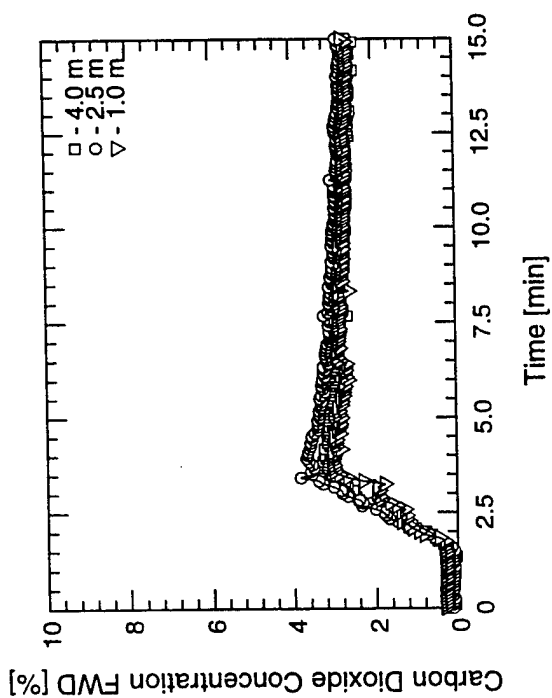
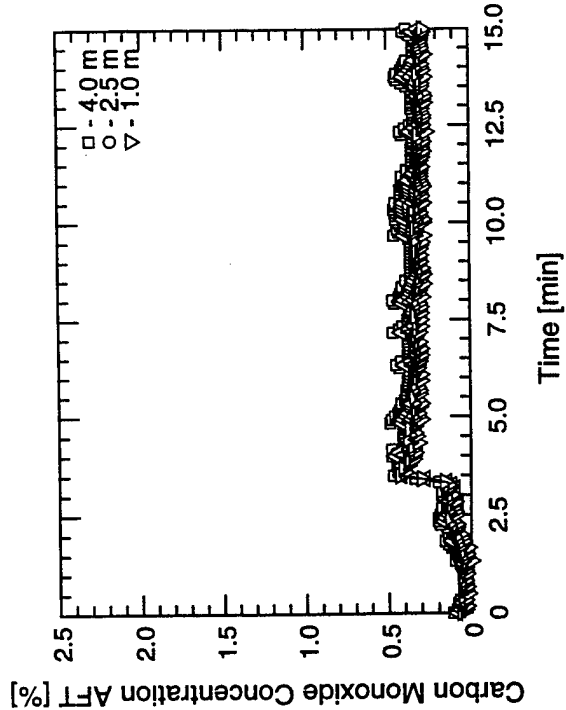
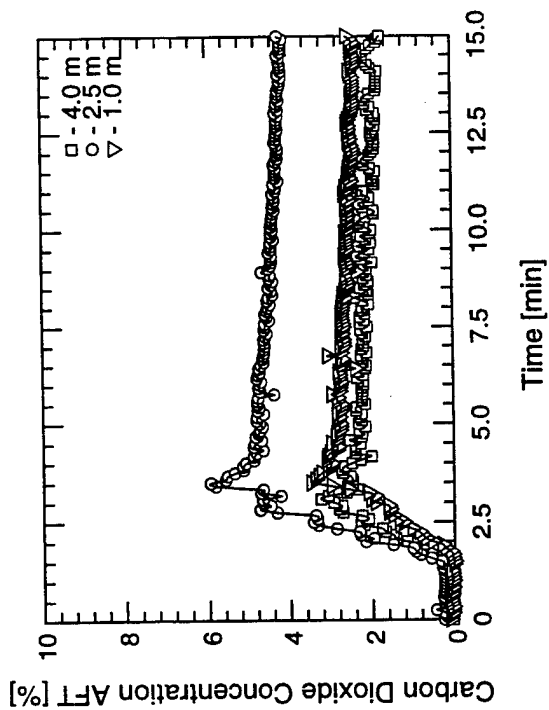




Test #16

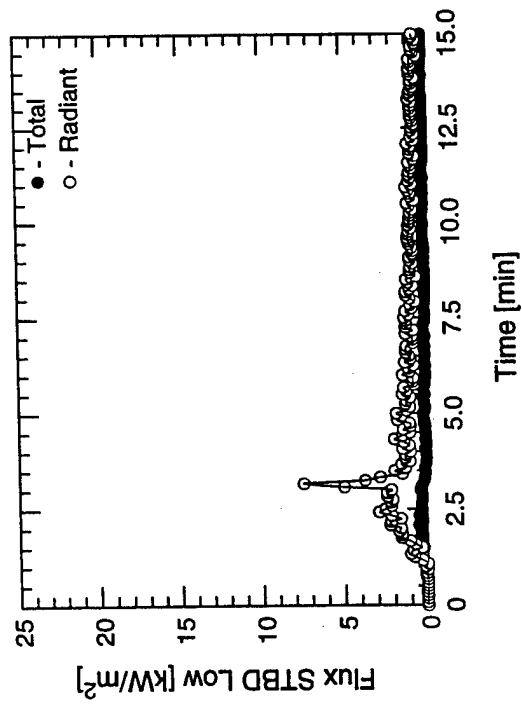
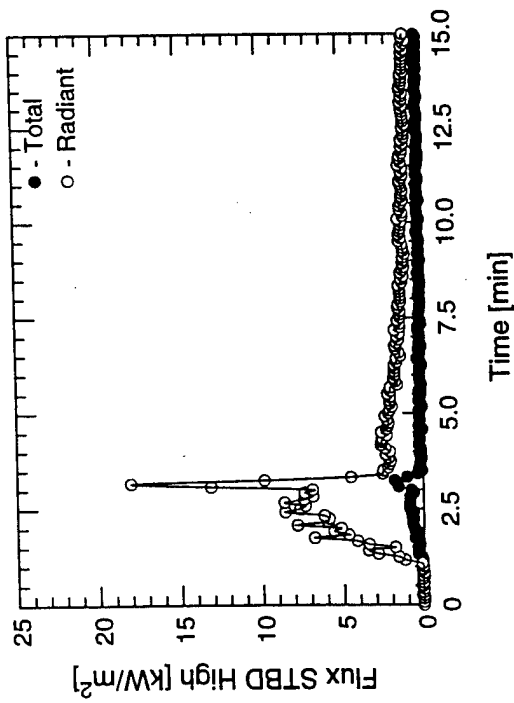
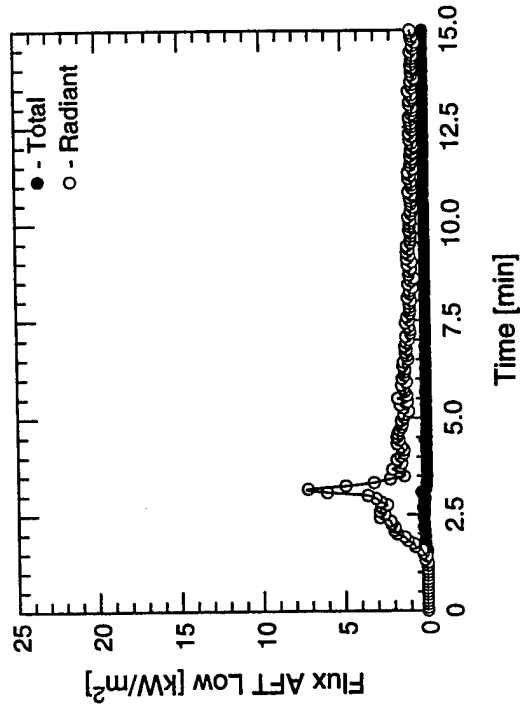
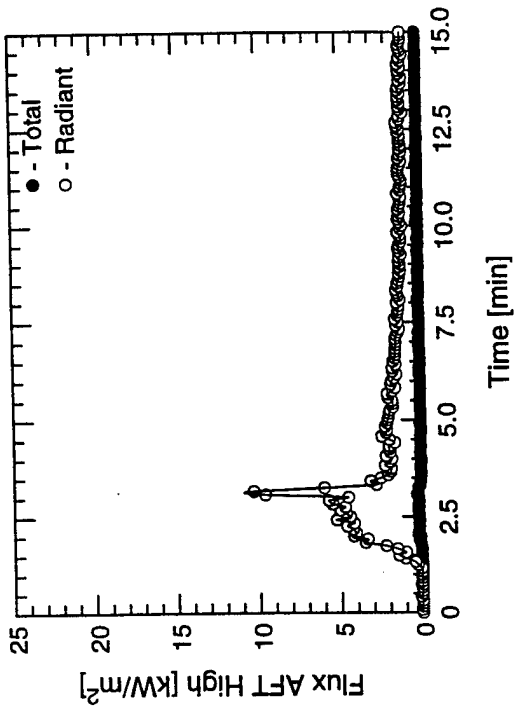


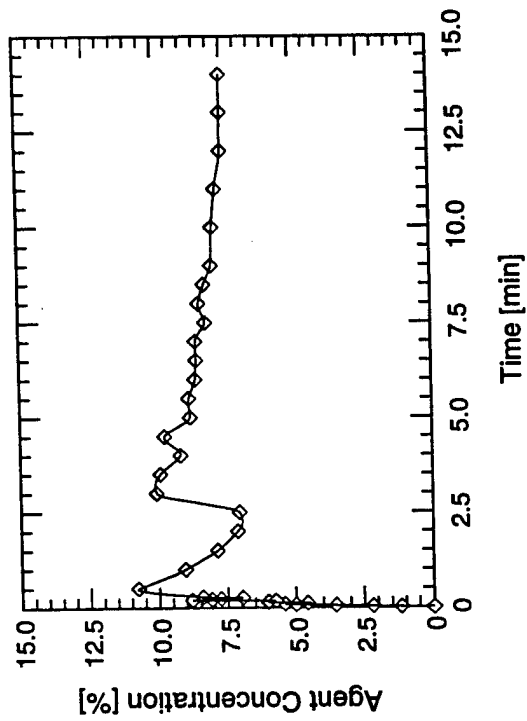
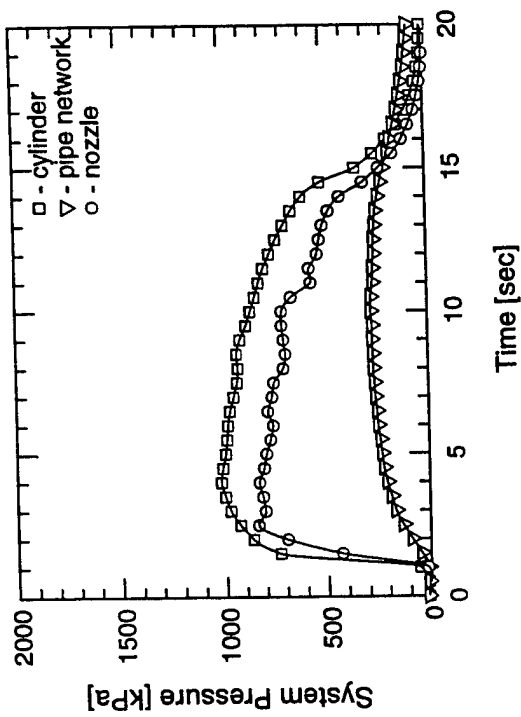
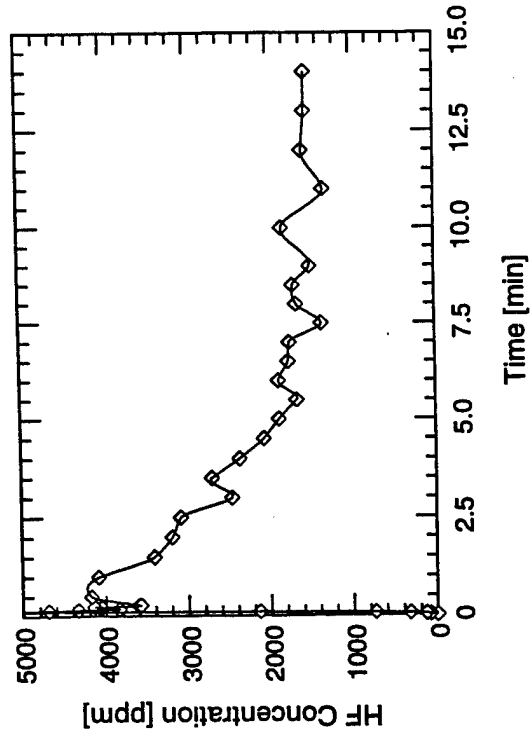
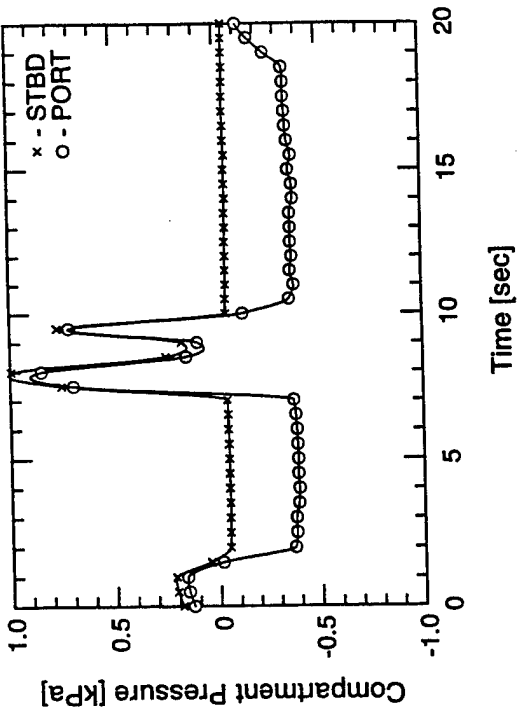
Test #17



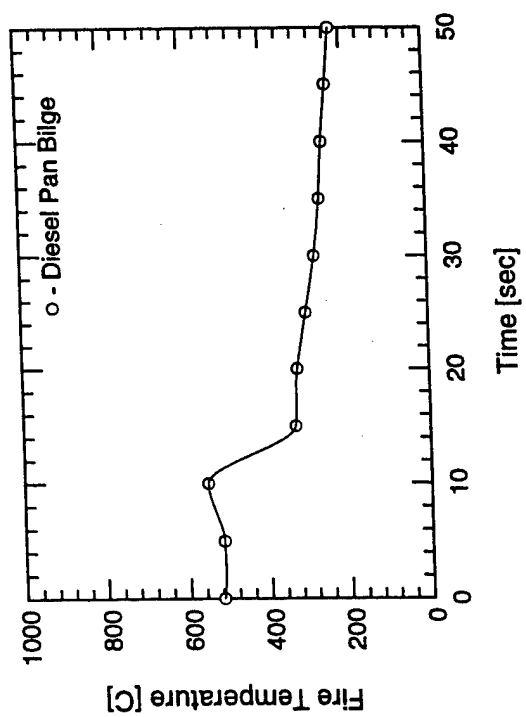
Test #17

Test #17



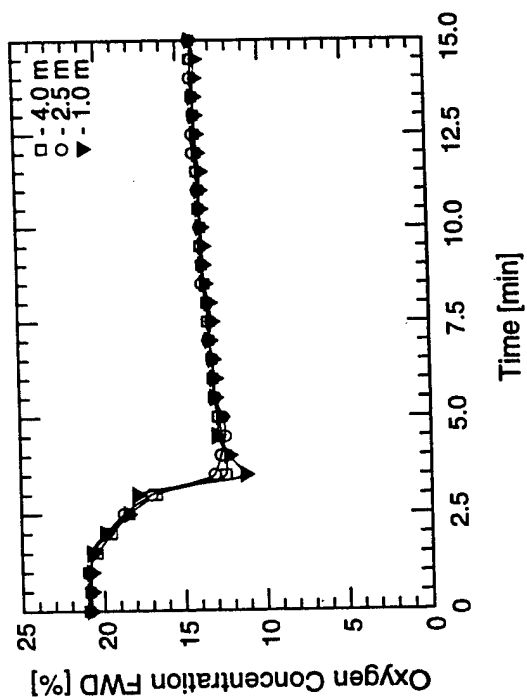
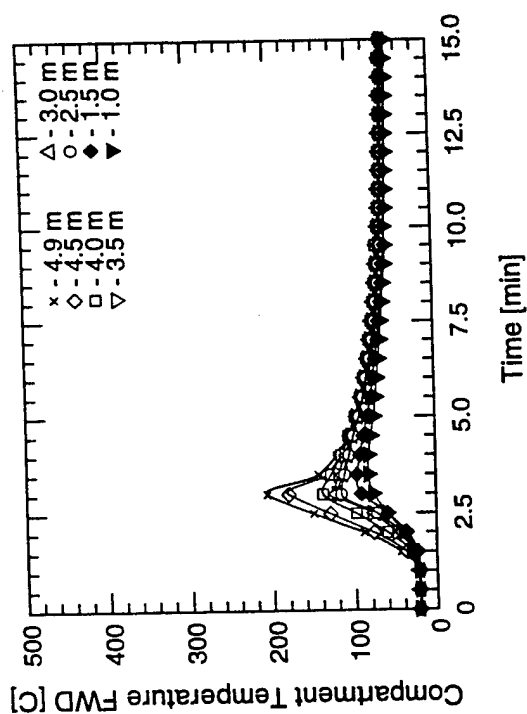
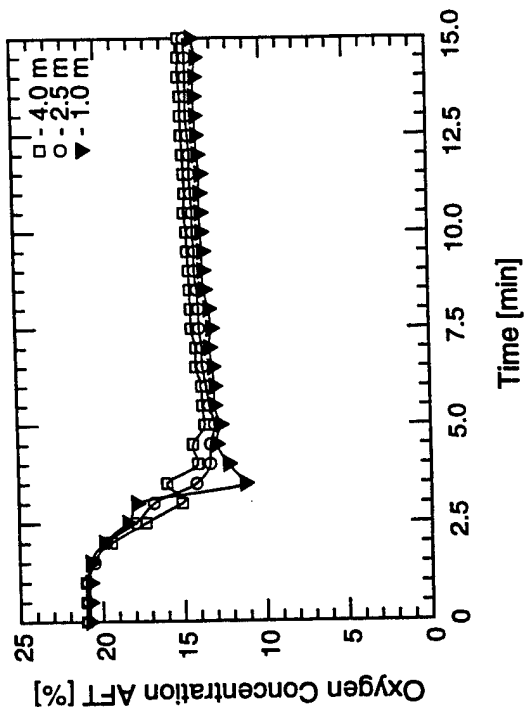
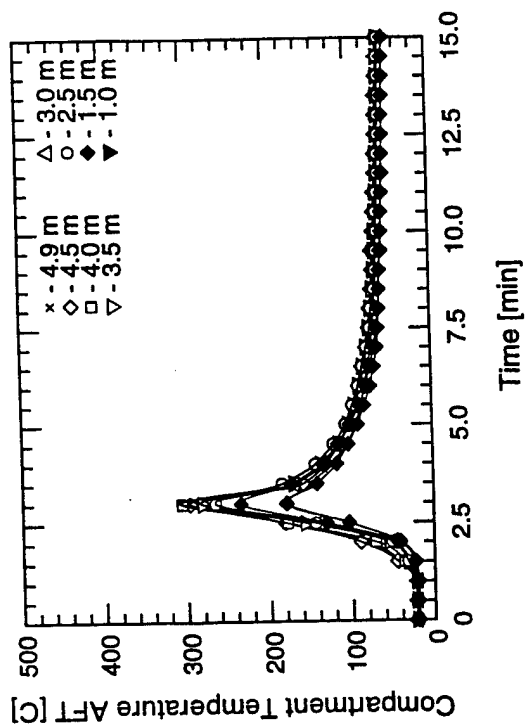


Test #17



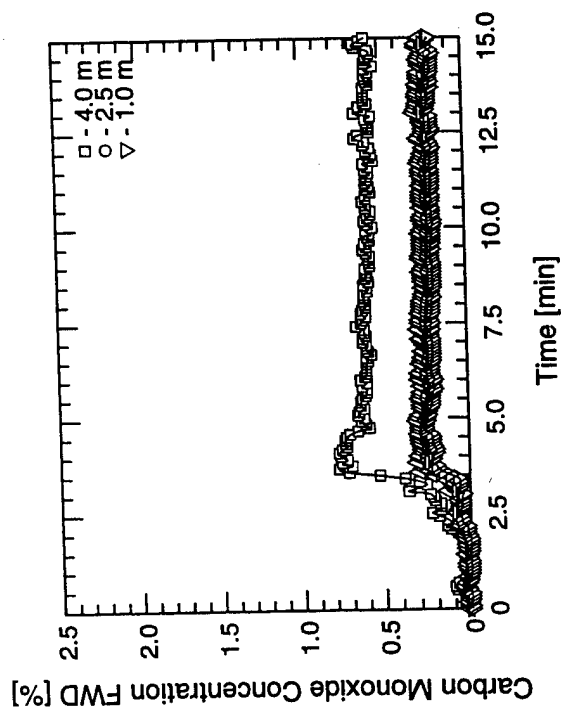
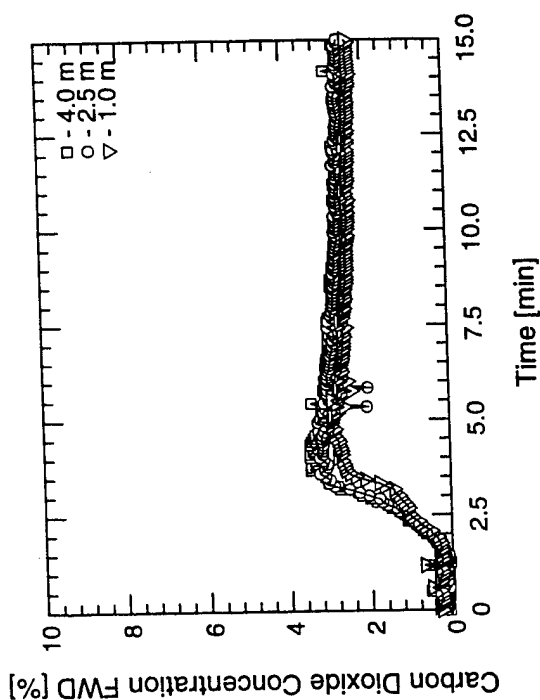
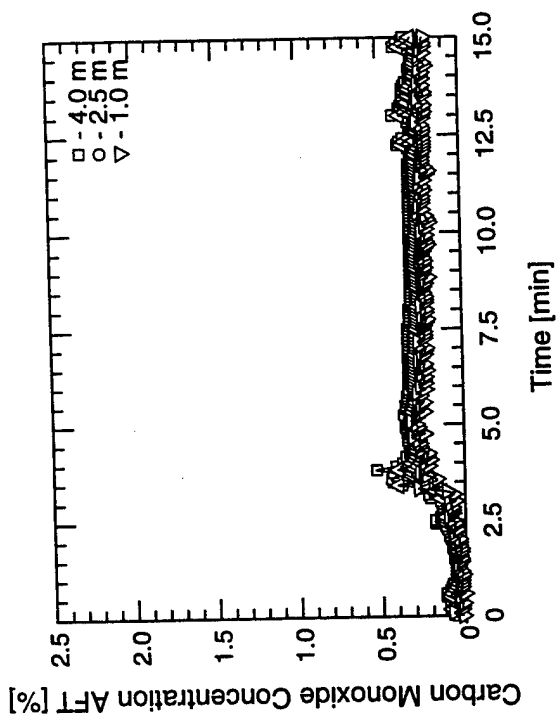
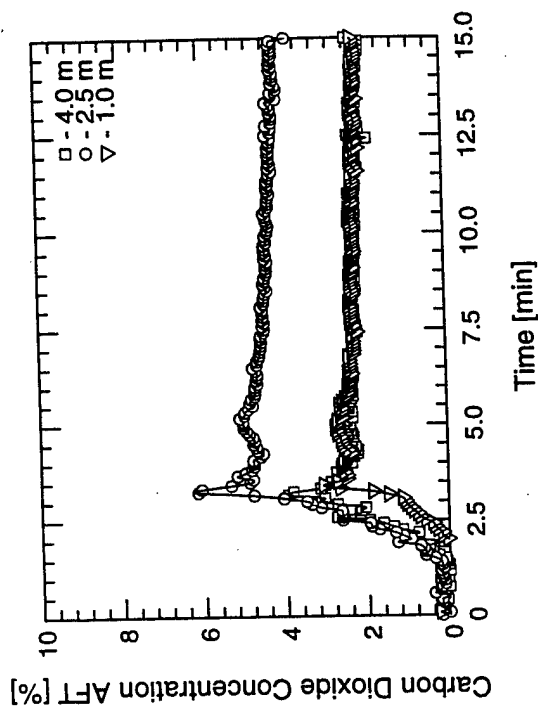
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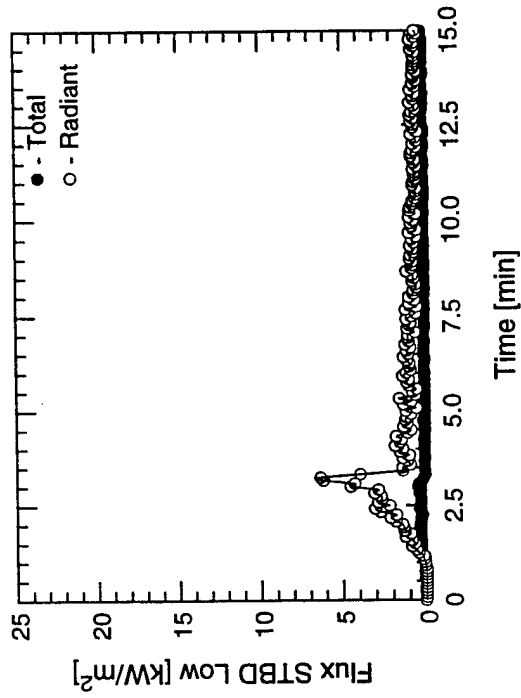
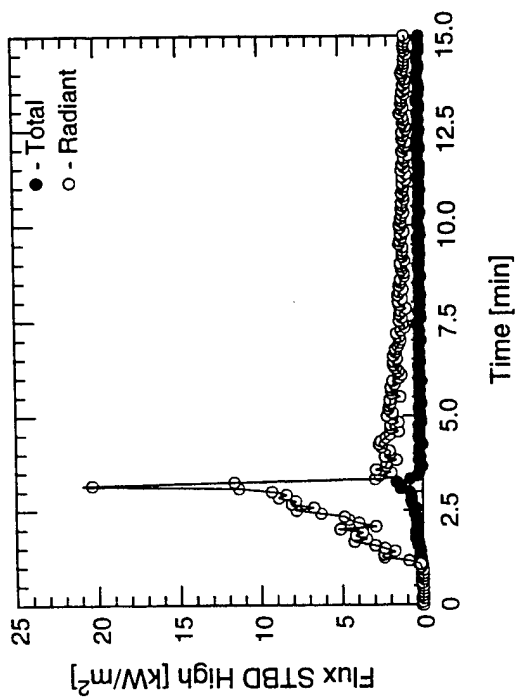
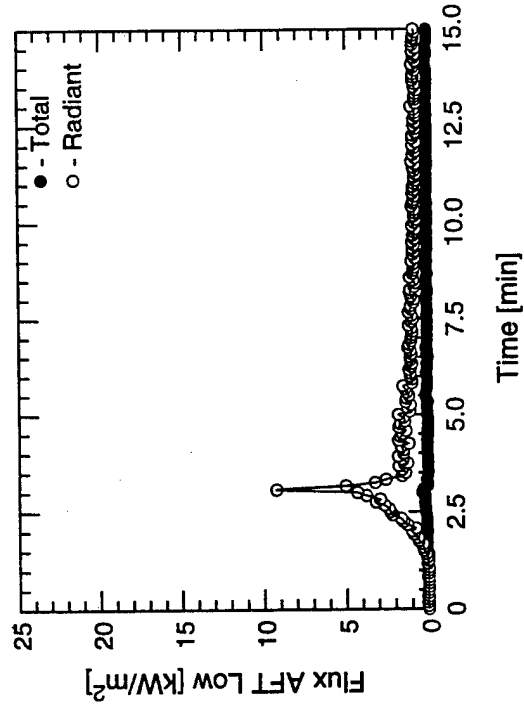
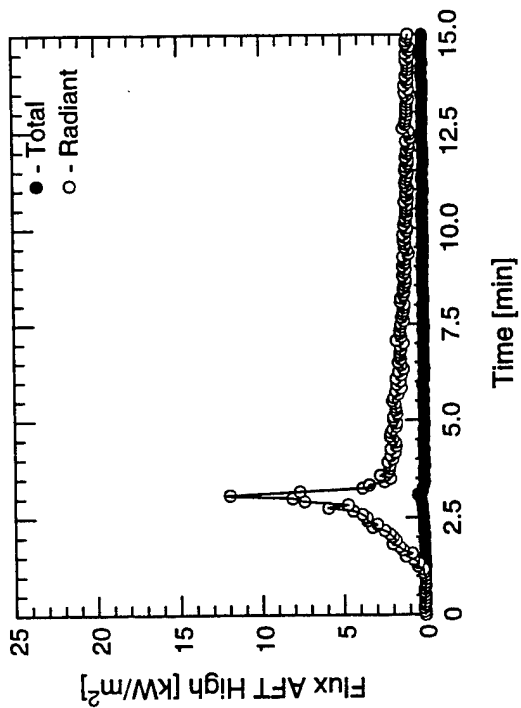
Test #17



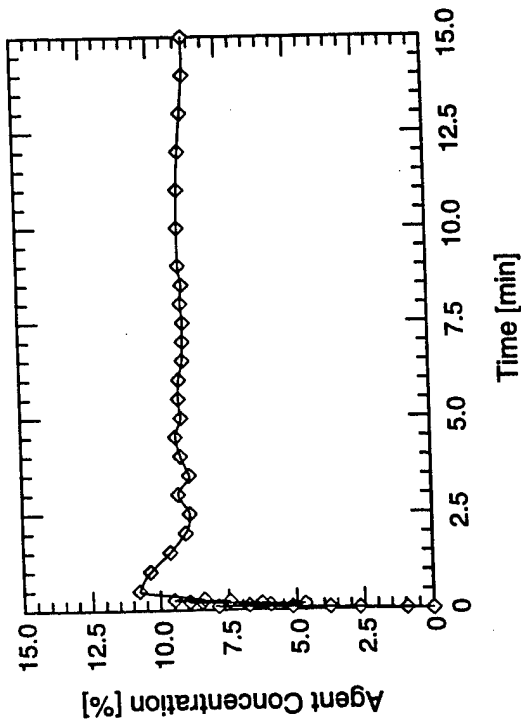
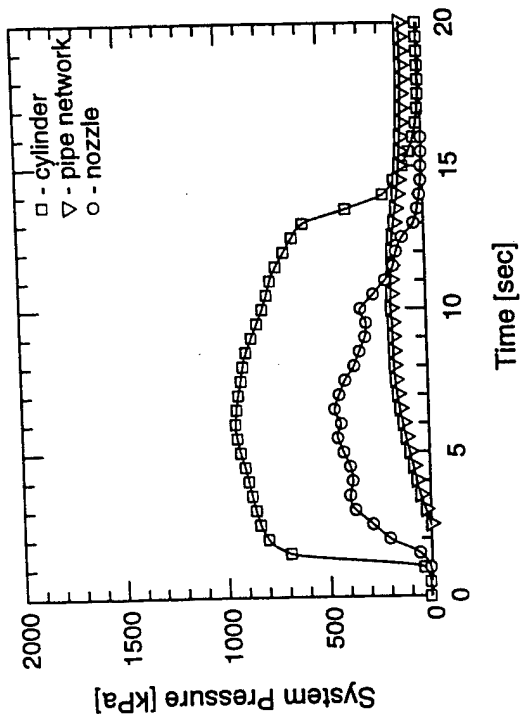
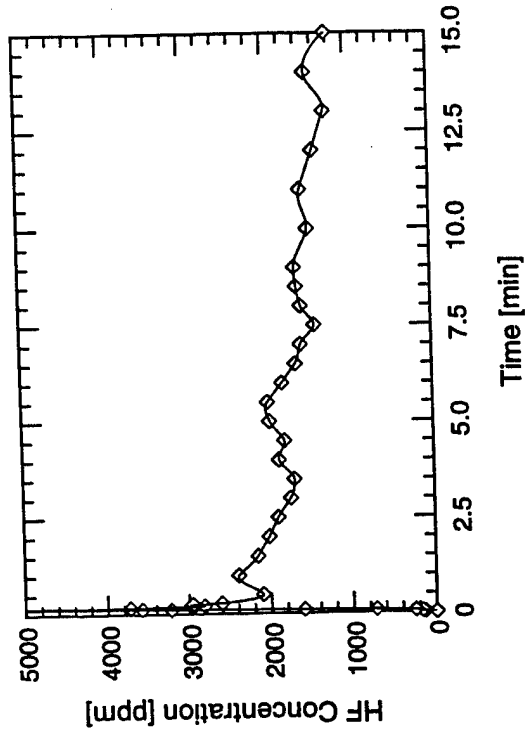
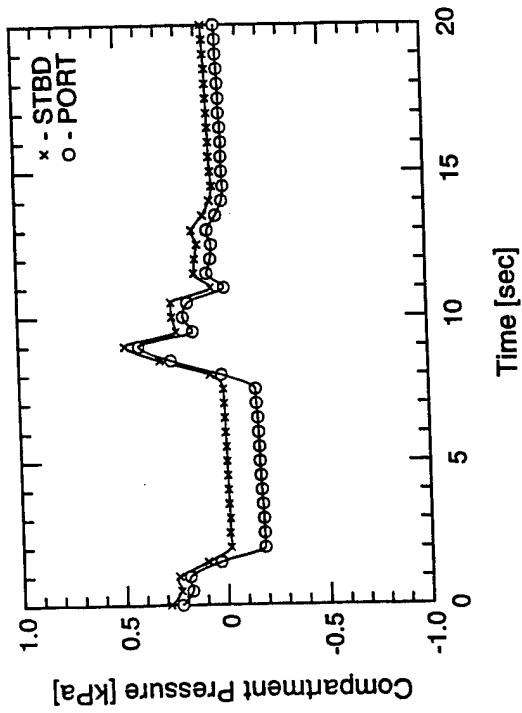
Test #18

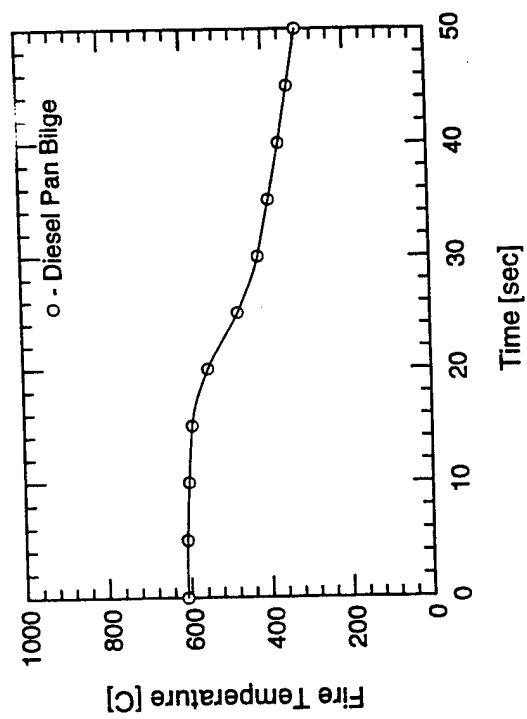
Test #18

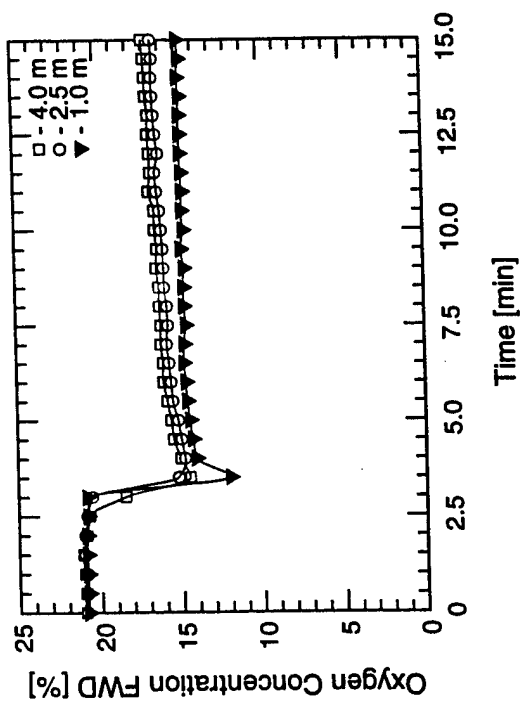
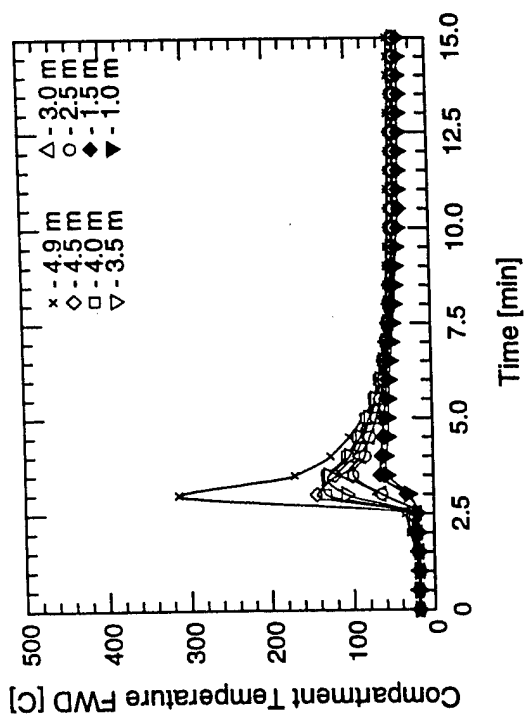
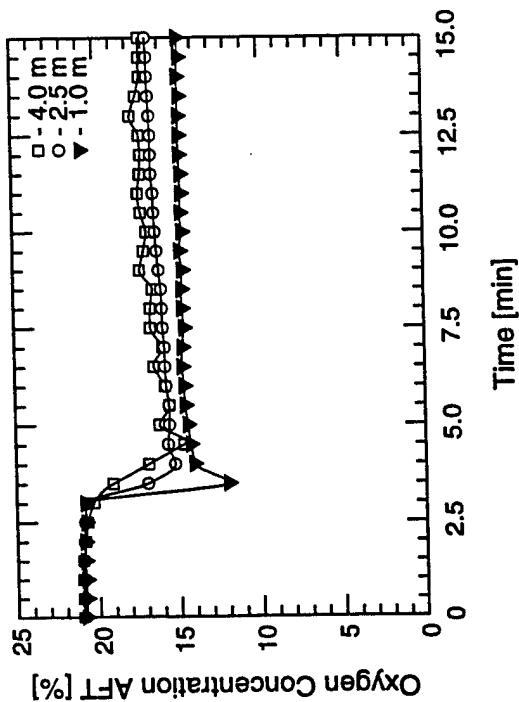
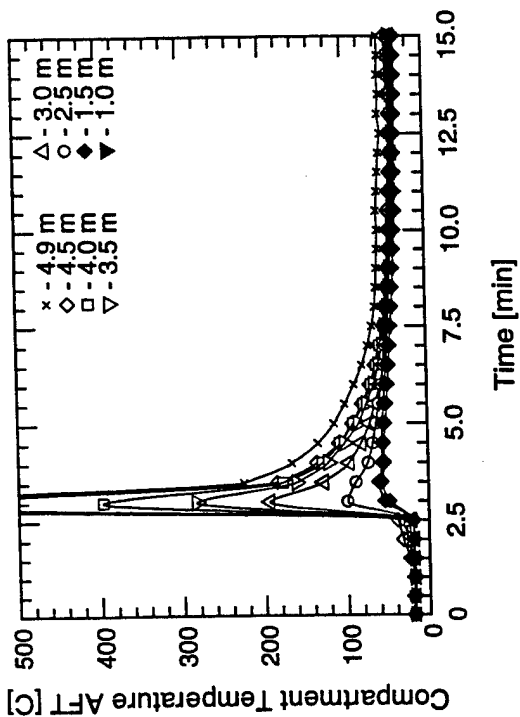




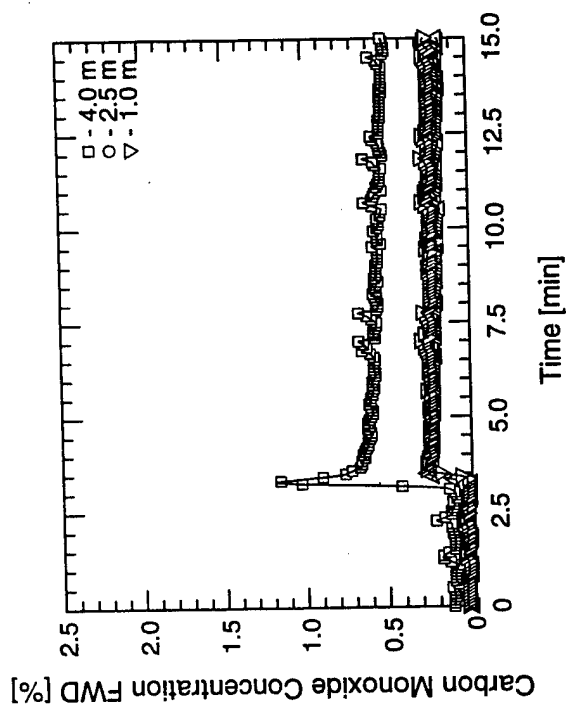
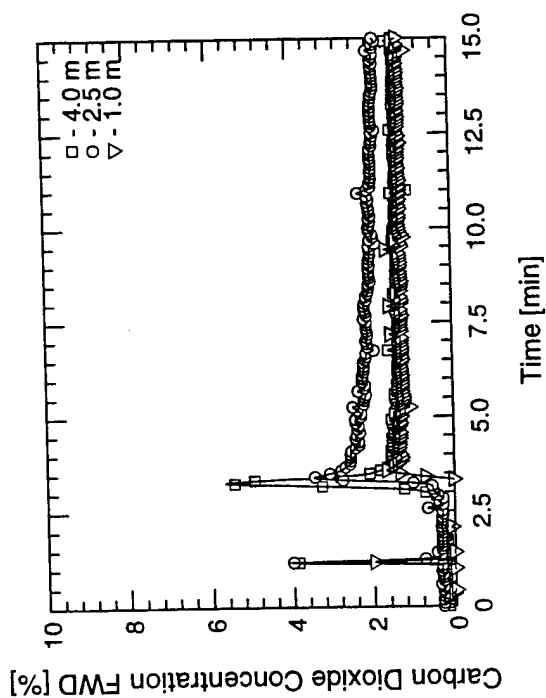
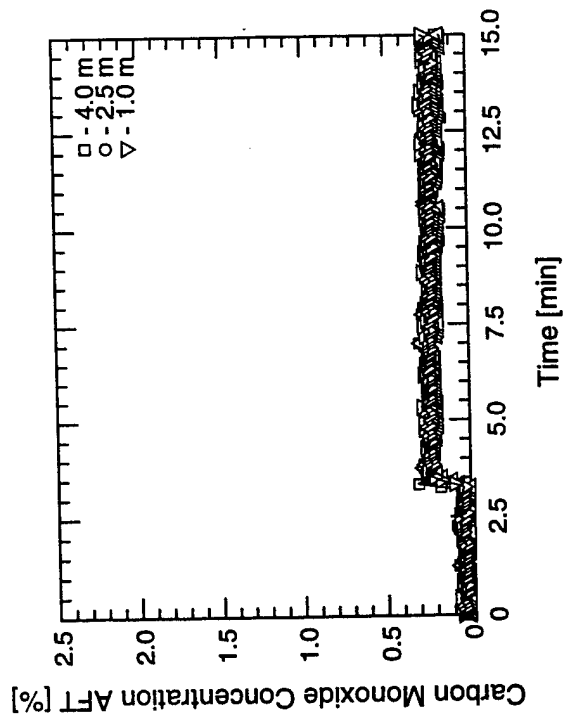
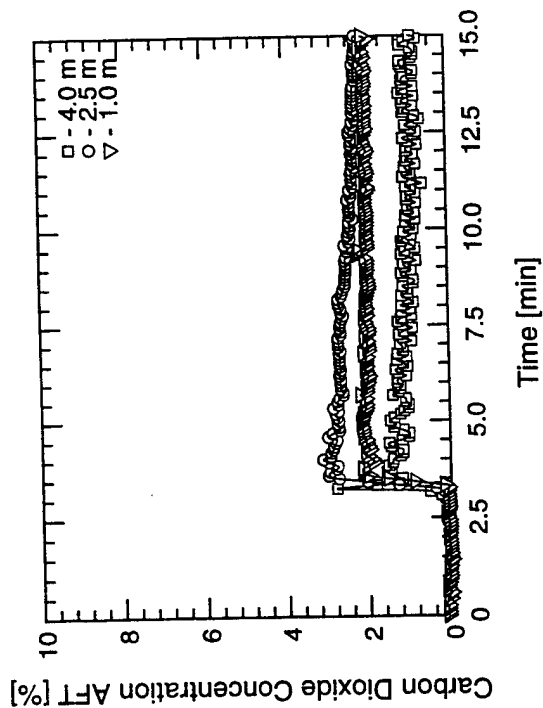
Test #18





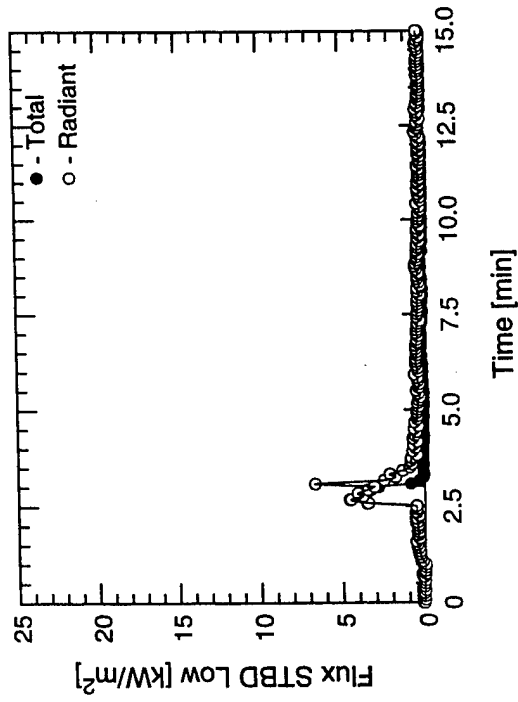
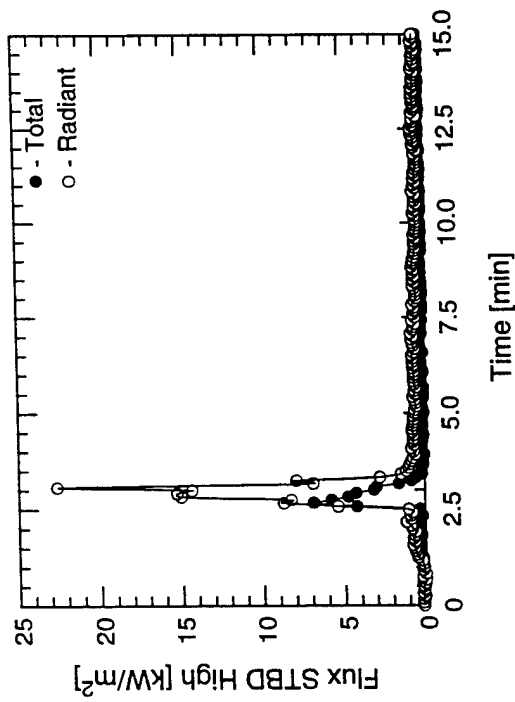
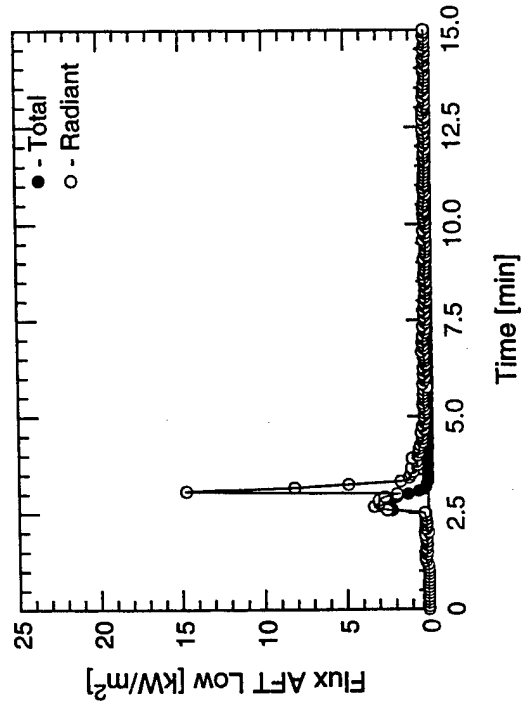
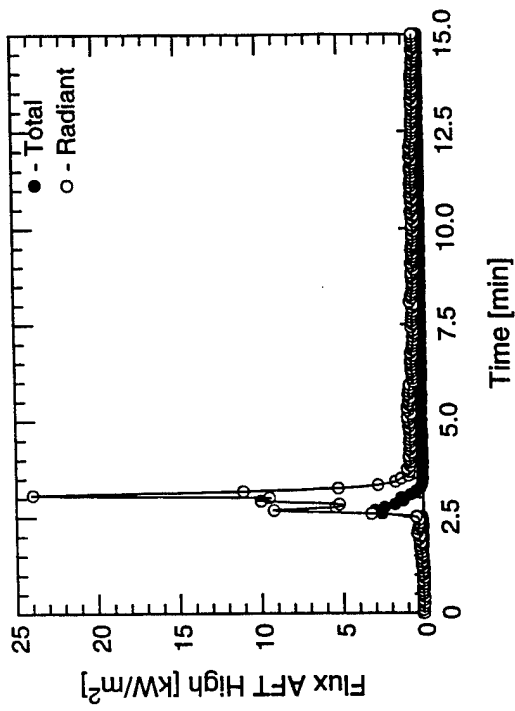


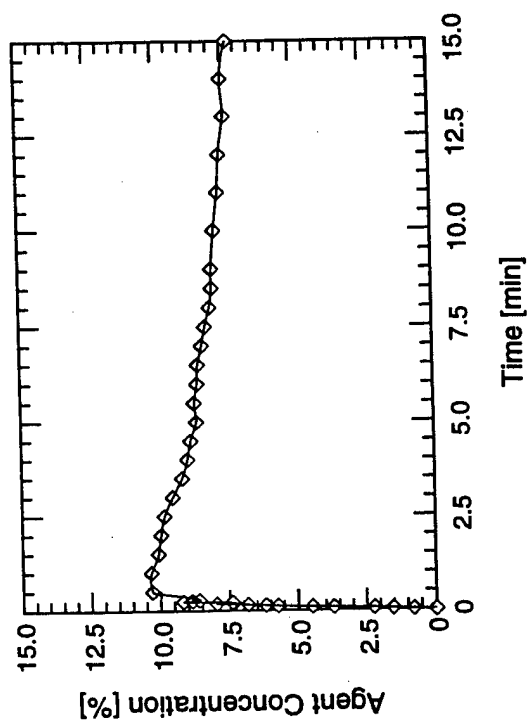
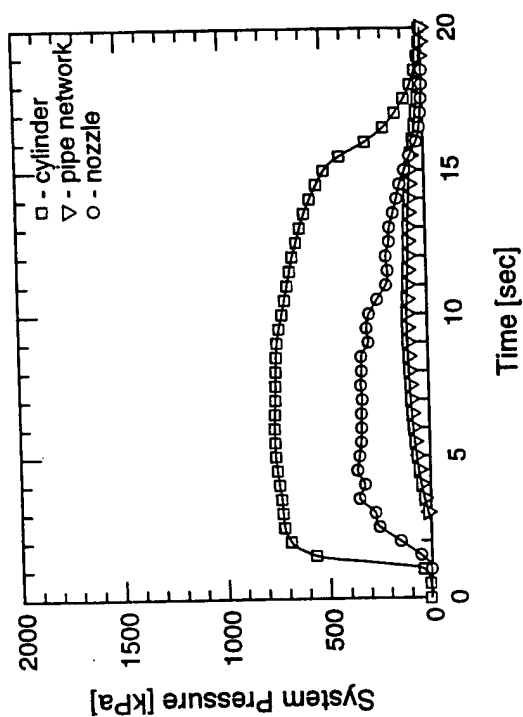
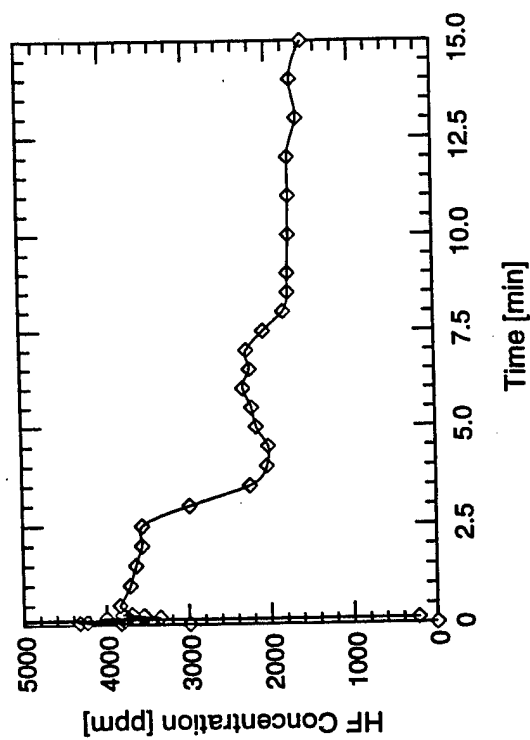
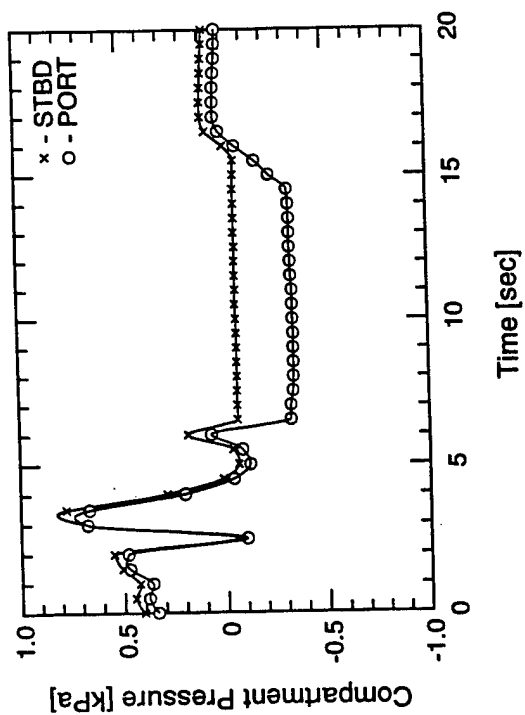
Test #19



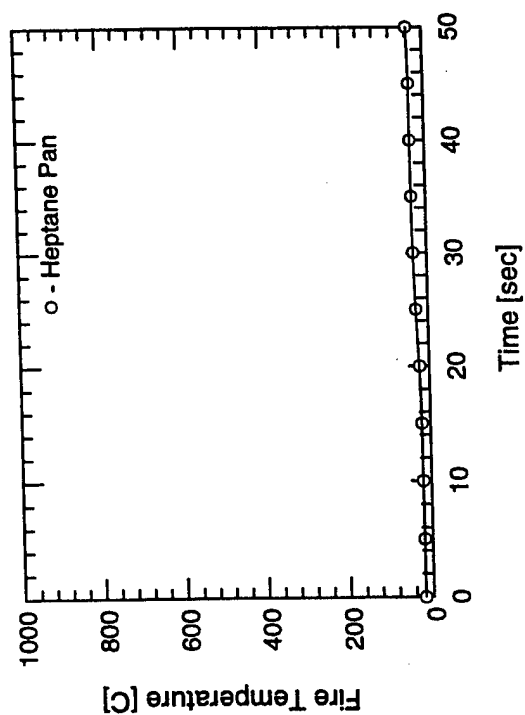
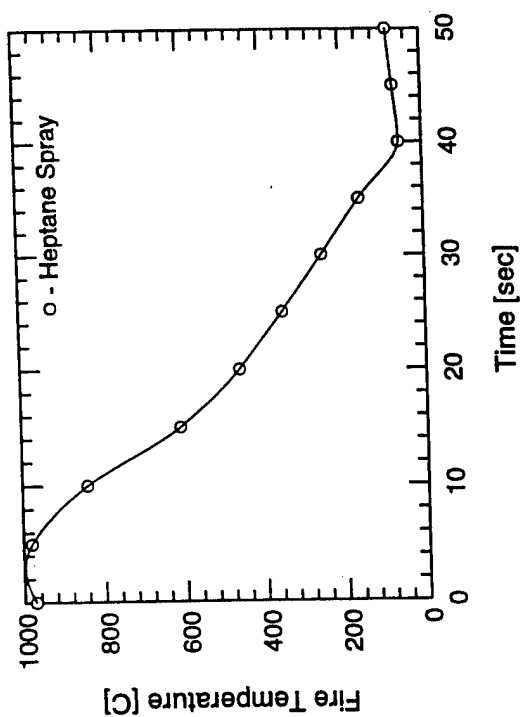
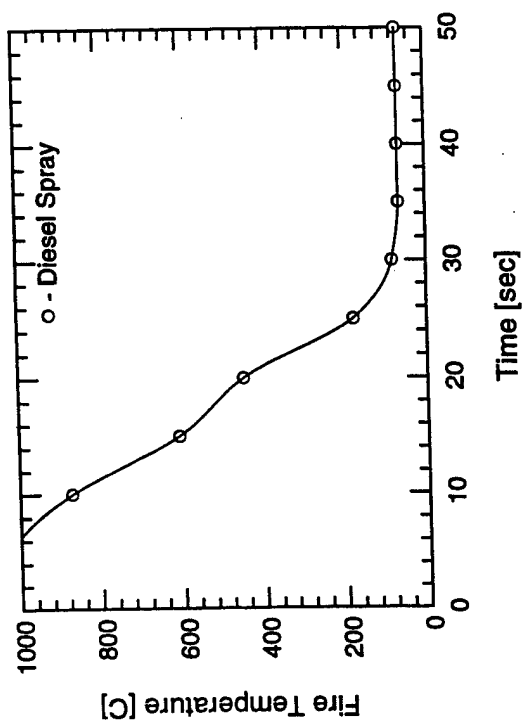
Test #19

Test #19

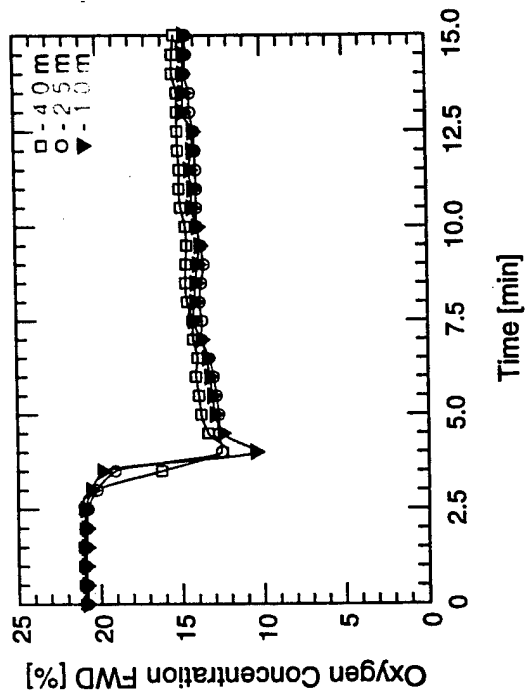
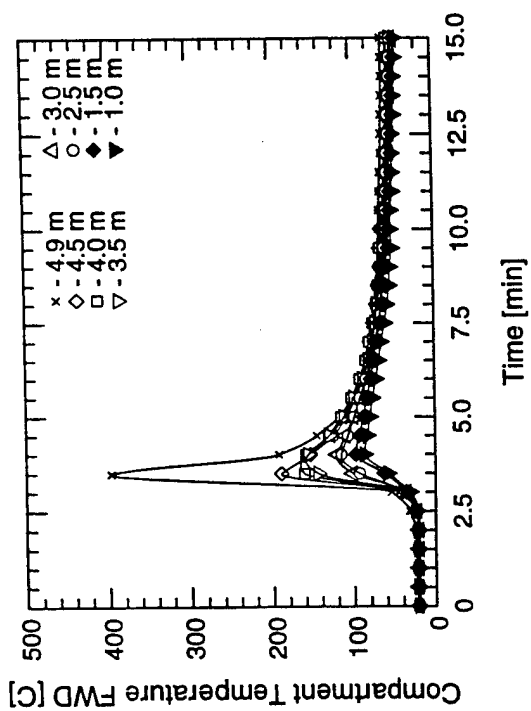
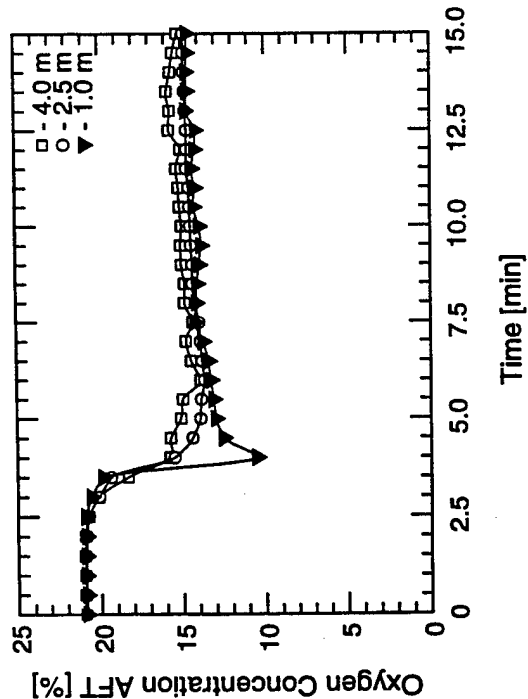
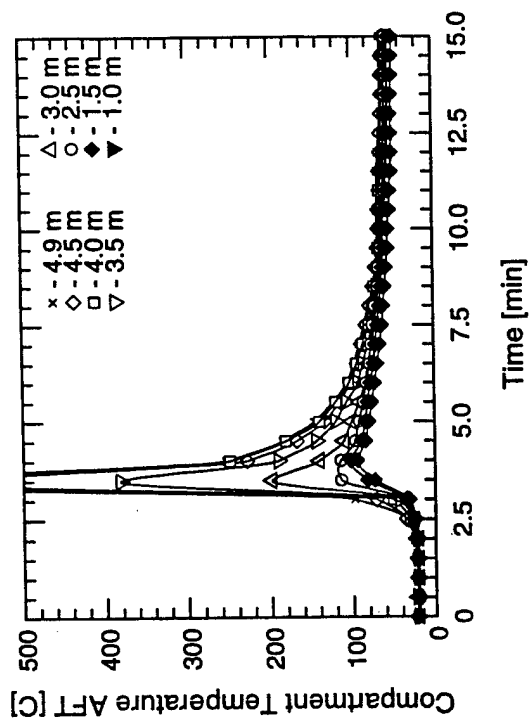




Test #19

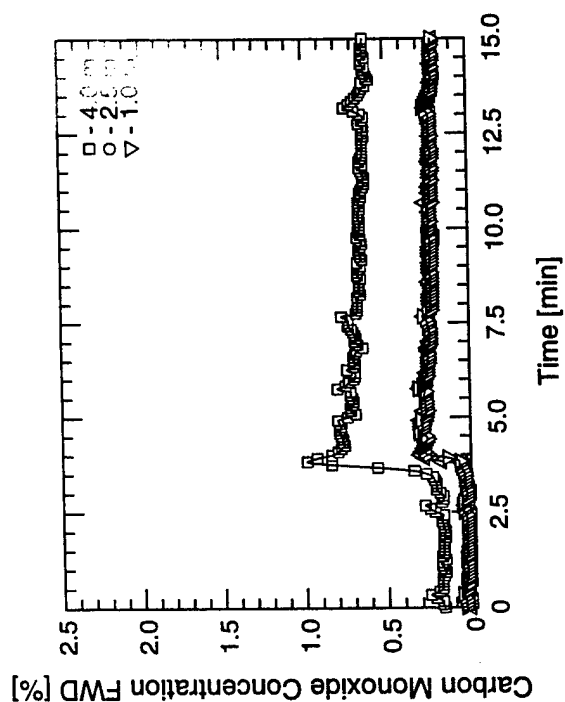
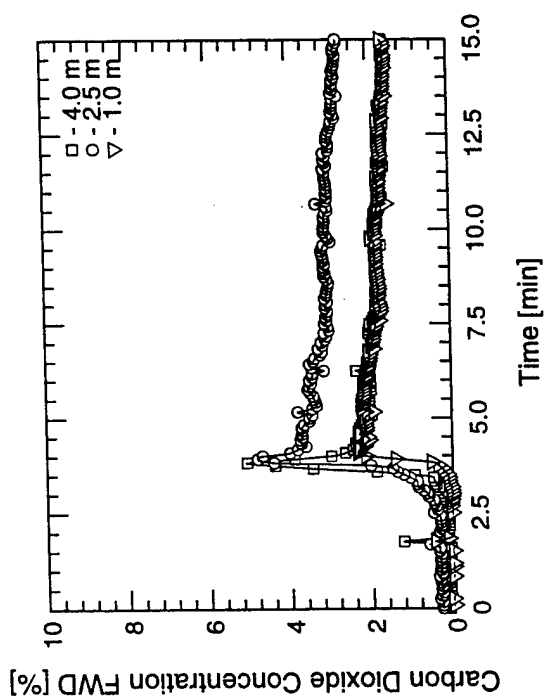
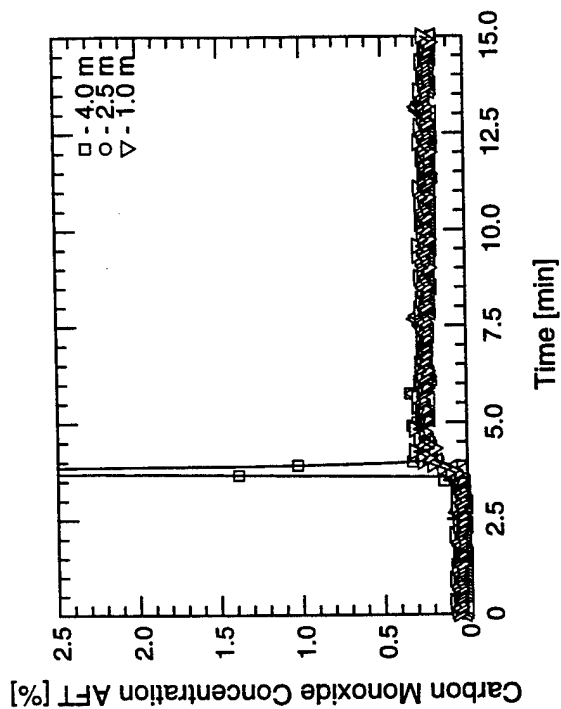
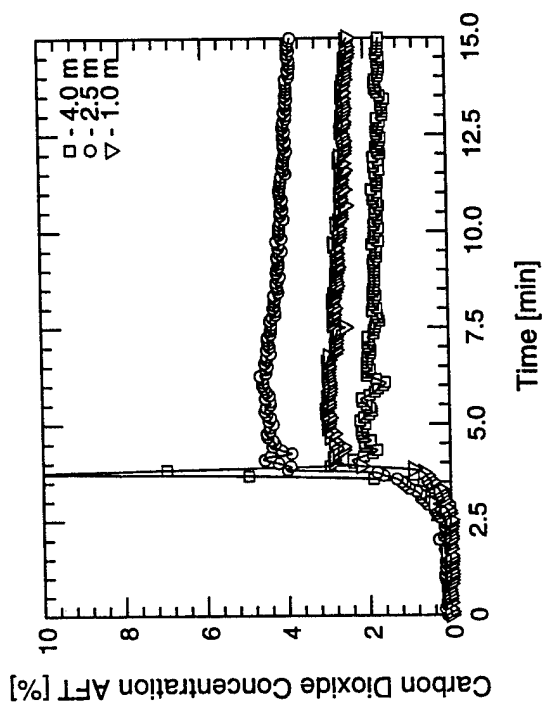


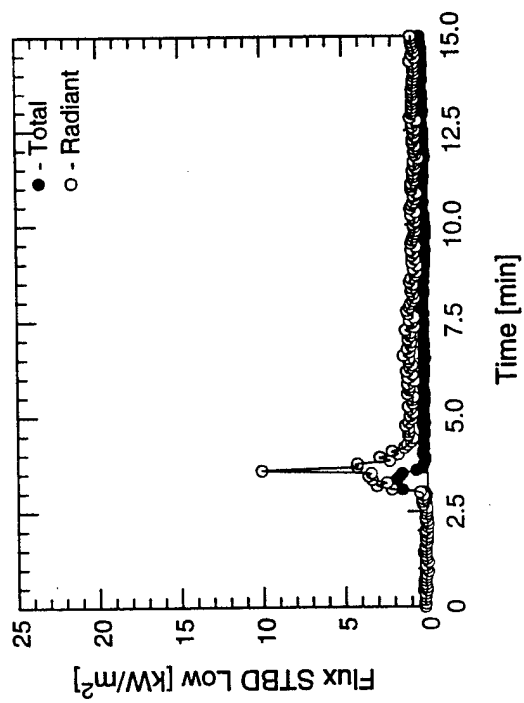
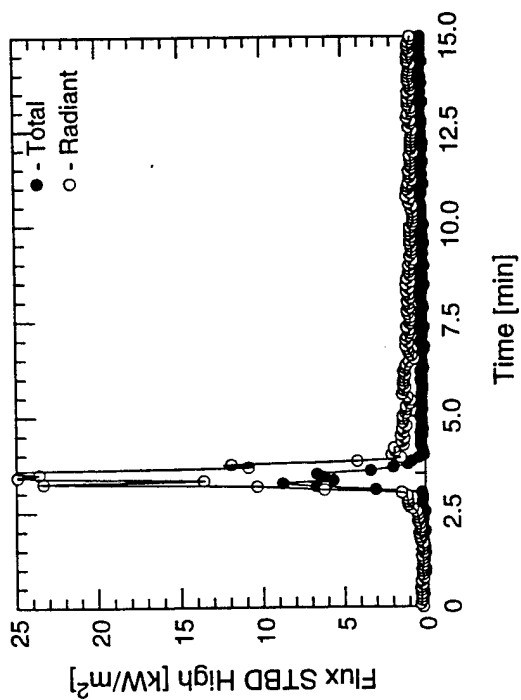
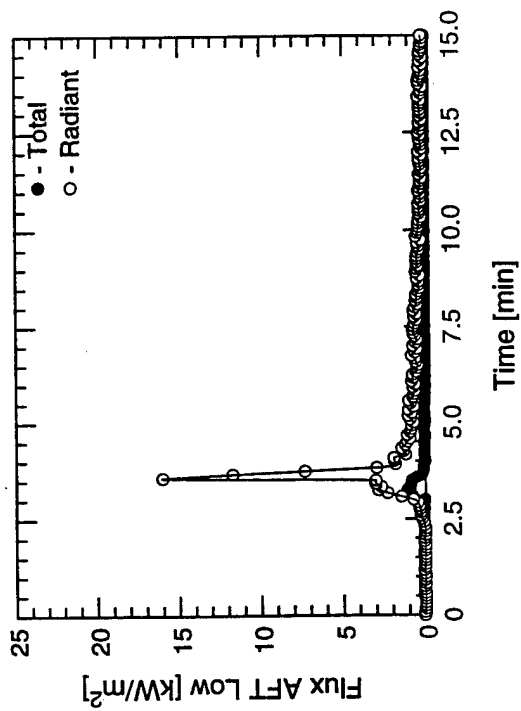
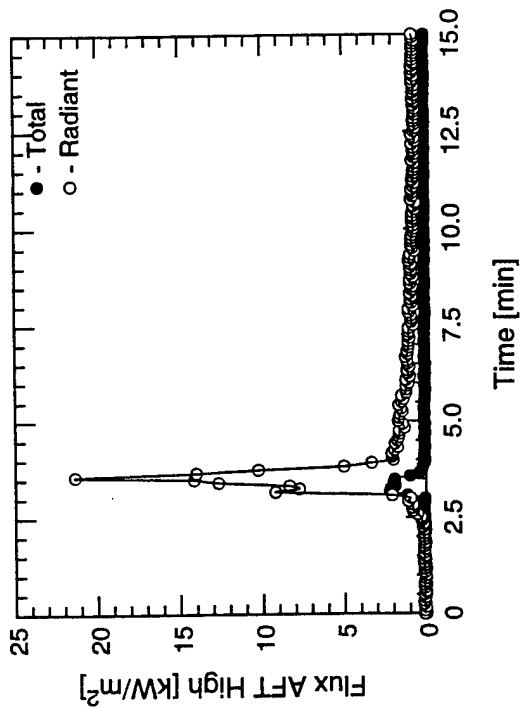
Test #19



Test #20

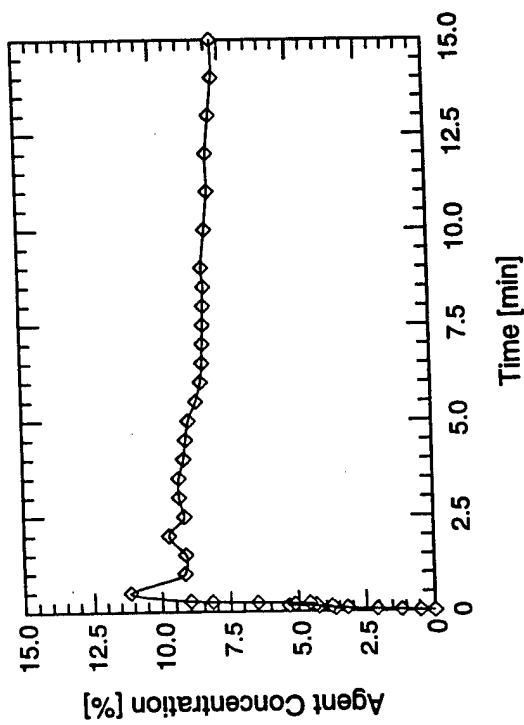
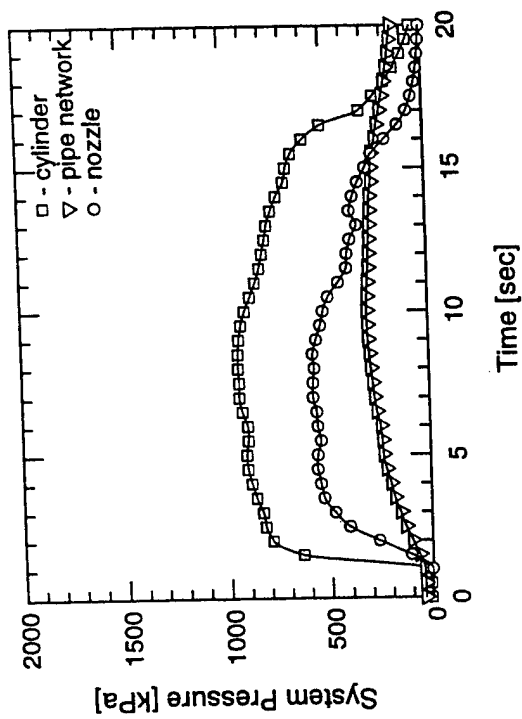
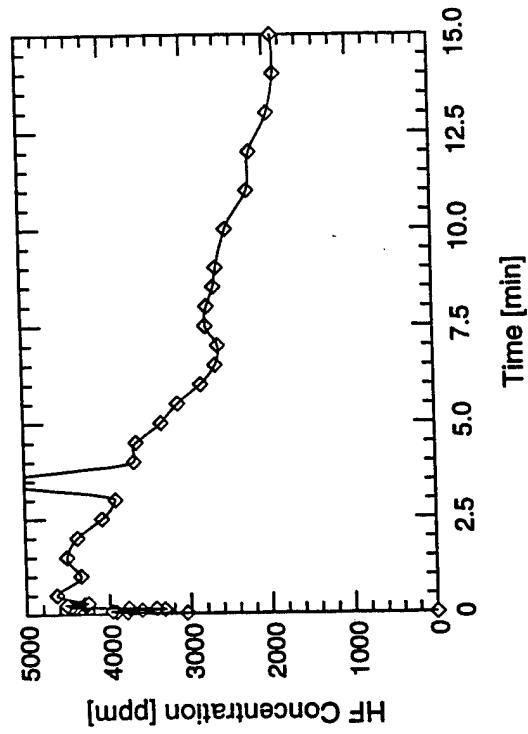
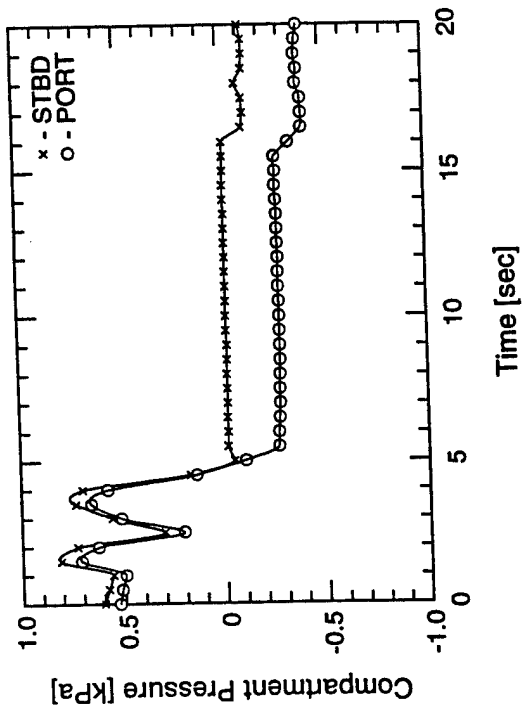
Test #20

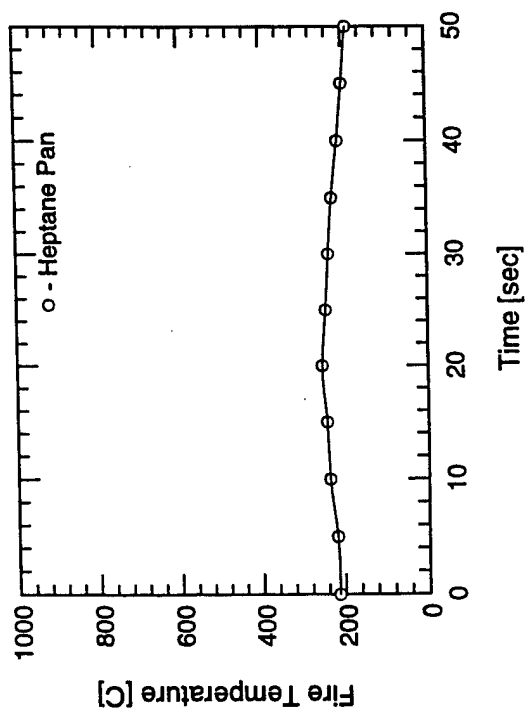
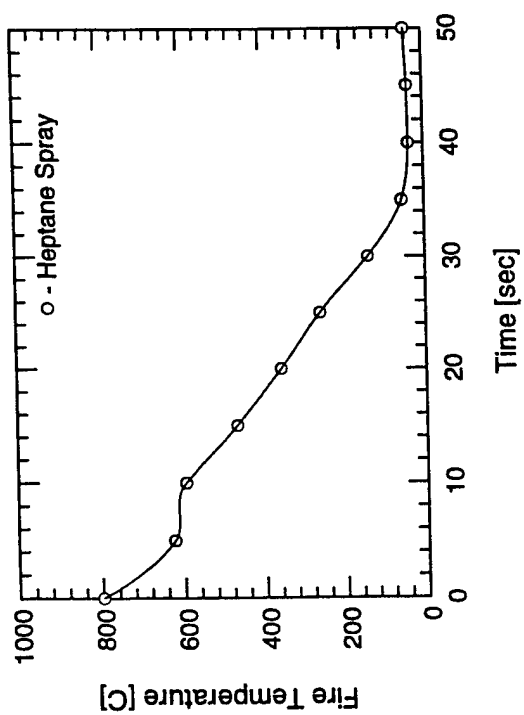
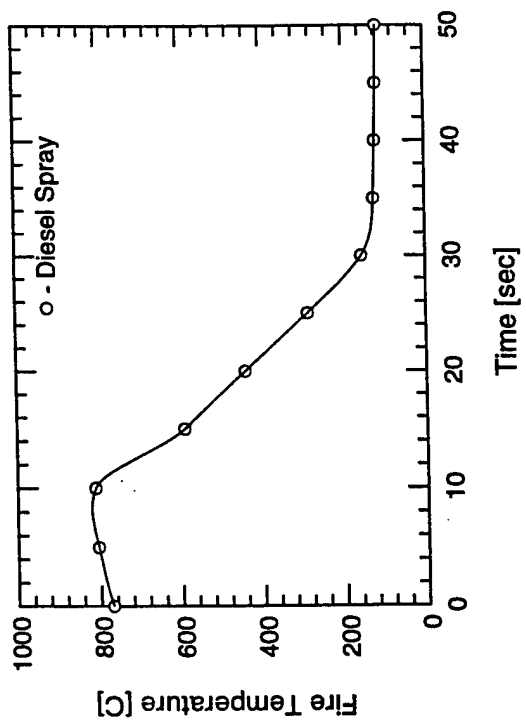




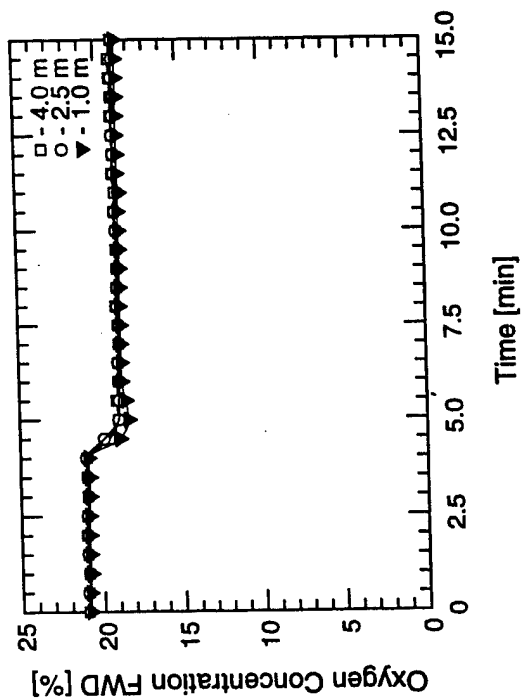
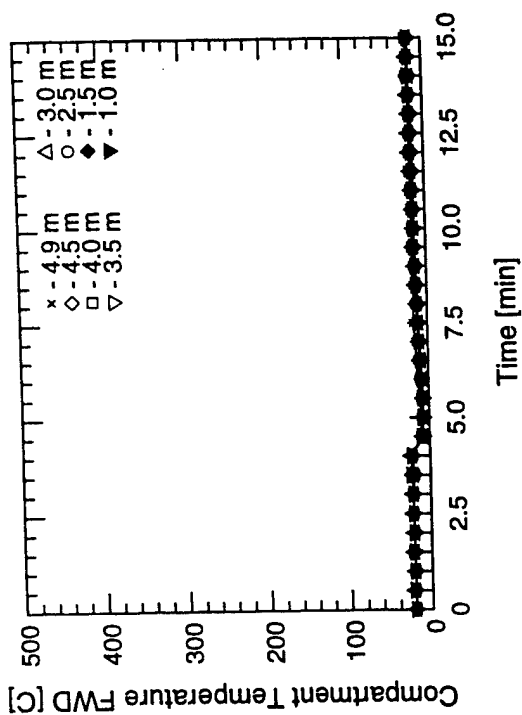
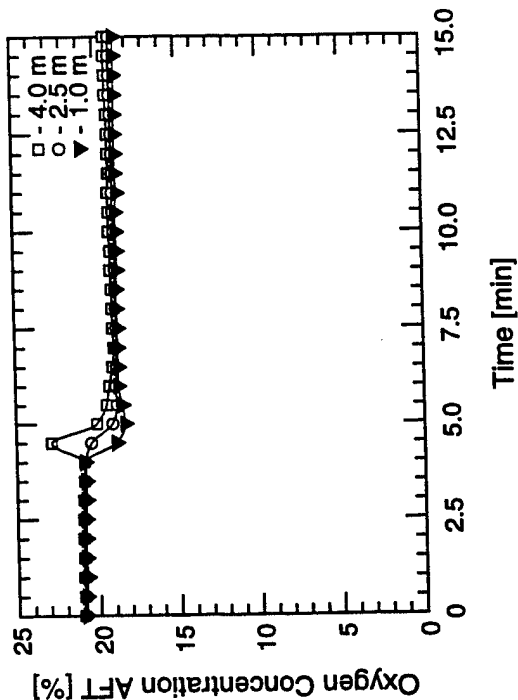
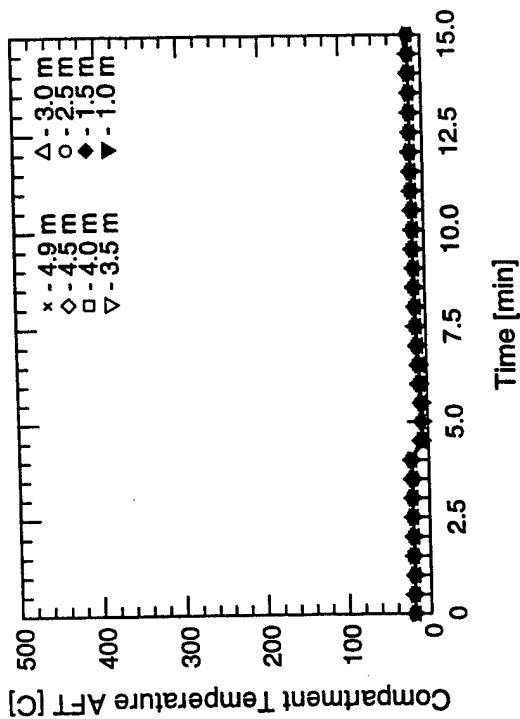
Test #20

Test #20



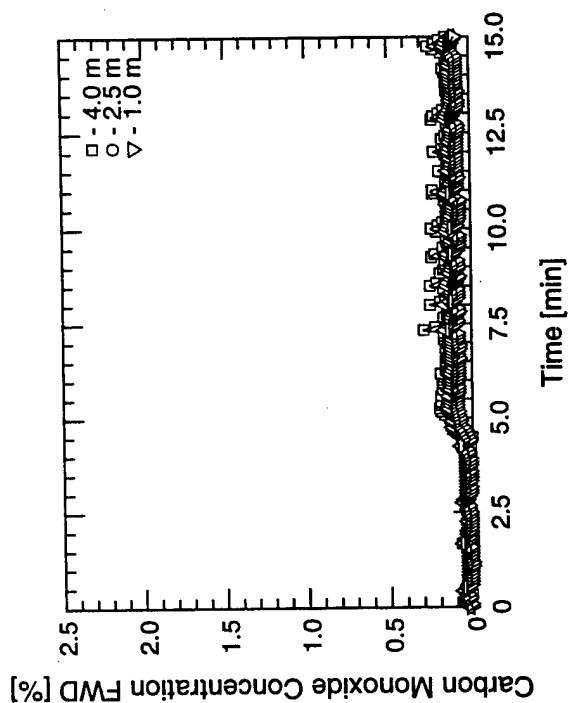
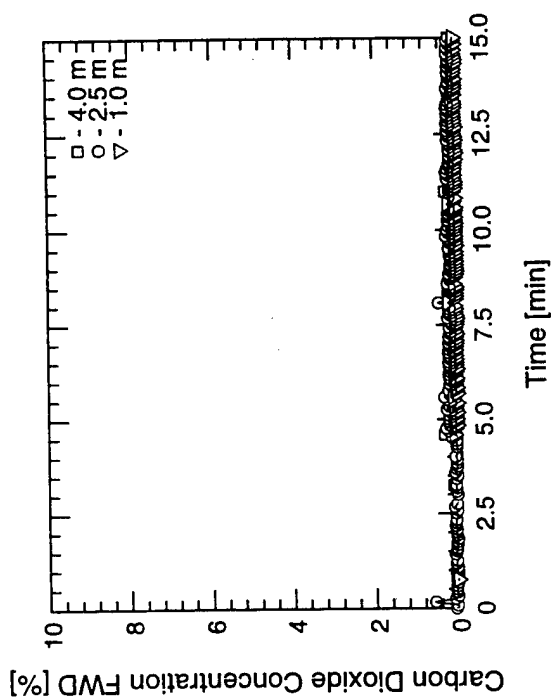
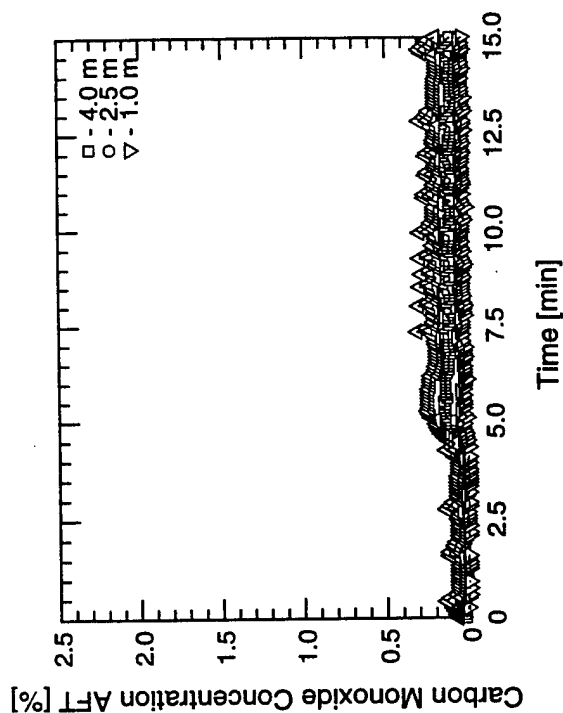
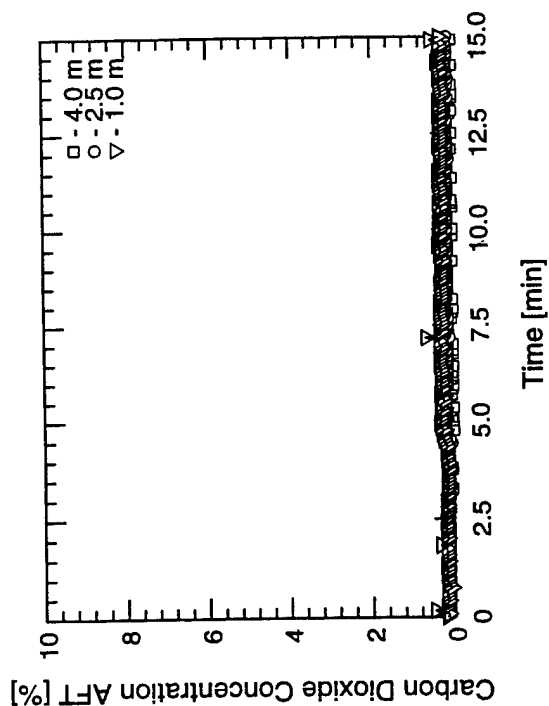


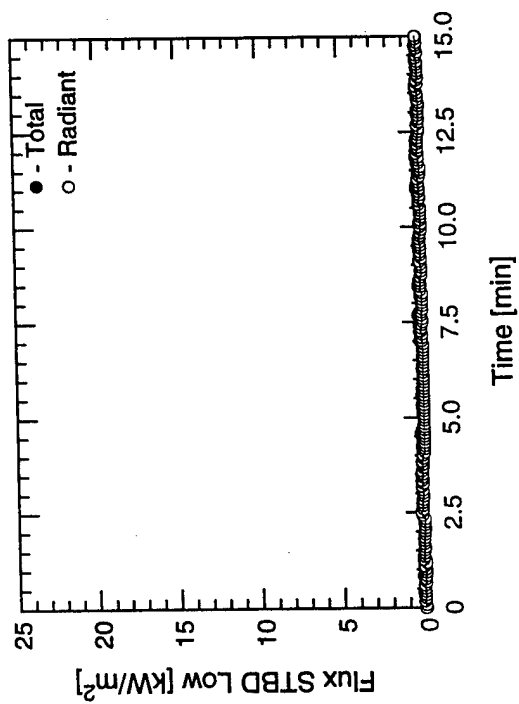
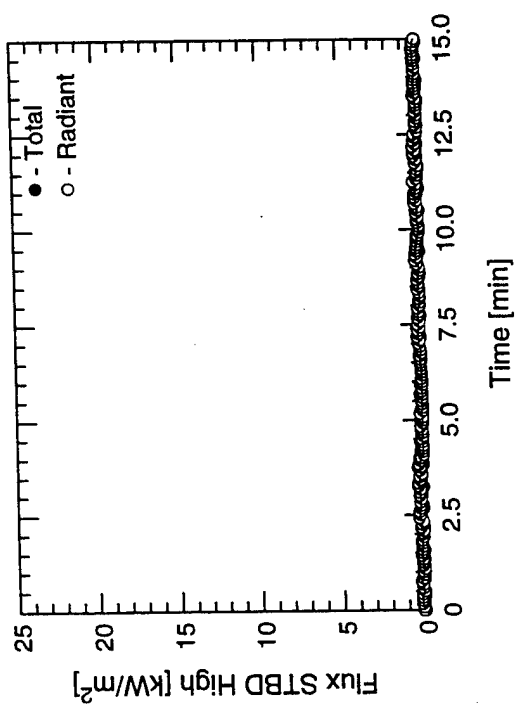
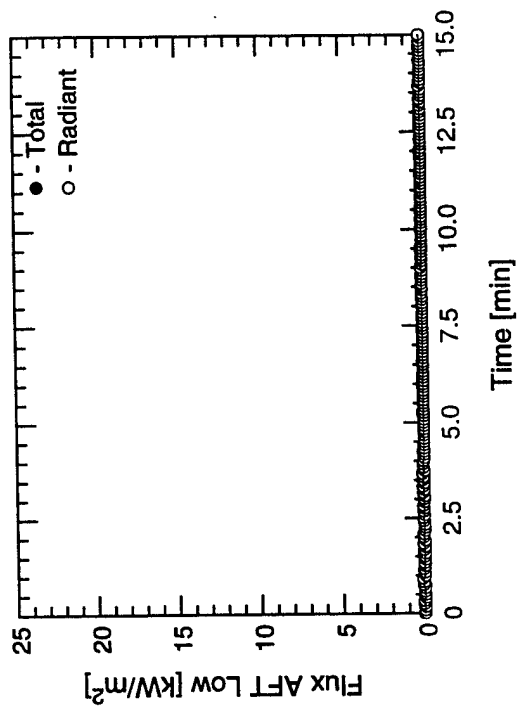
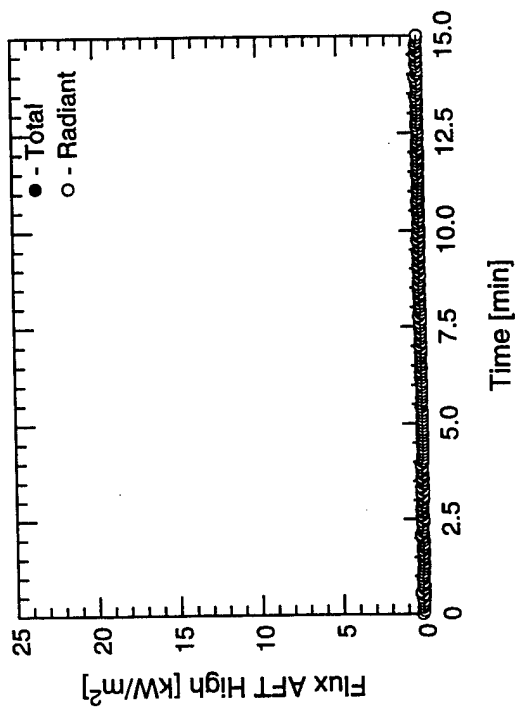
Test #20



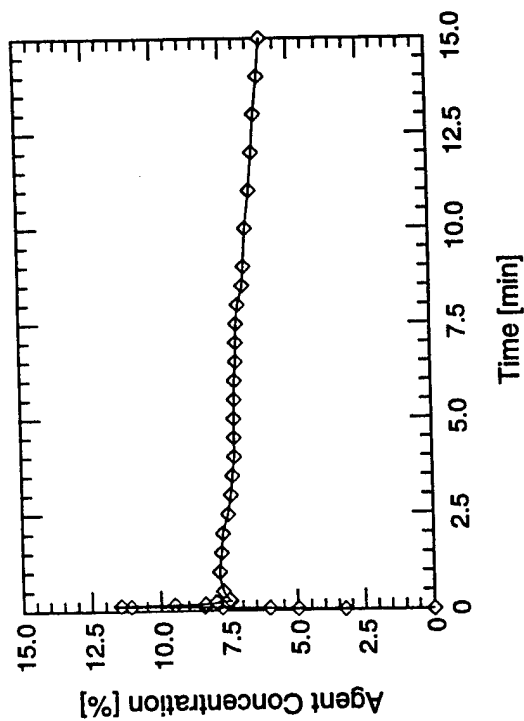
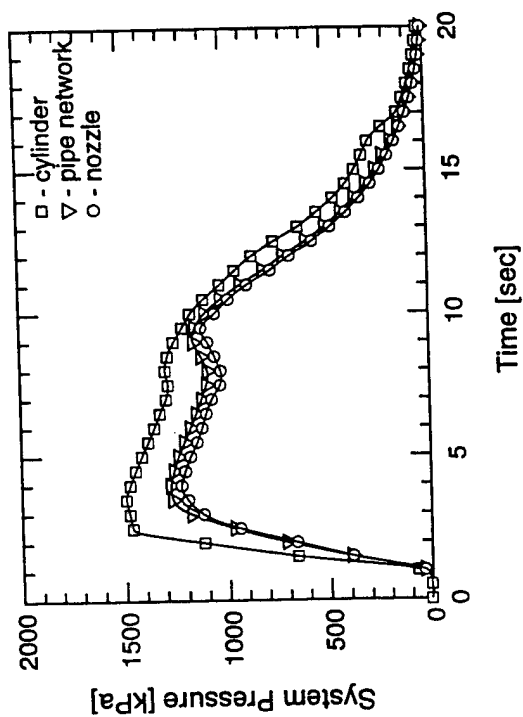
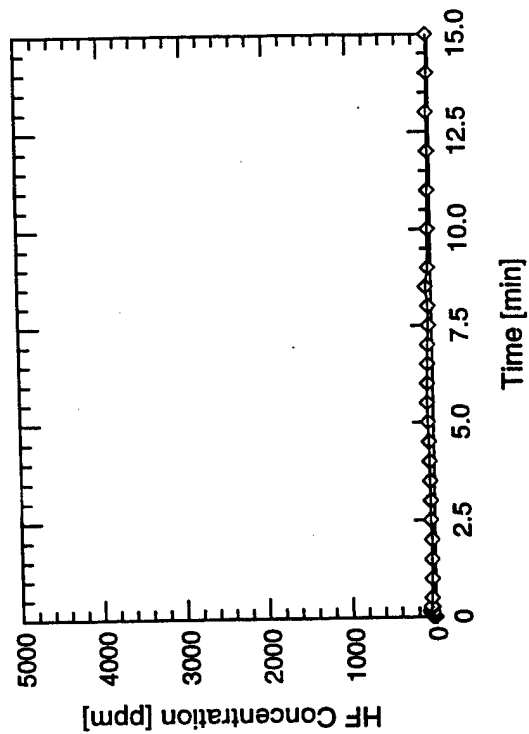
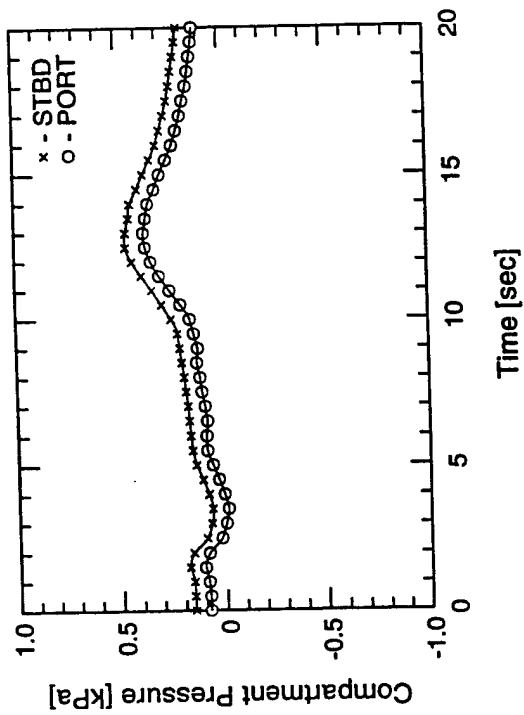
Test #21

Test #21



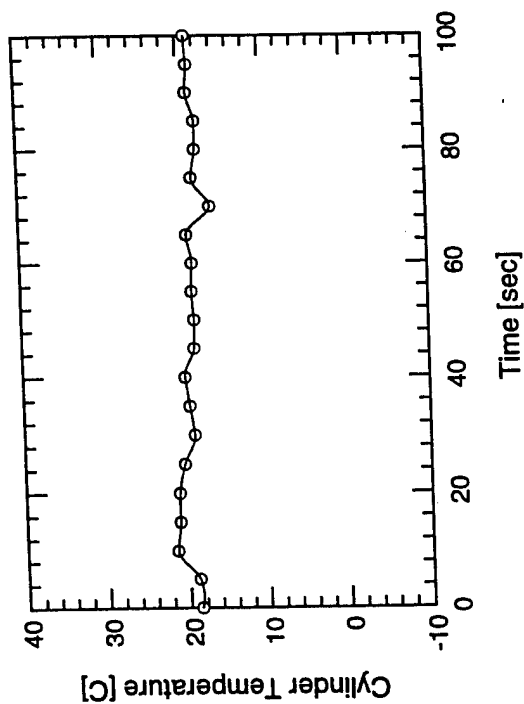
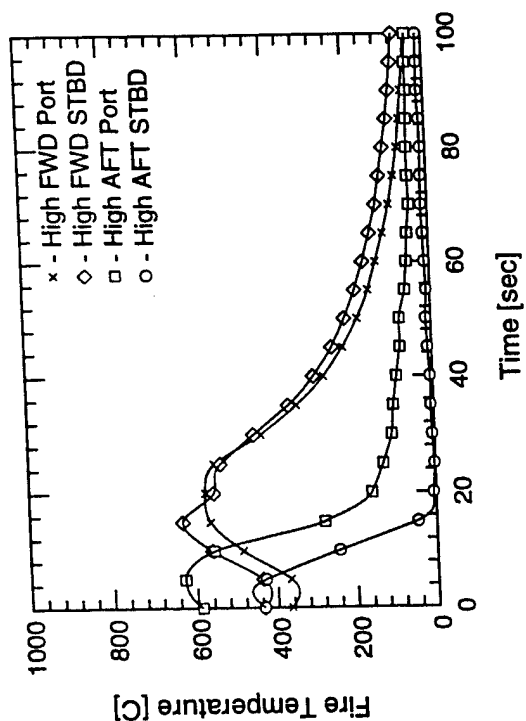
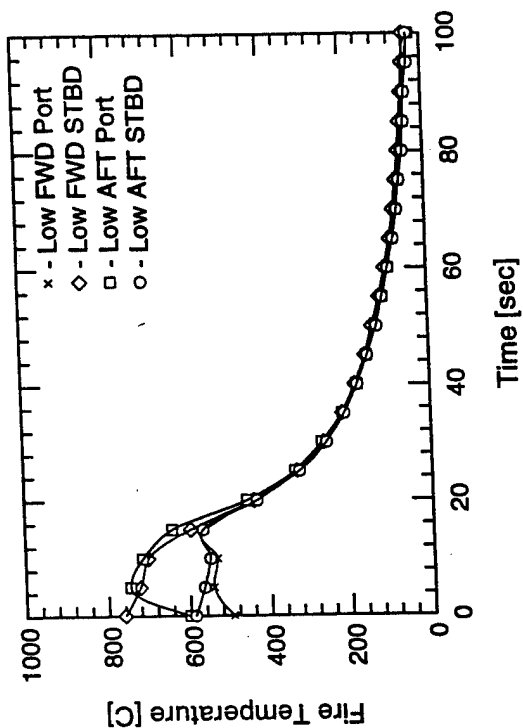


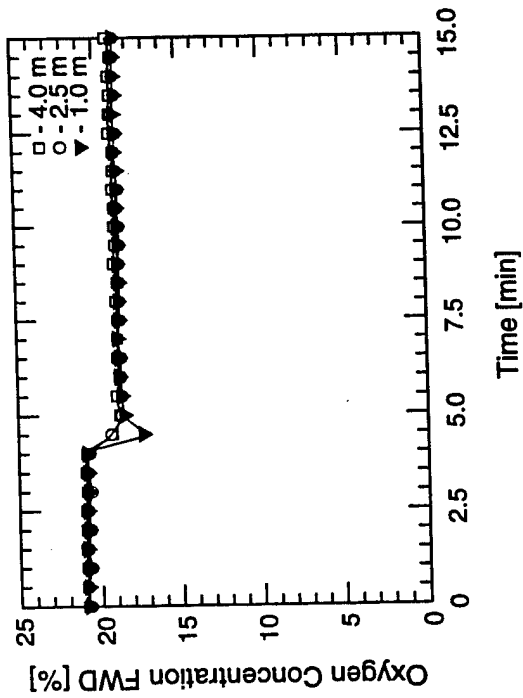
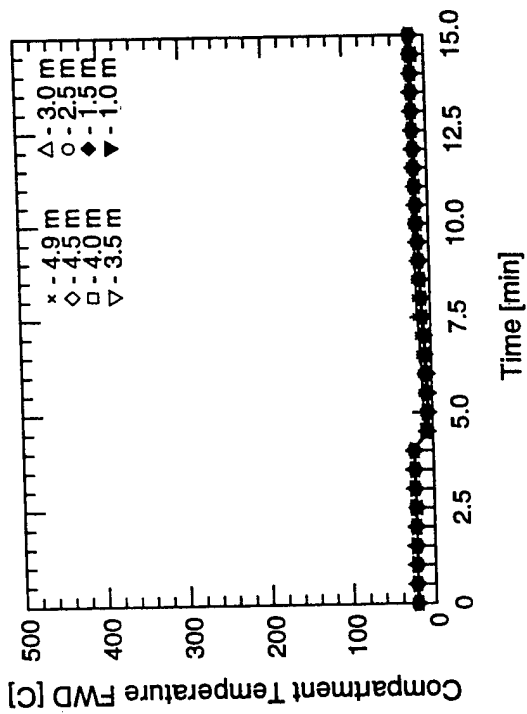
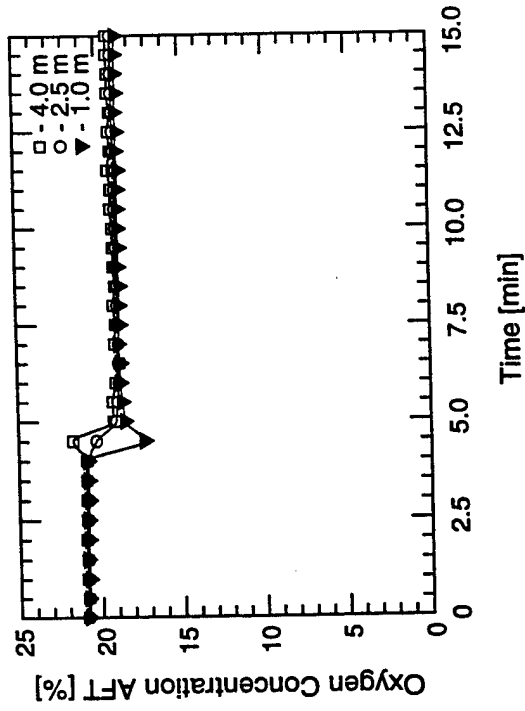
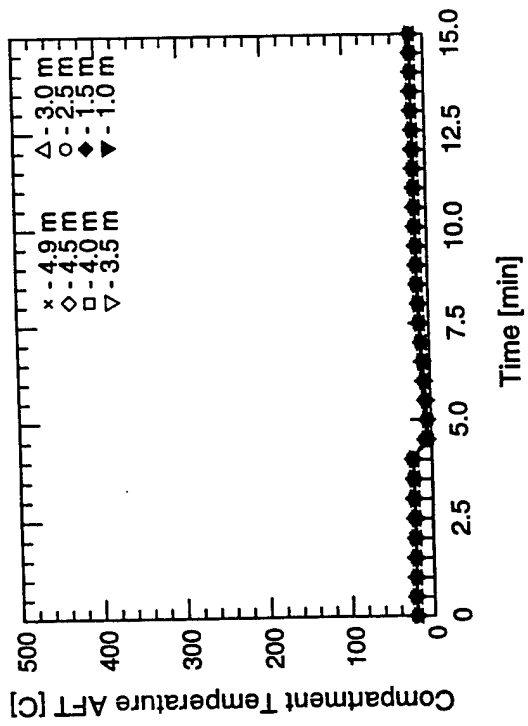
Test #21



Test #21

Test #21

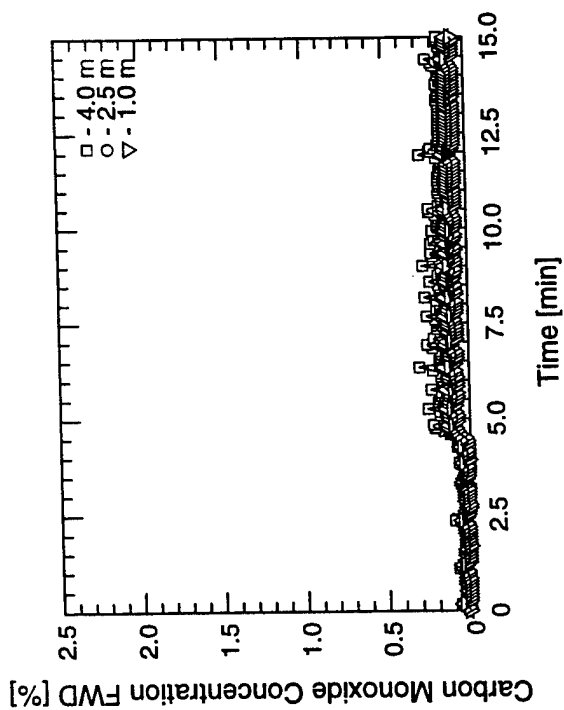
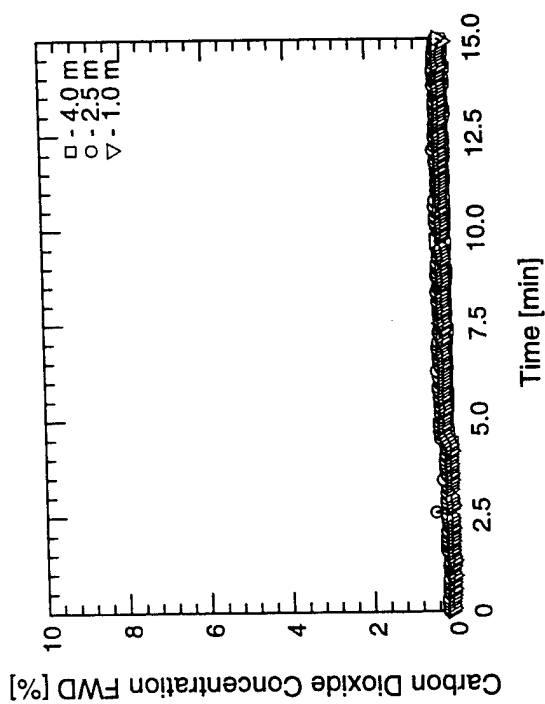
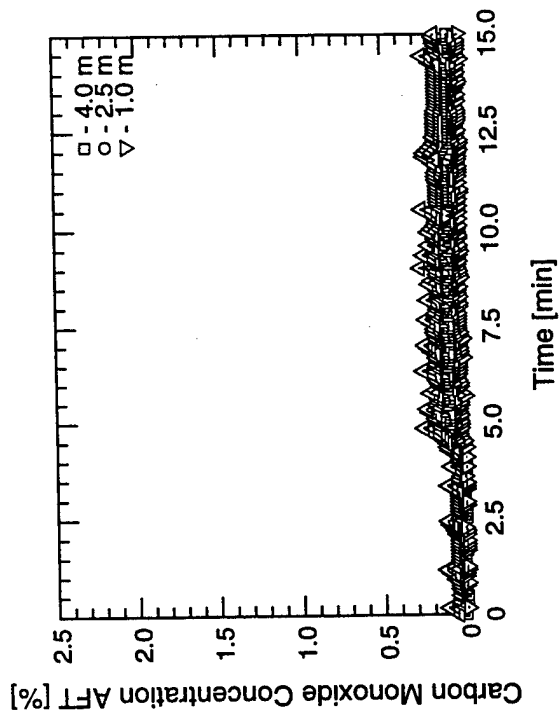
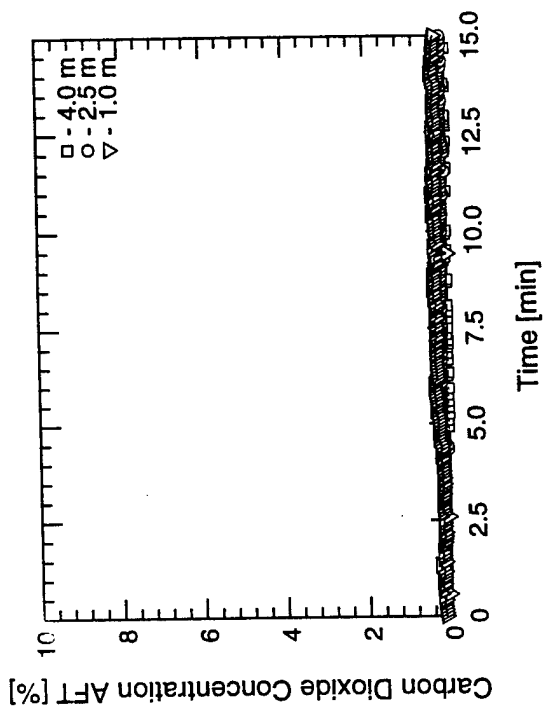


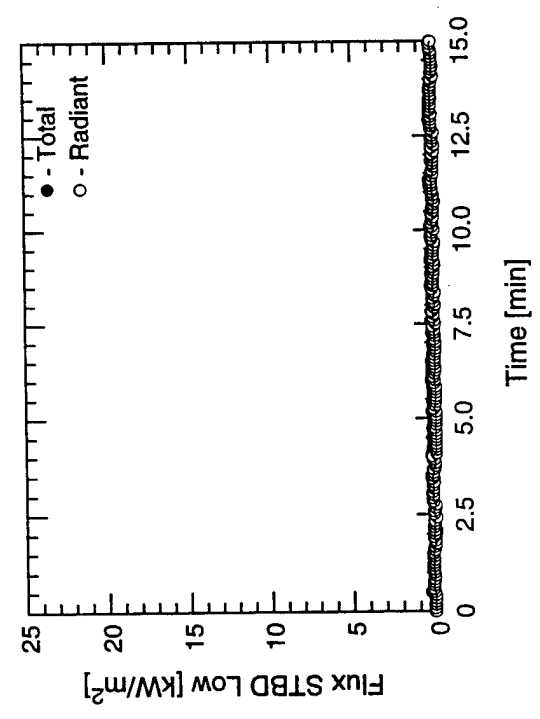
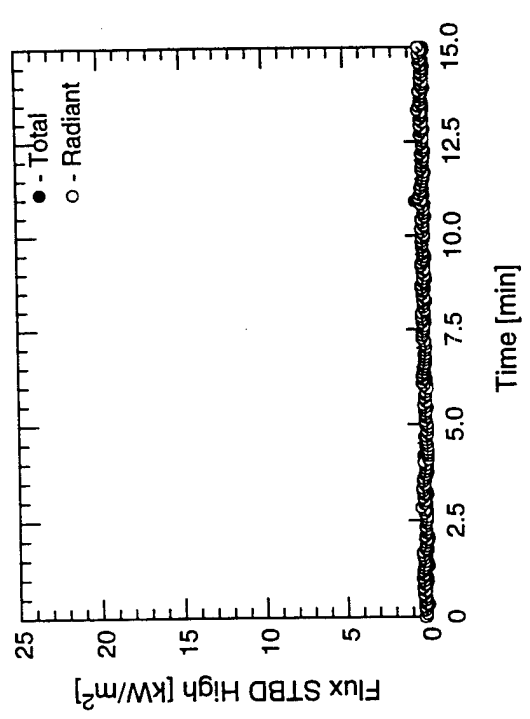
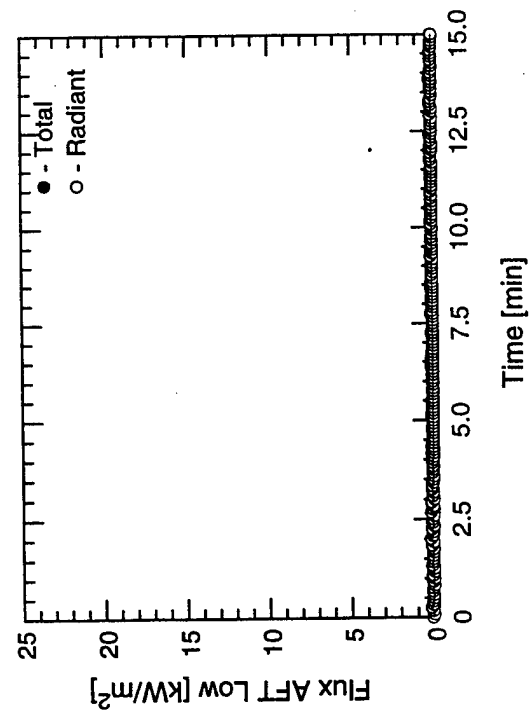
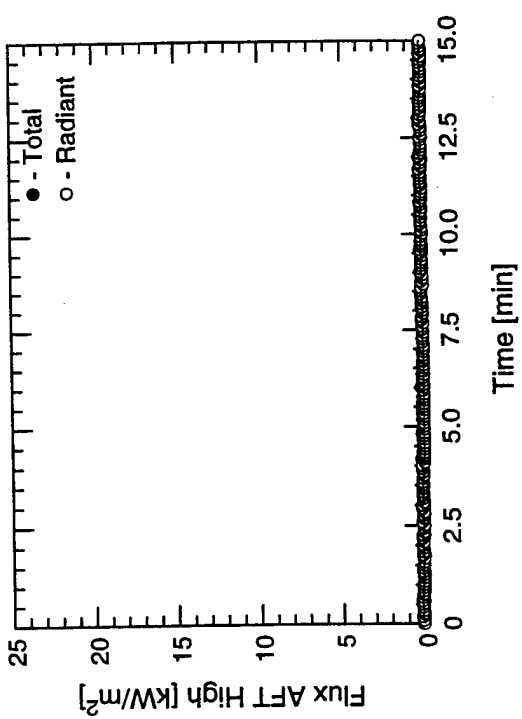


Test #22

Test #22

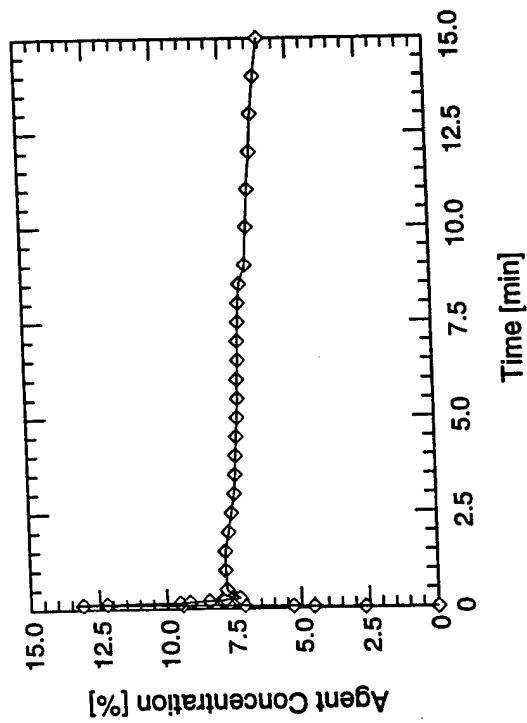
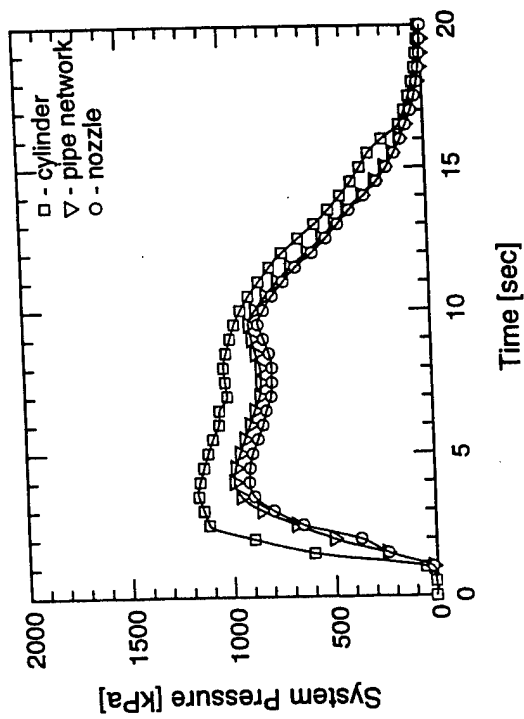
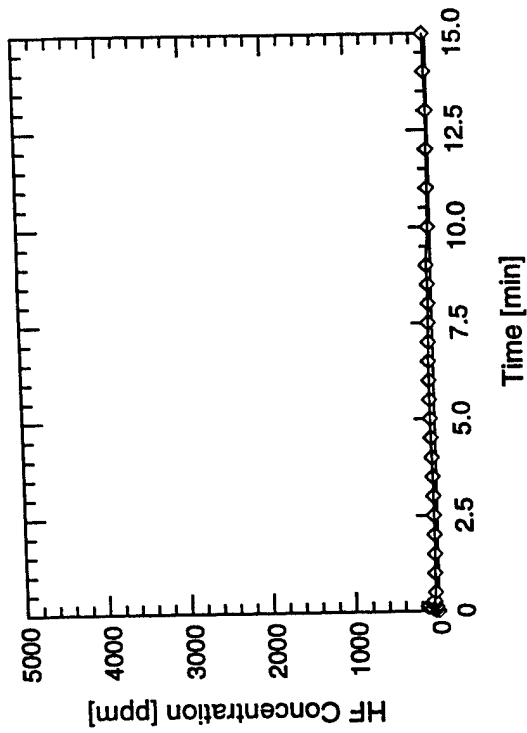
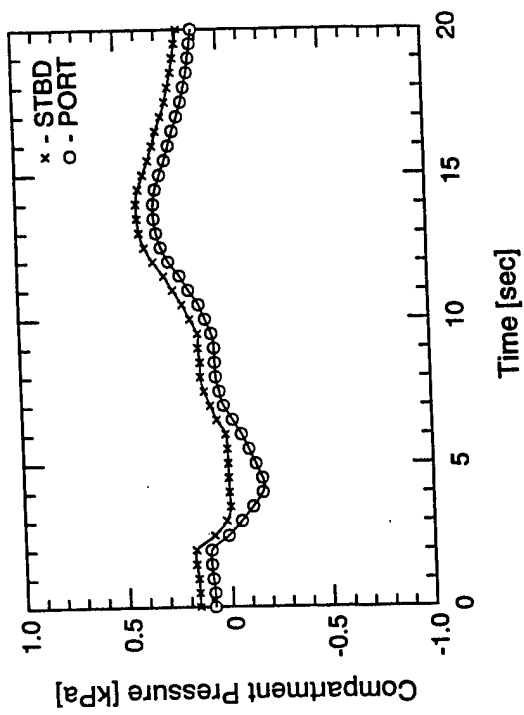
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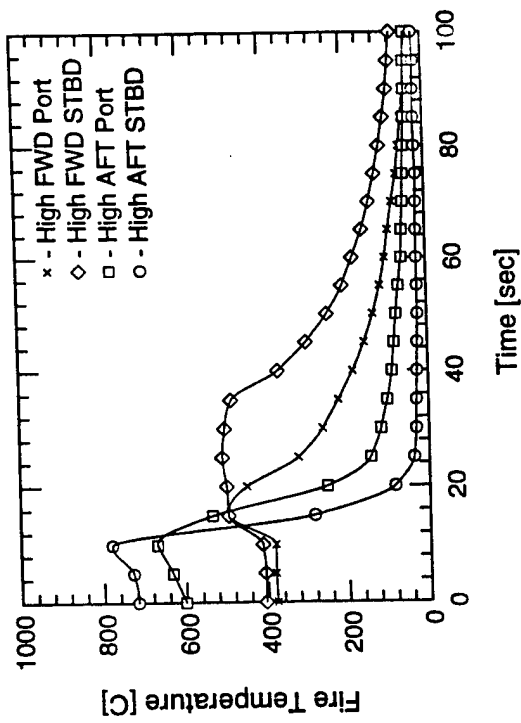
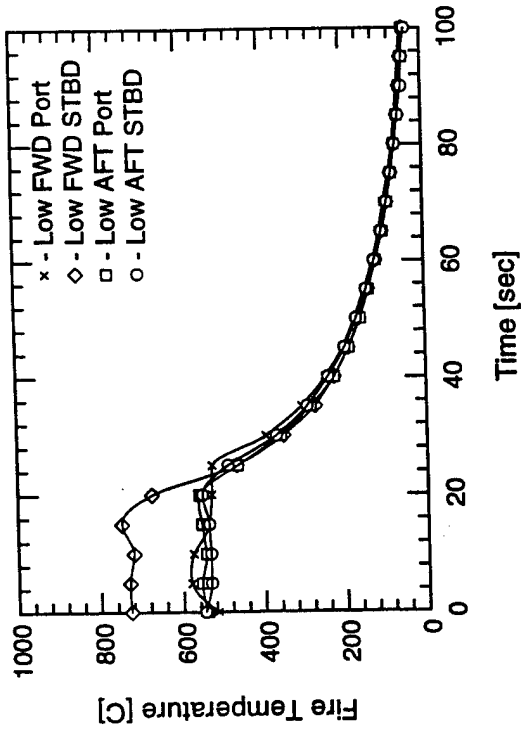




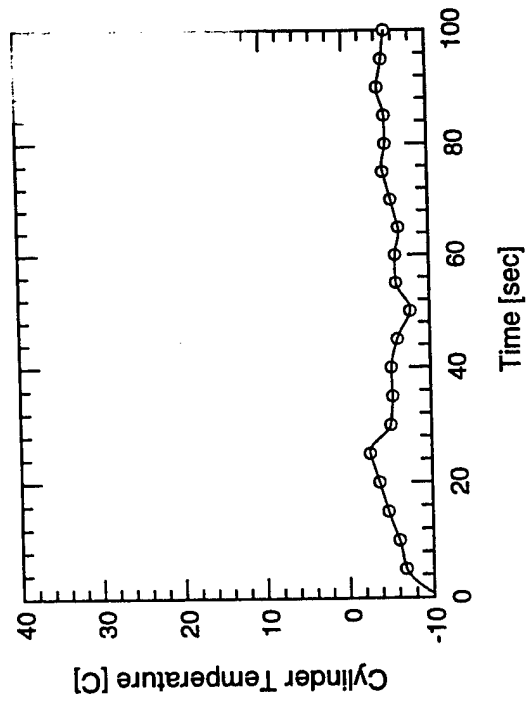
Test #22

Test #22



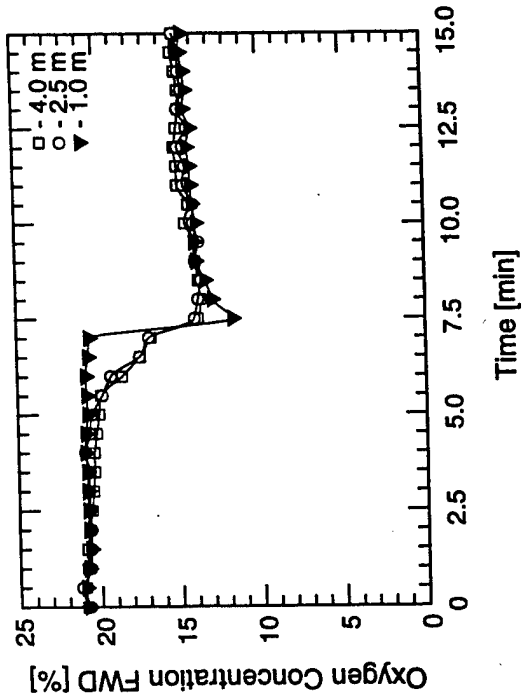
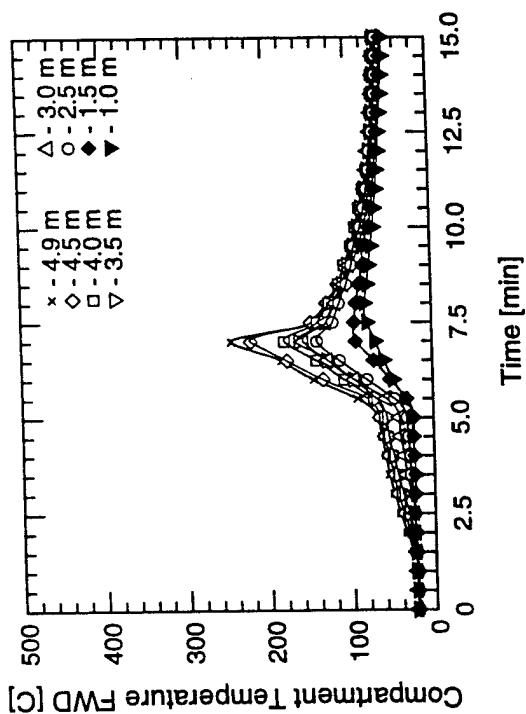
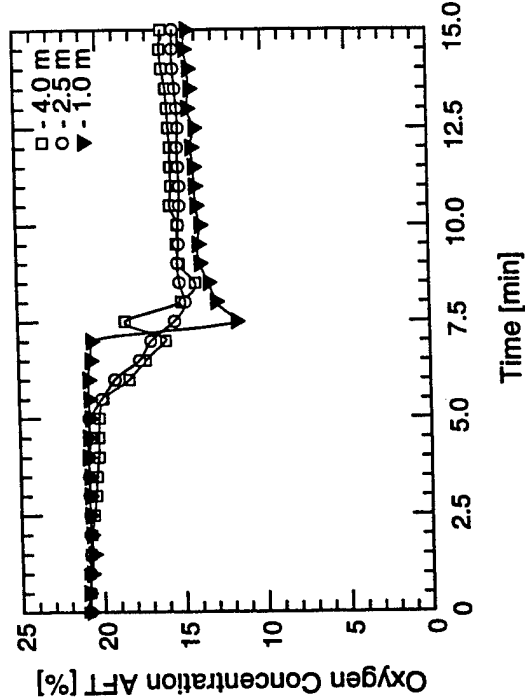
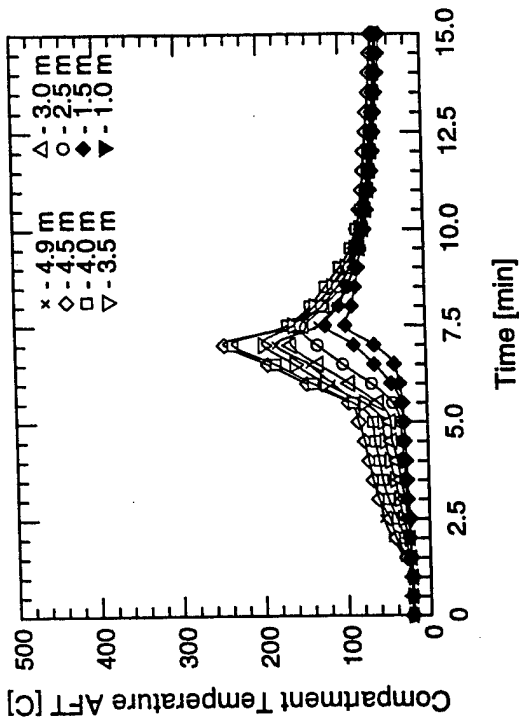


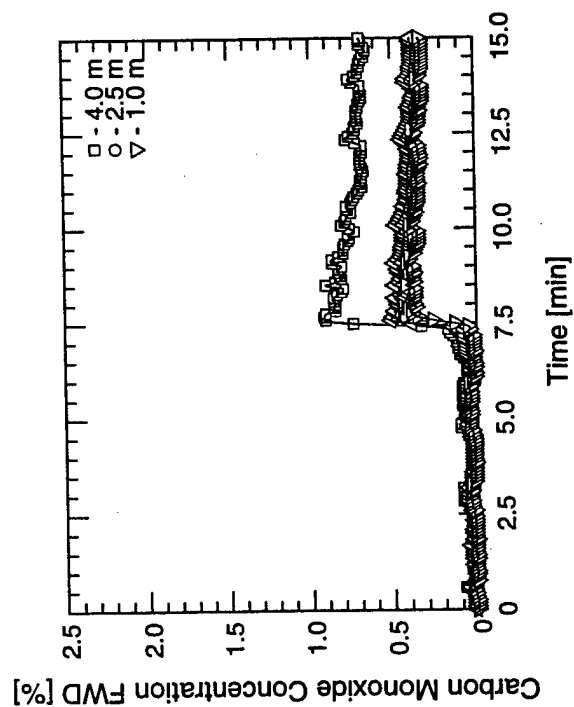
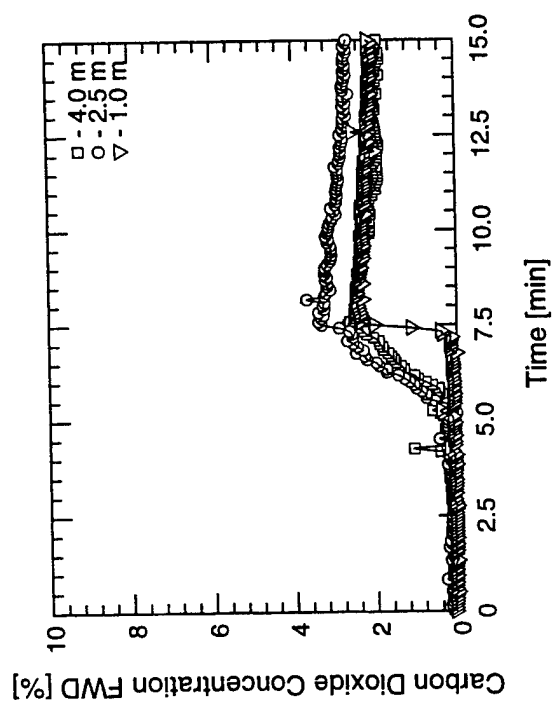
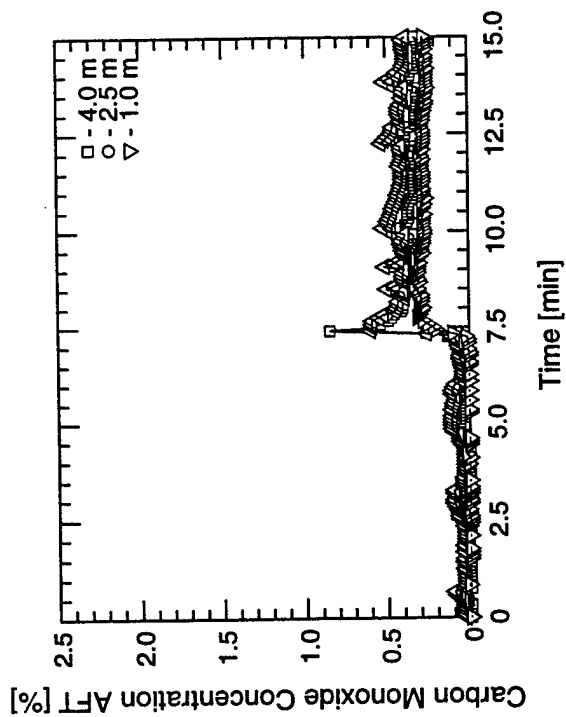
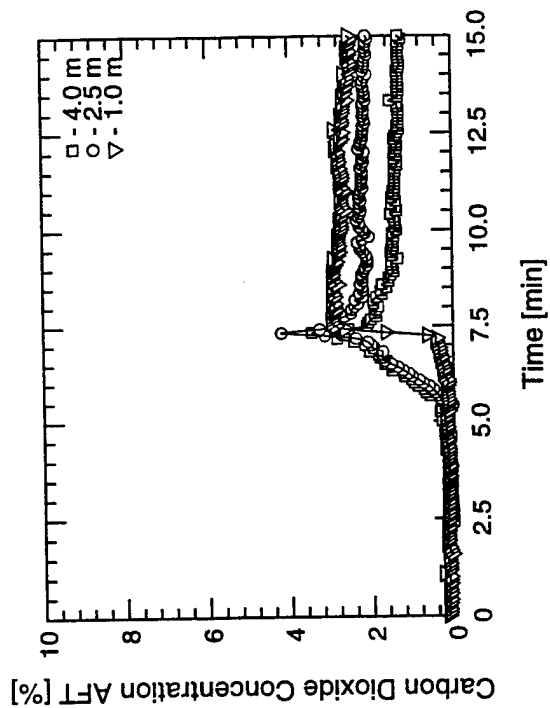
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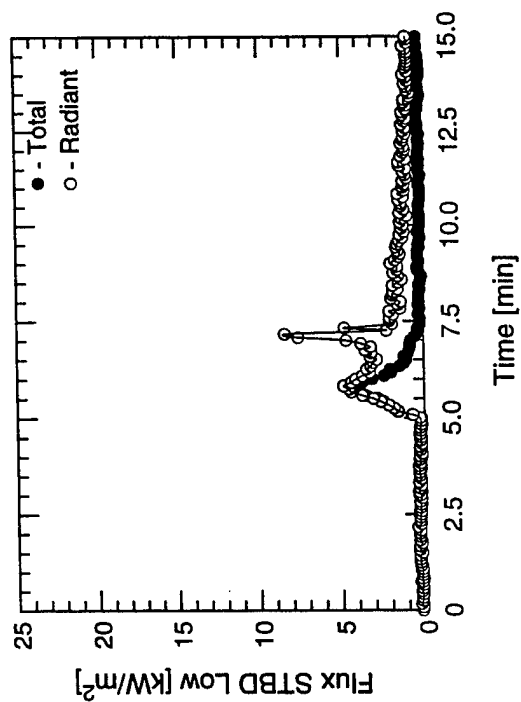
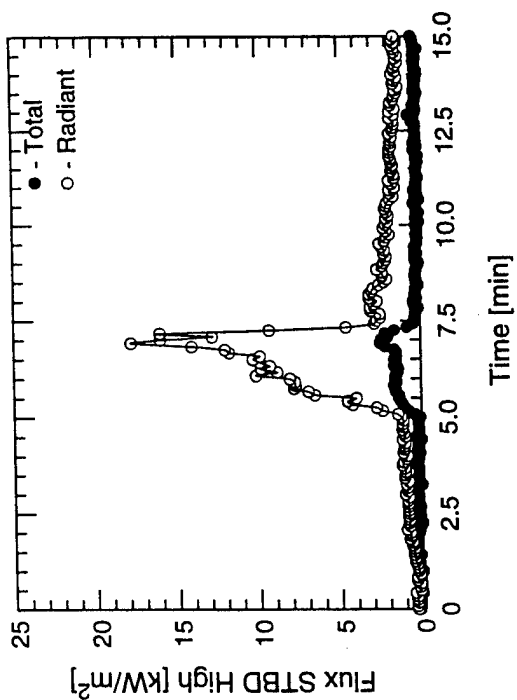
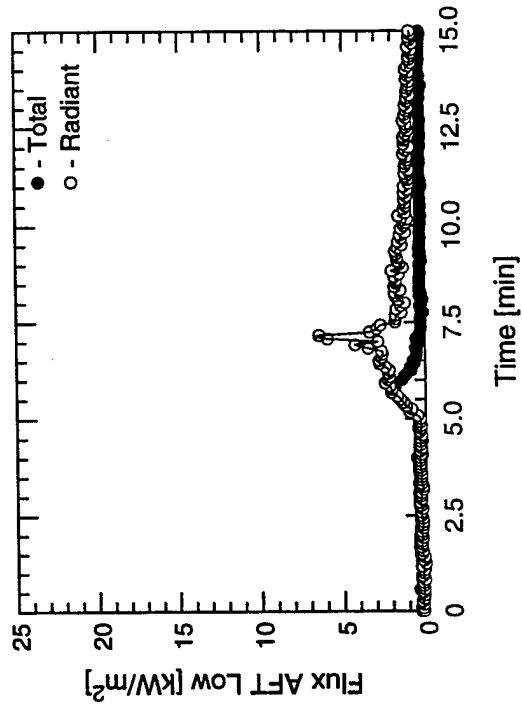
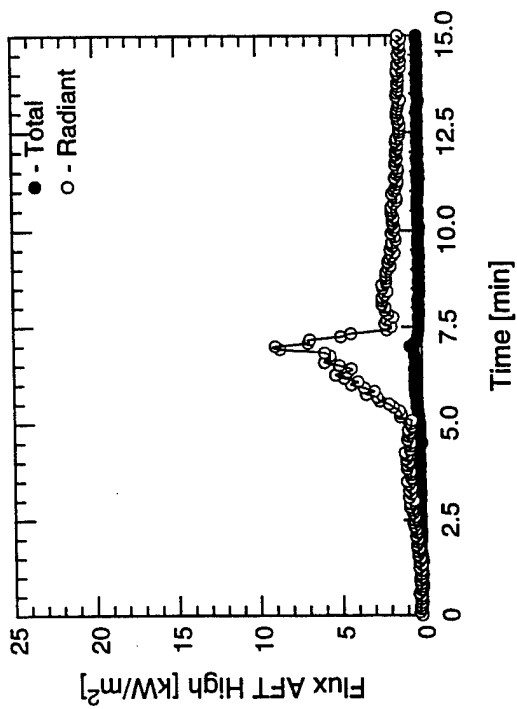
Test #22

Test #23

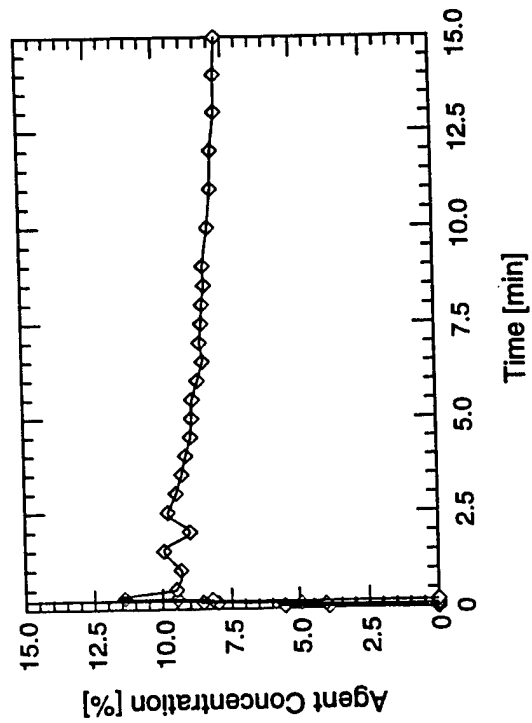
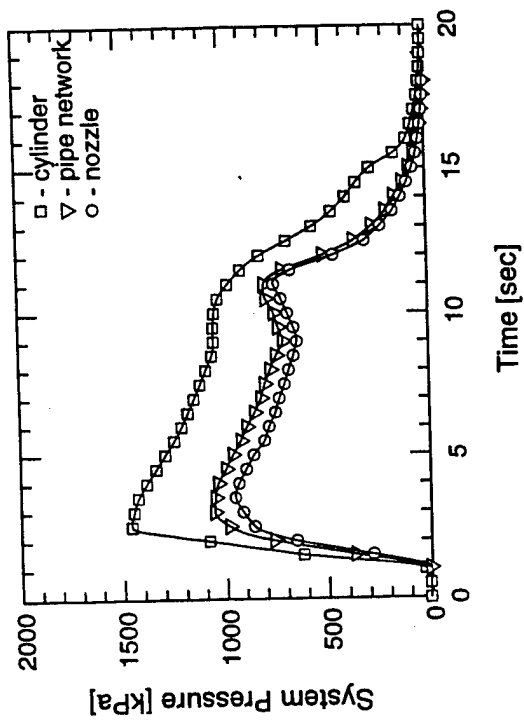
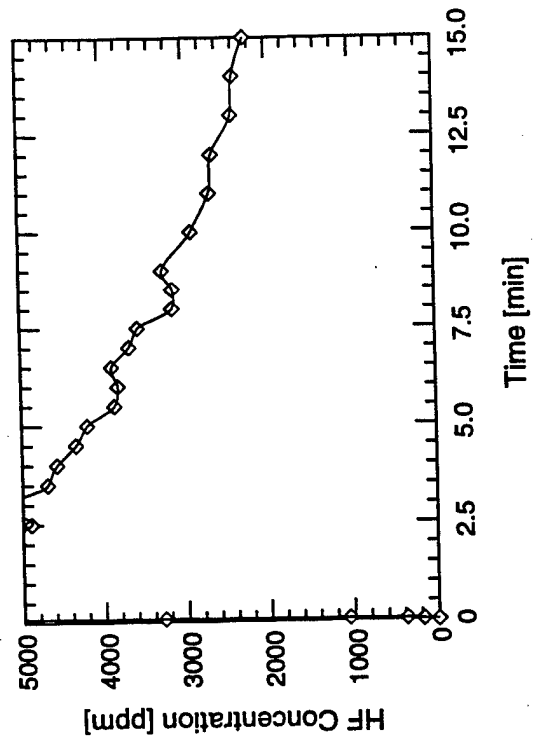
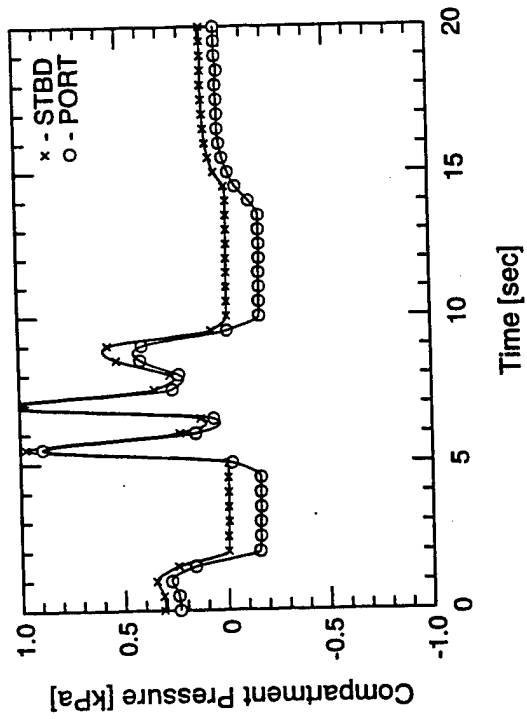




Test #23

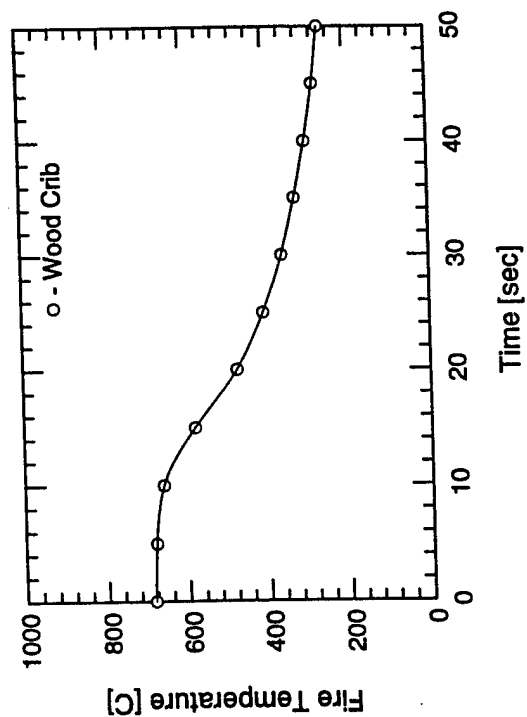
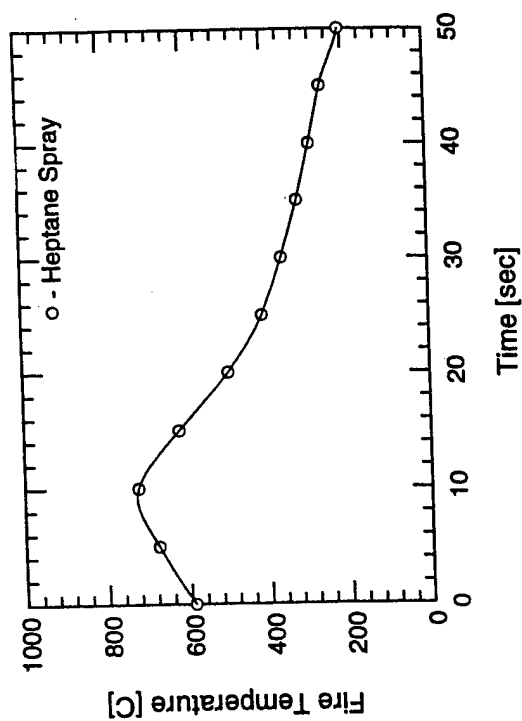
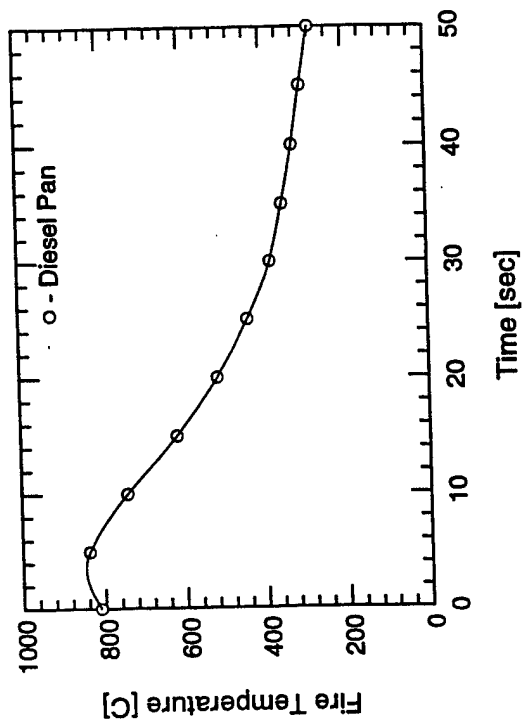


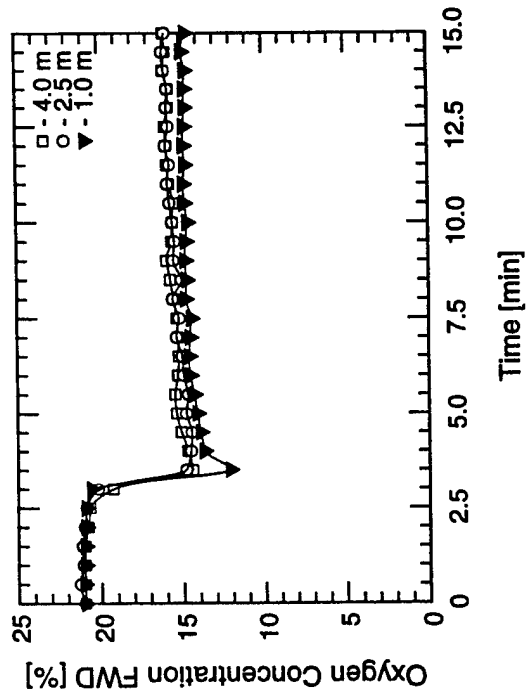
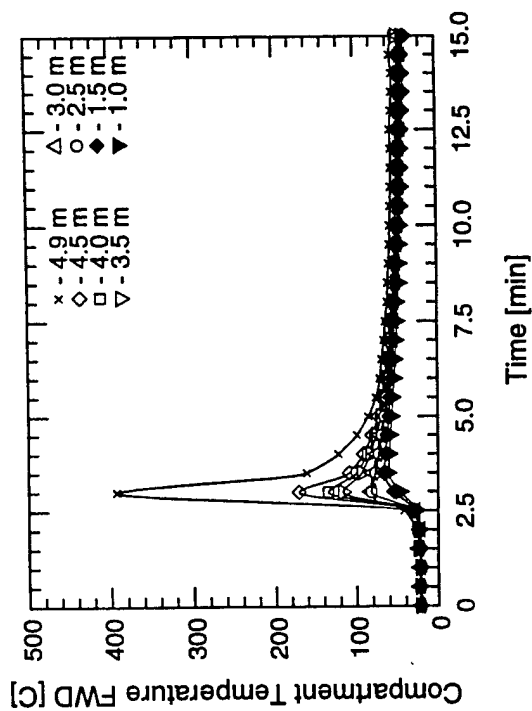
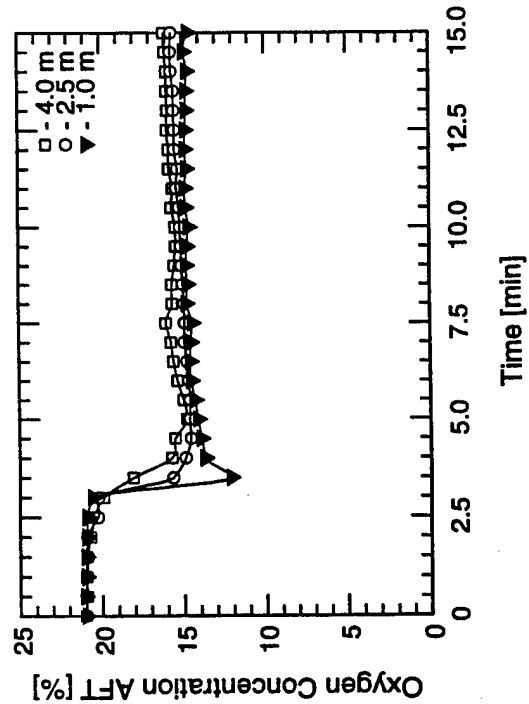
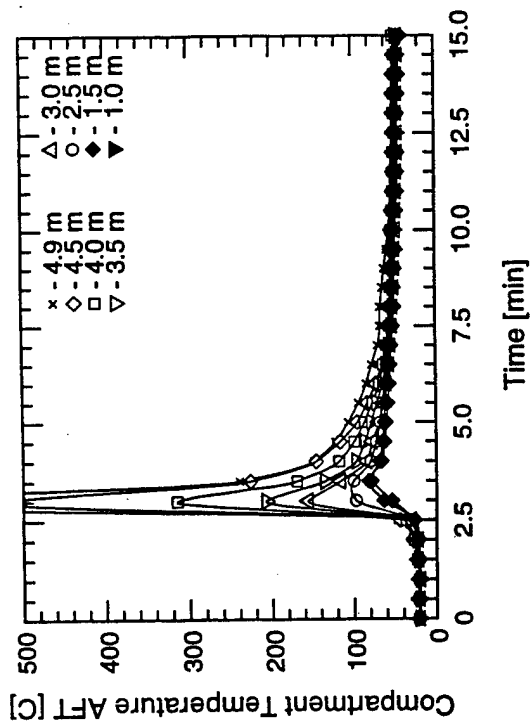
Test #23



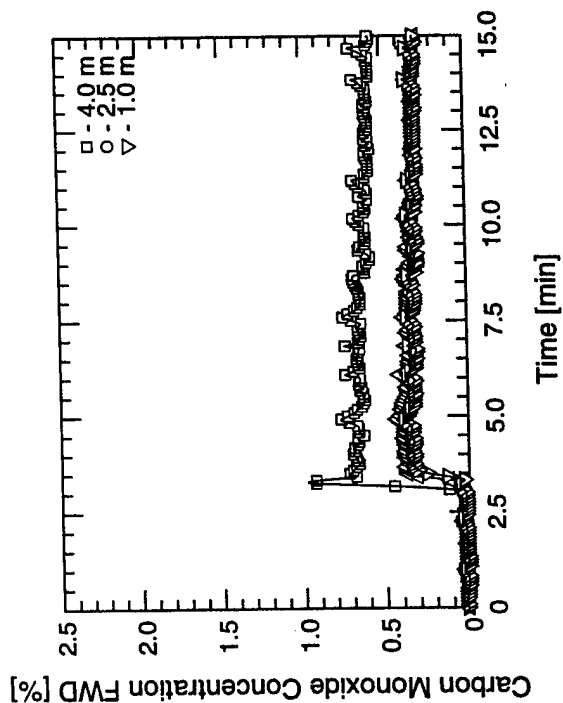
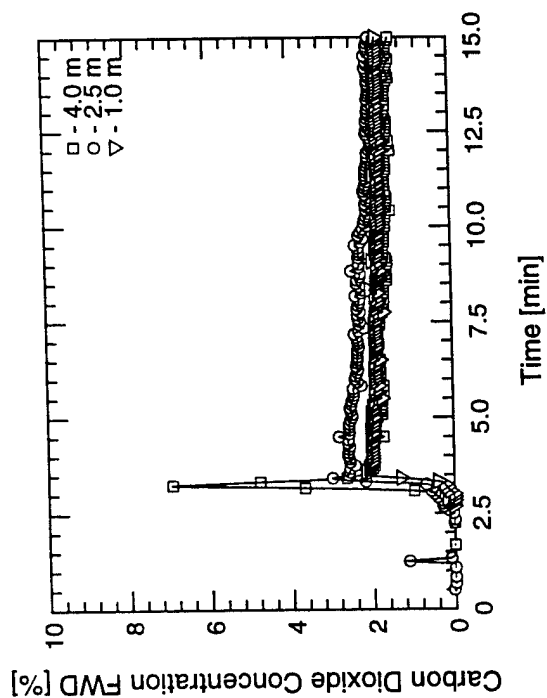
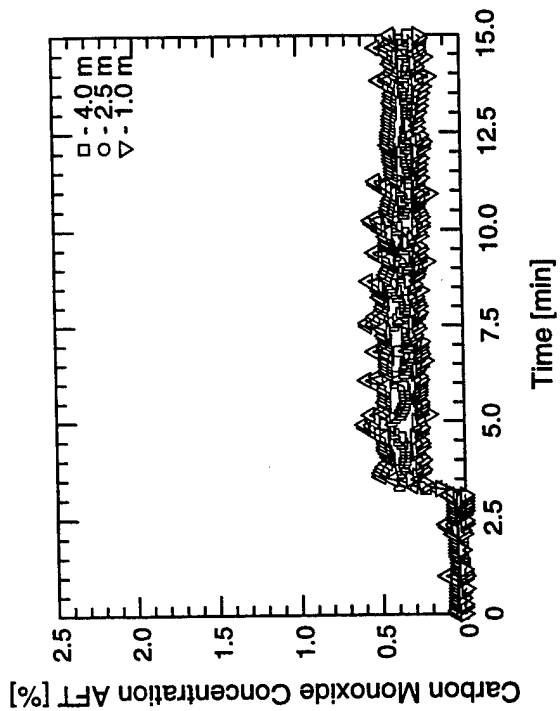
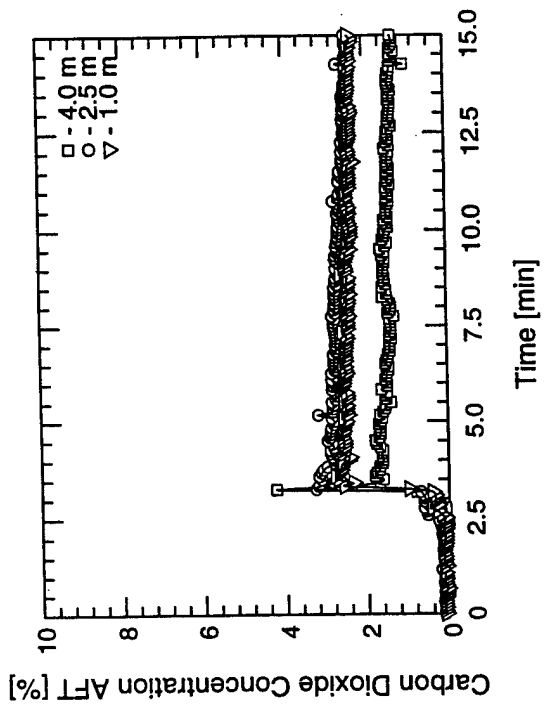
Test #23

Test #23

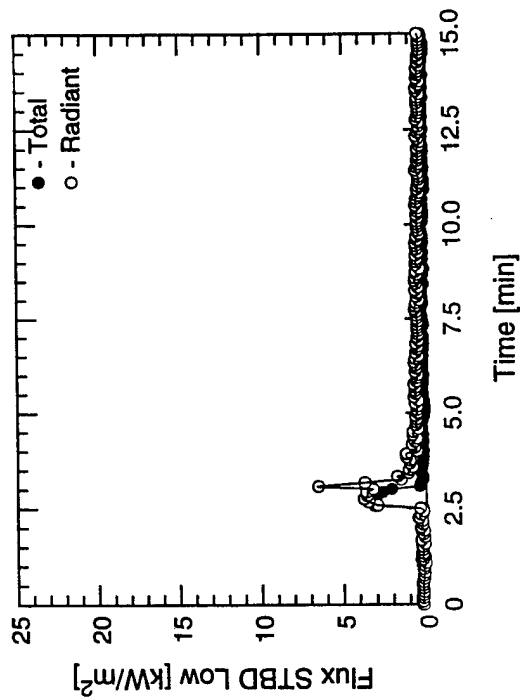
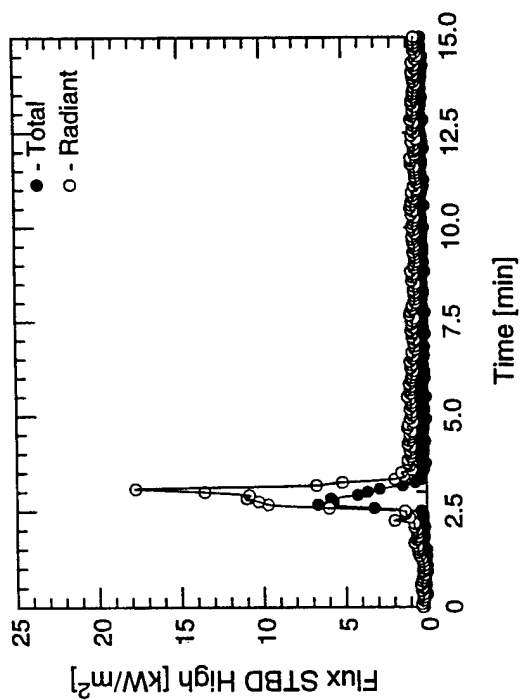
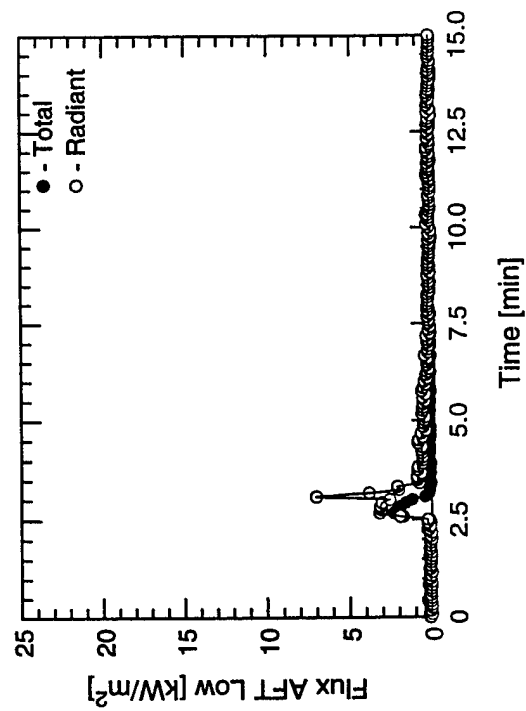
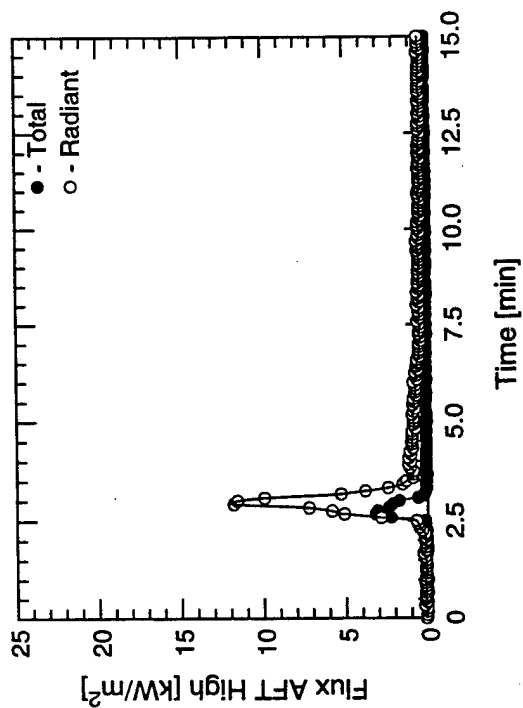




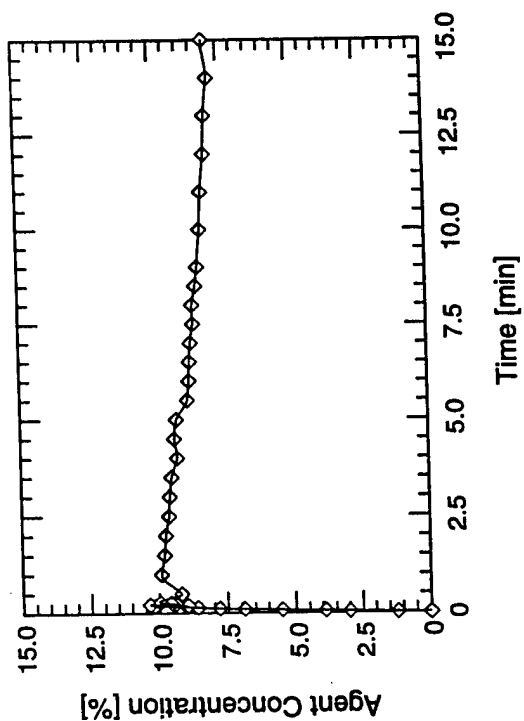
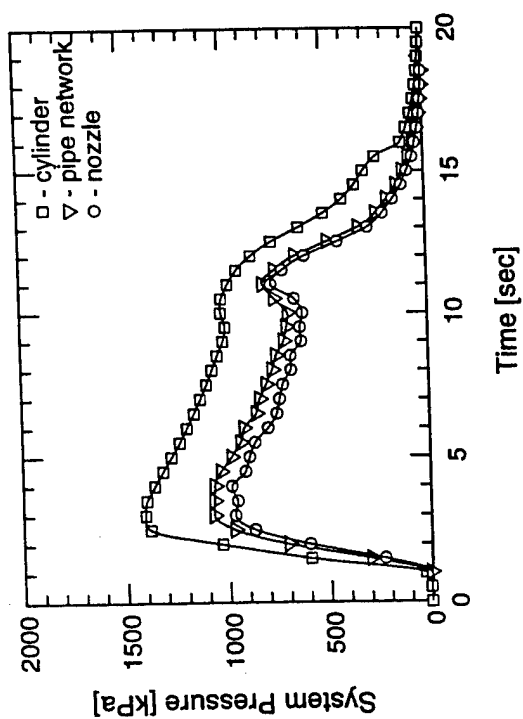
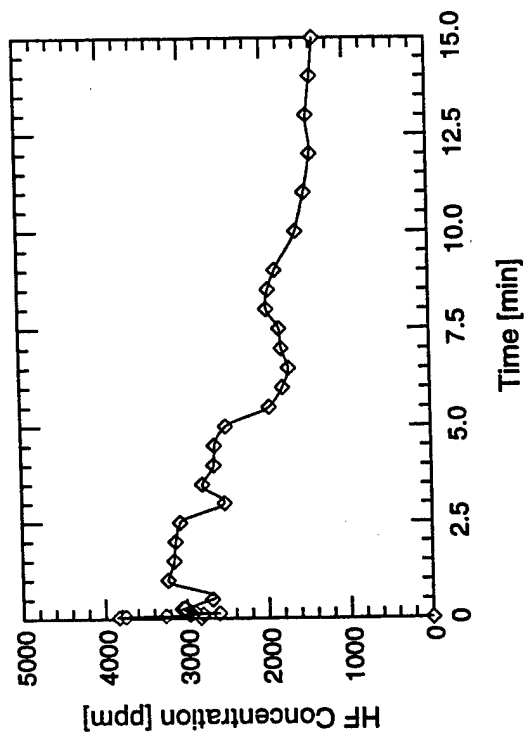
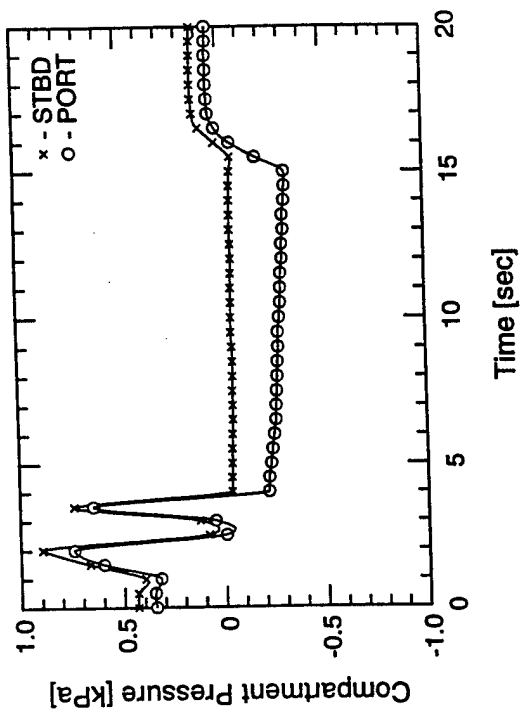
Test #24



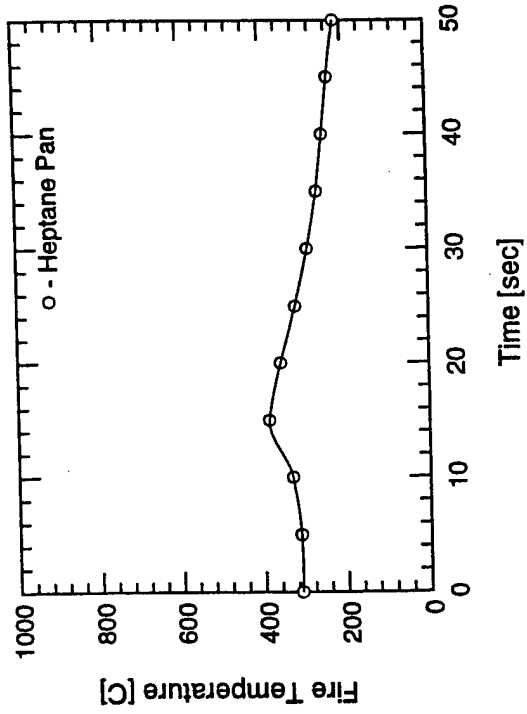
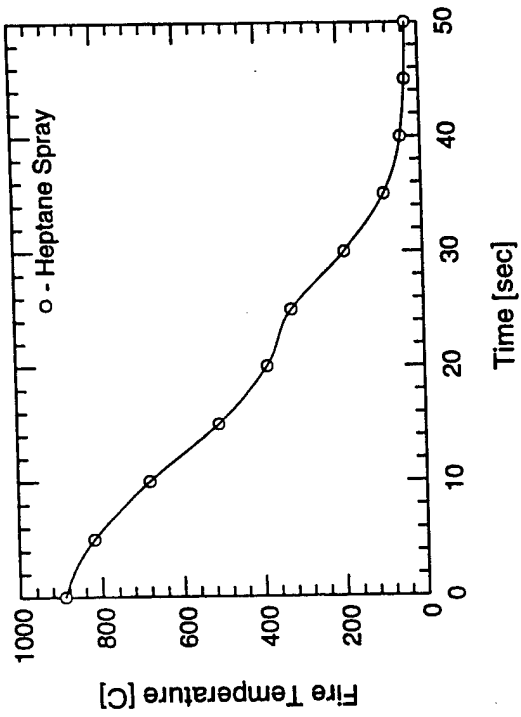
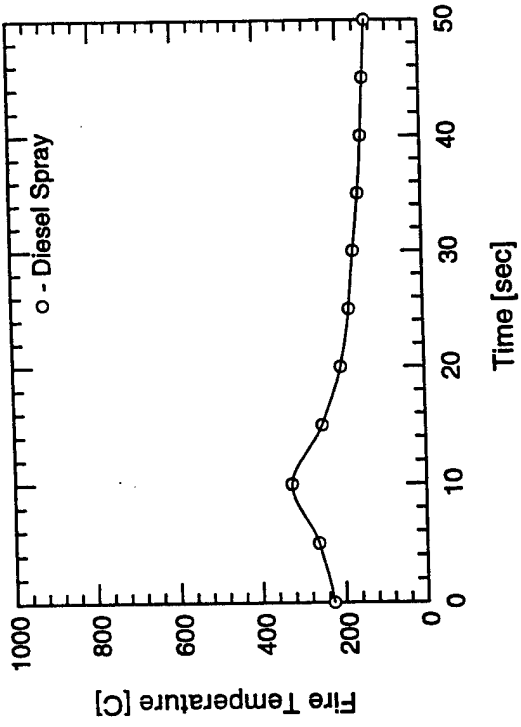
Test #24



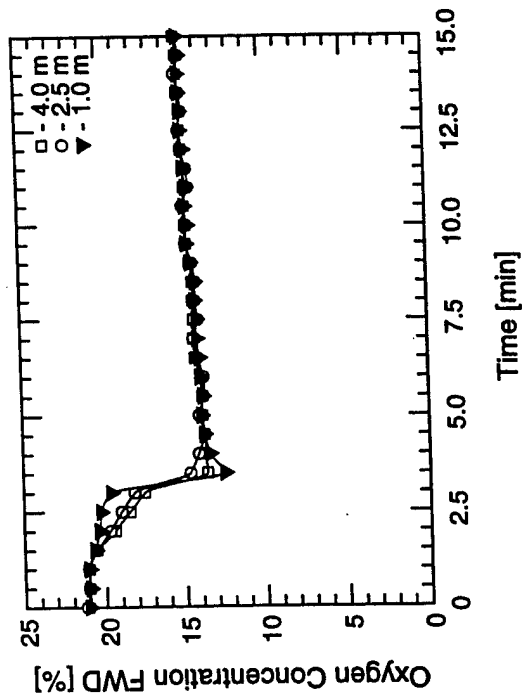
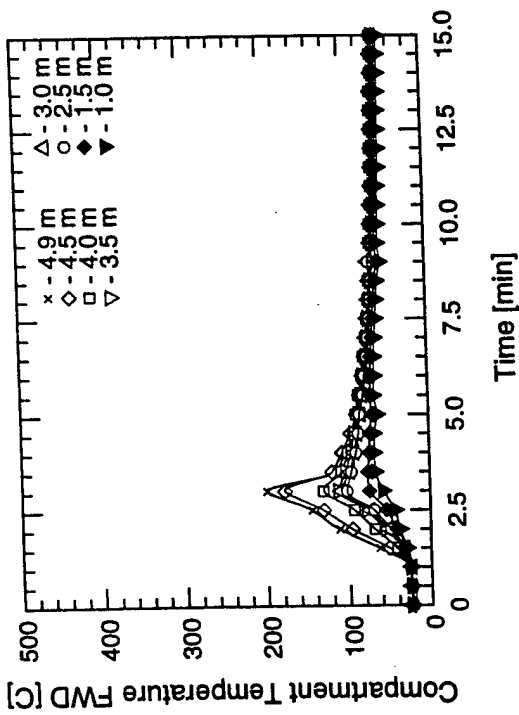
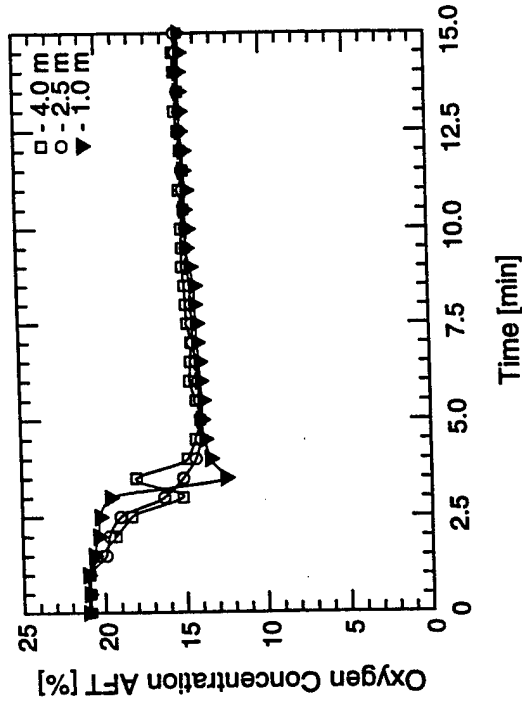
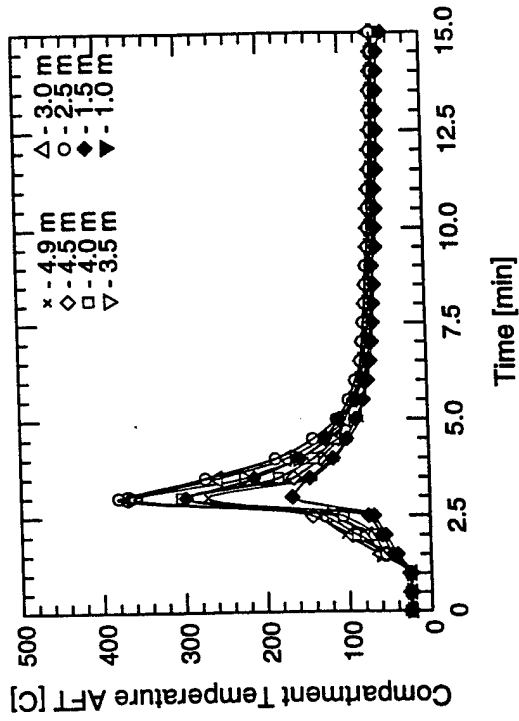
Test #24



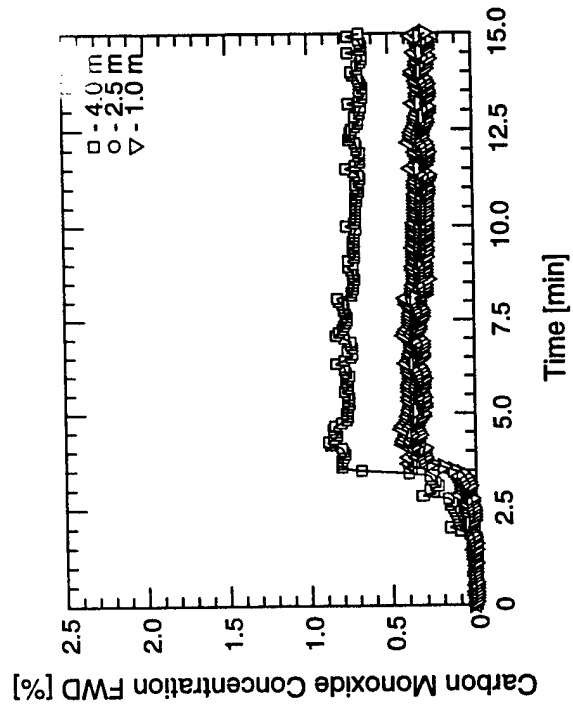
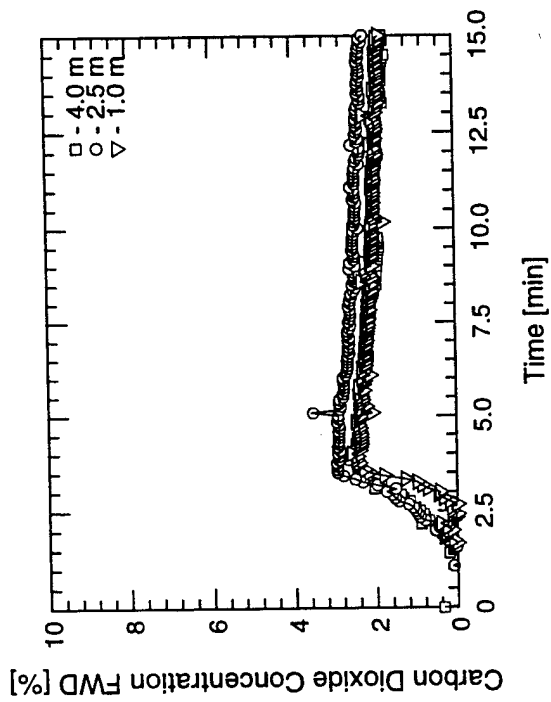
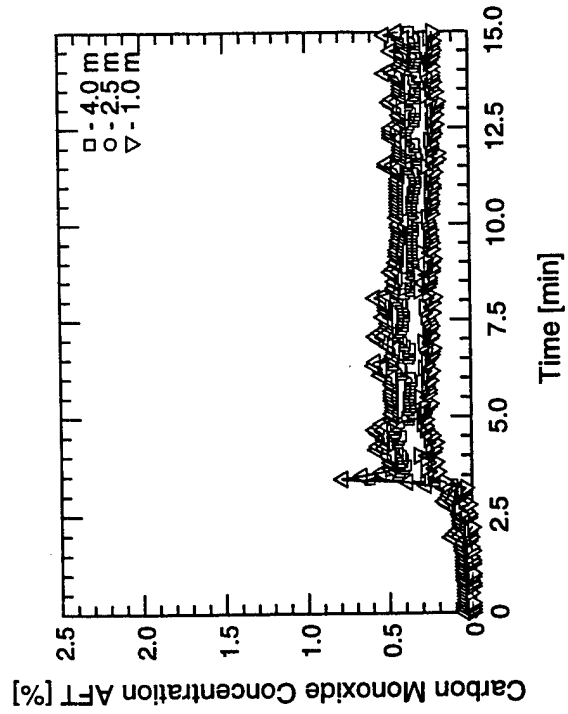
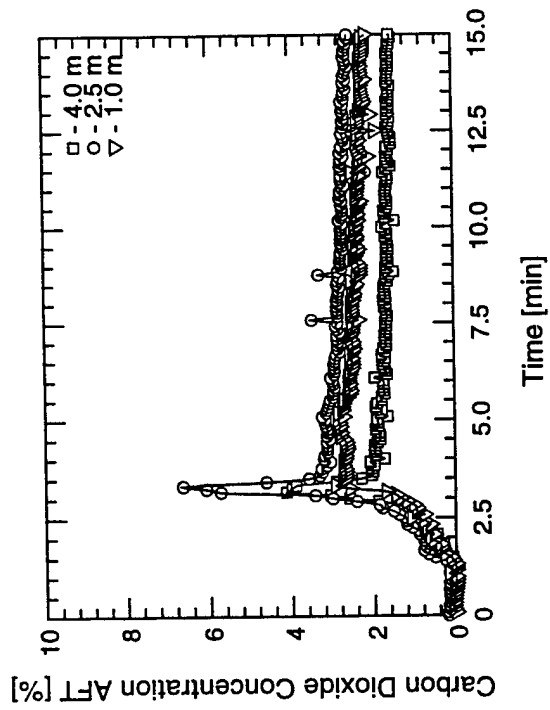
Test #24



Test #24

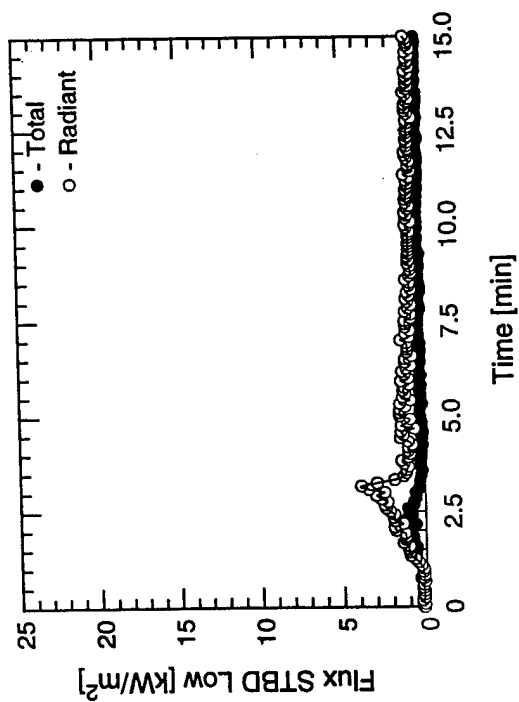
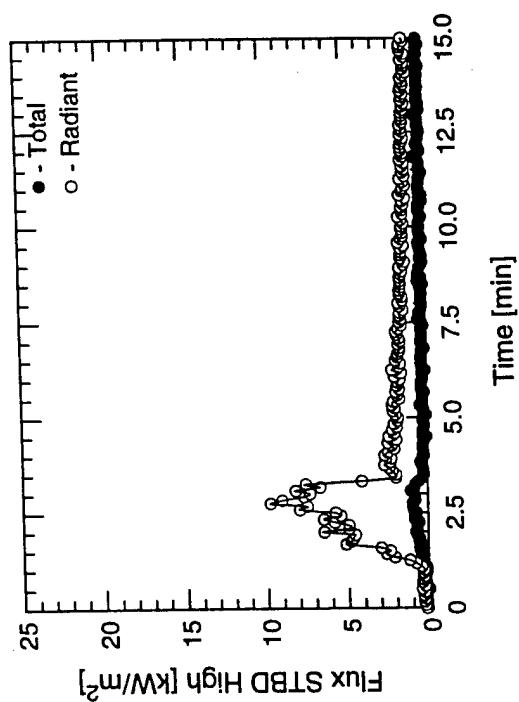
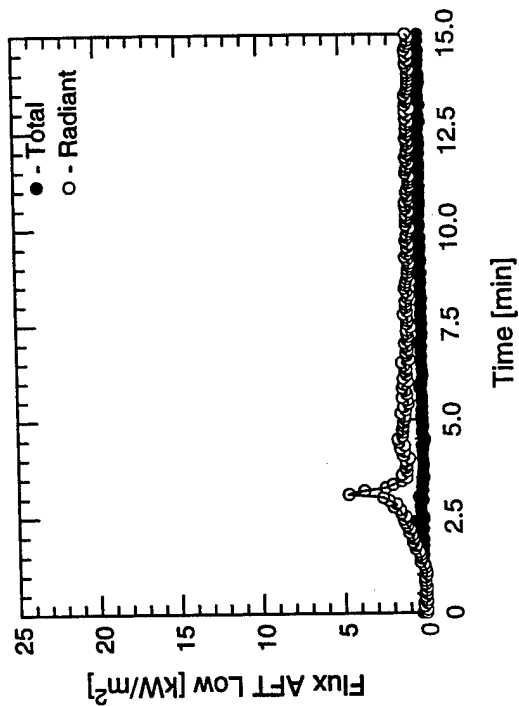
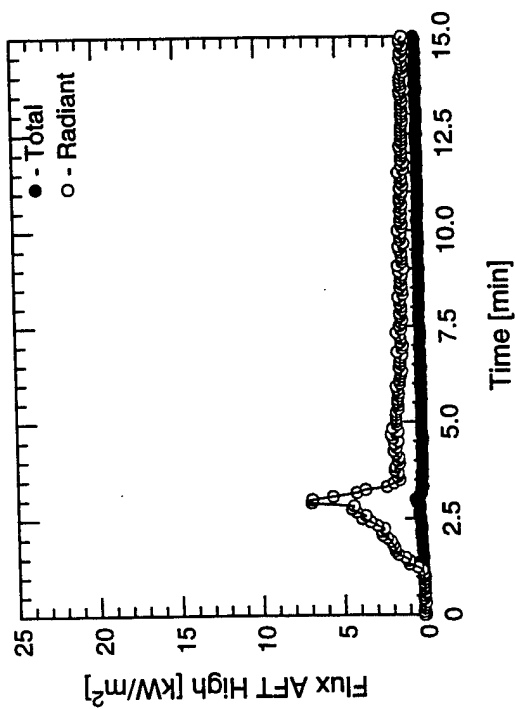


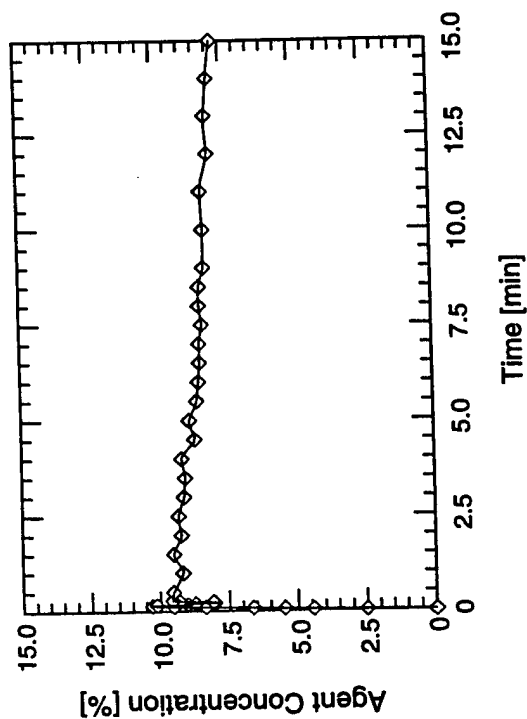
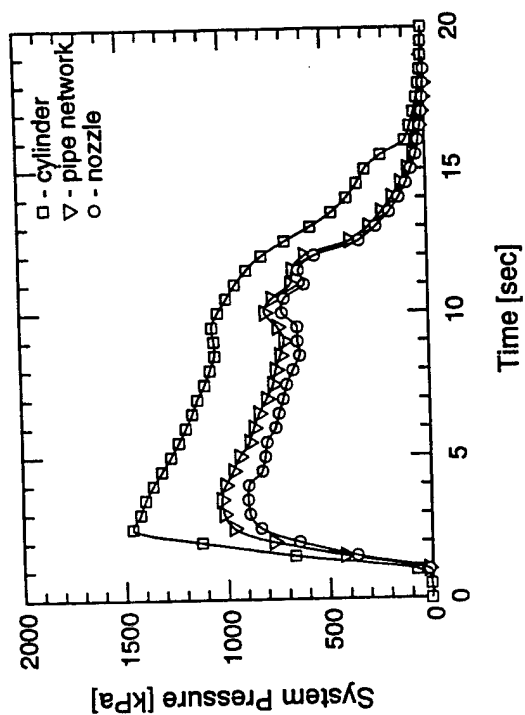
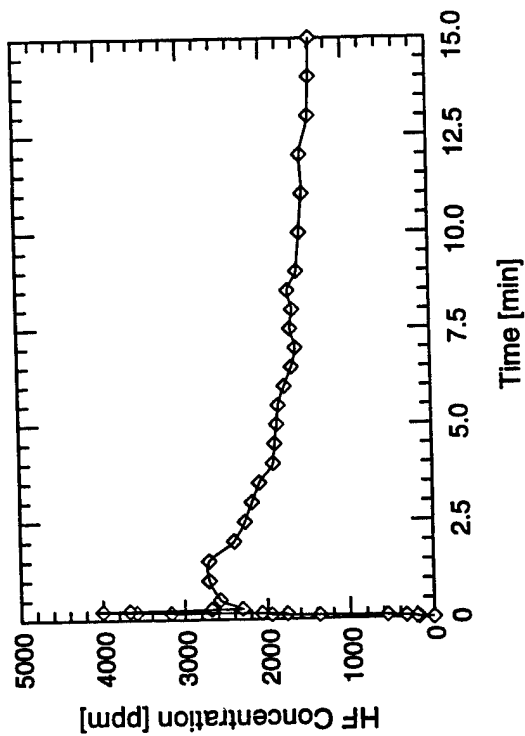
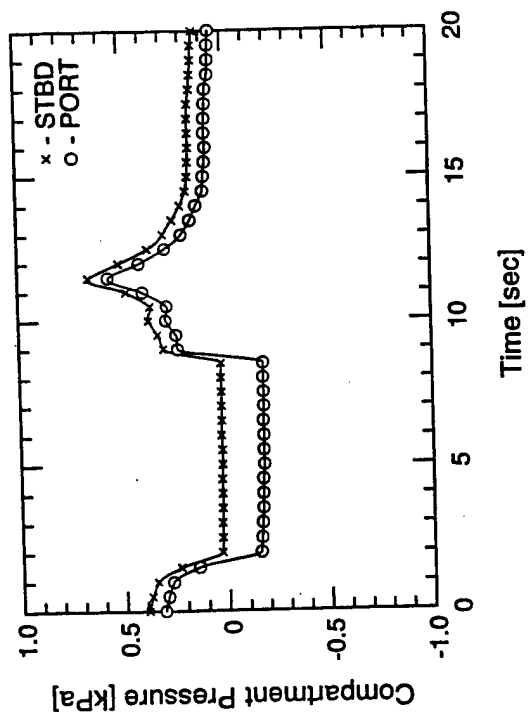
Test #25



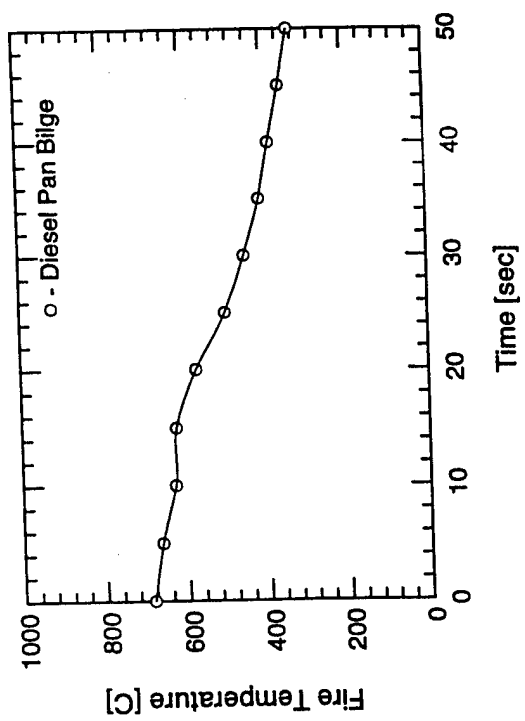
Test #25

Test #25



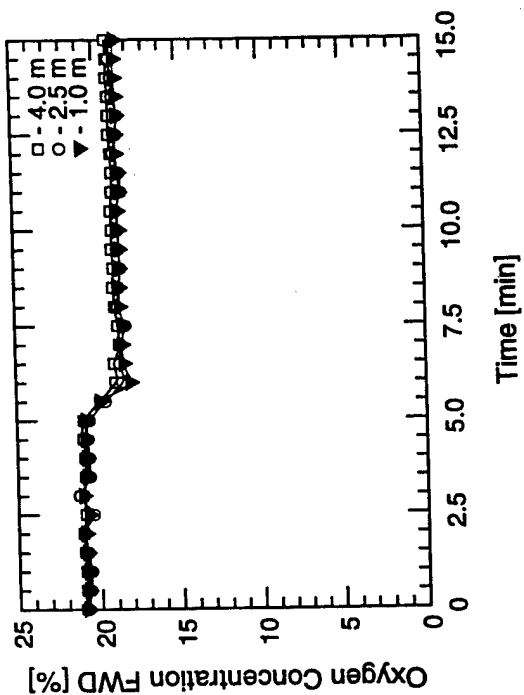
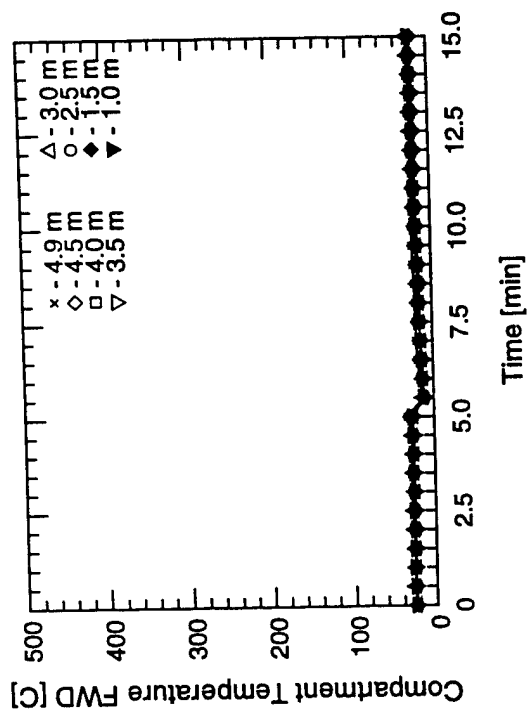
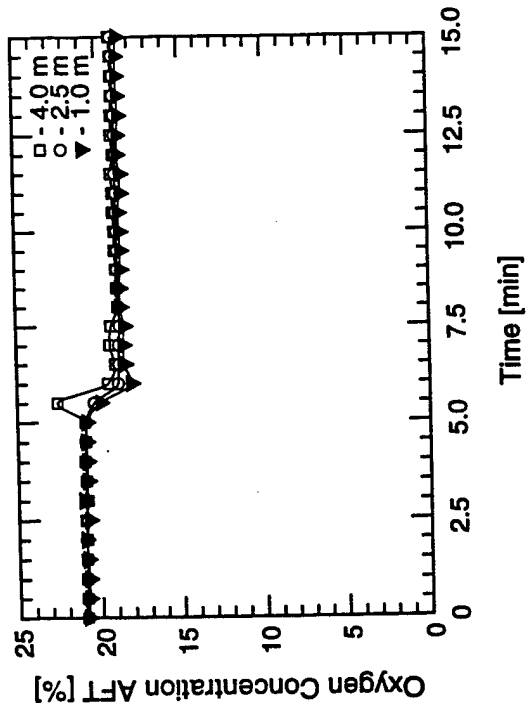
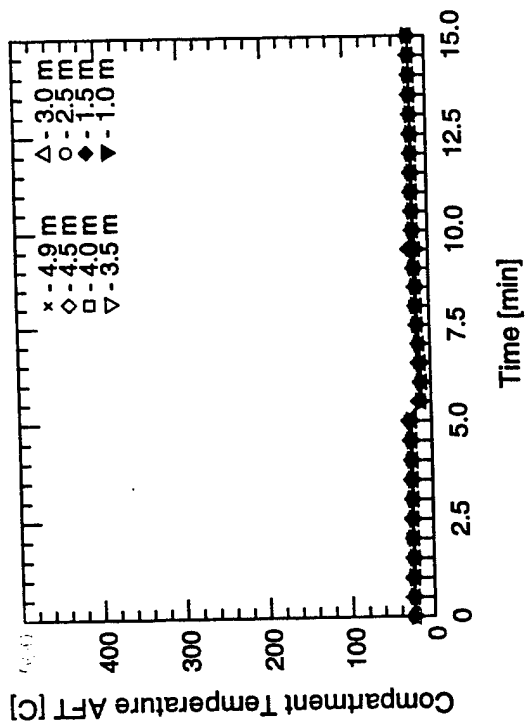


Test #25



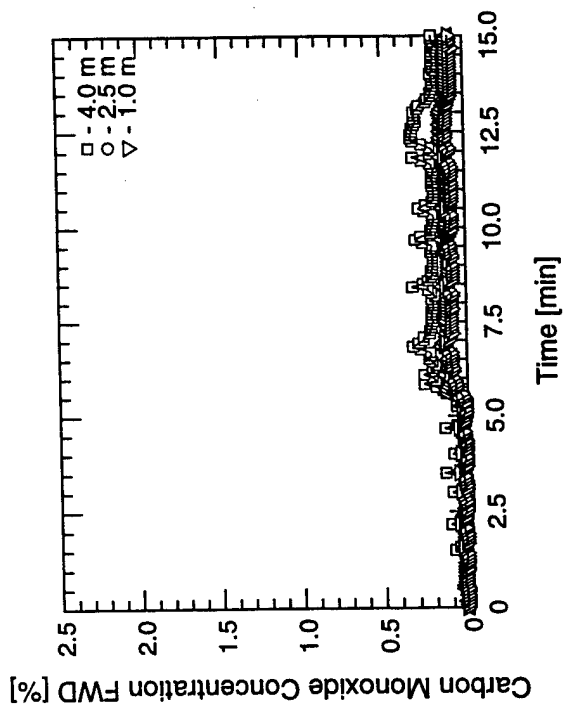
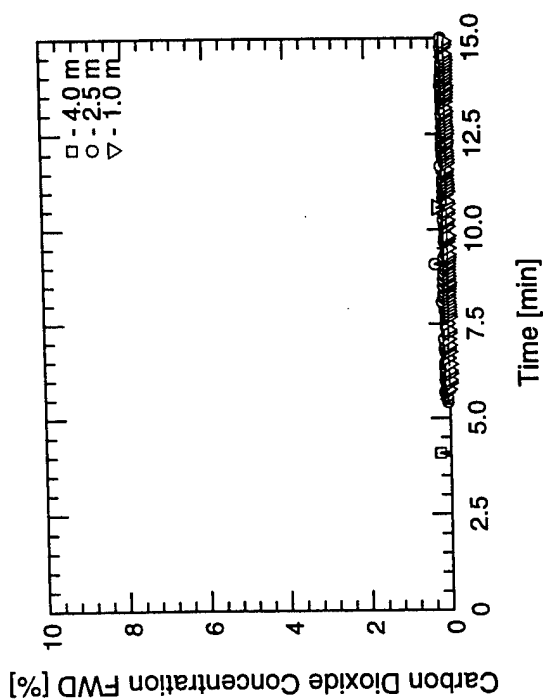
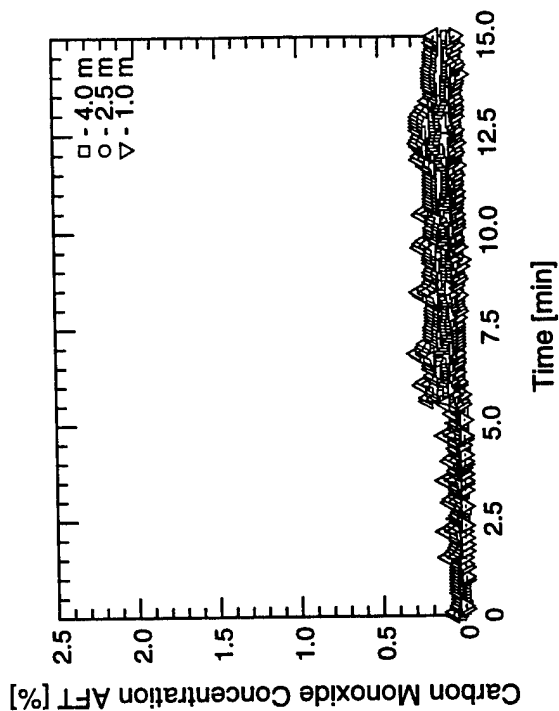
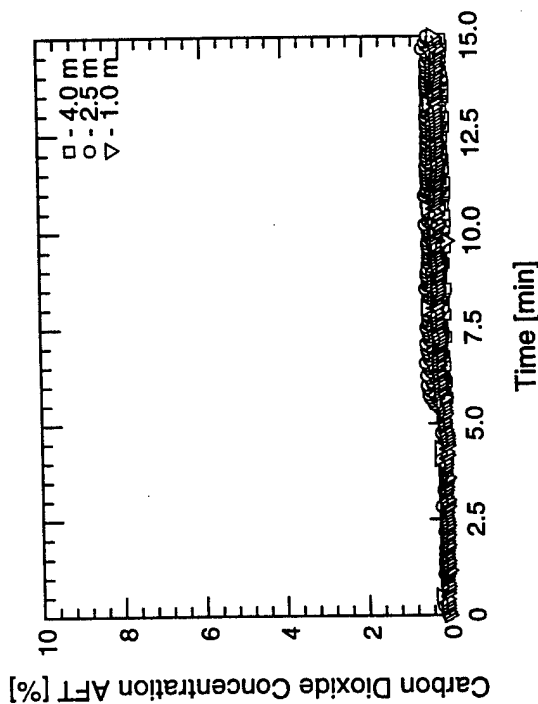
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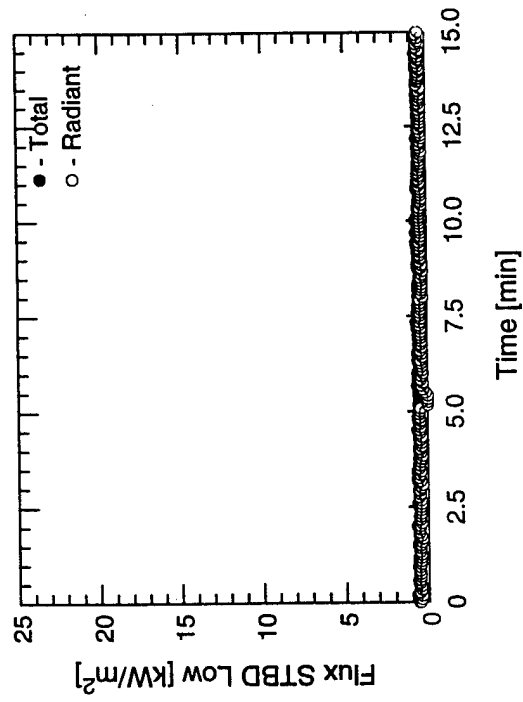
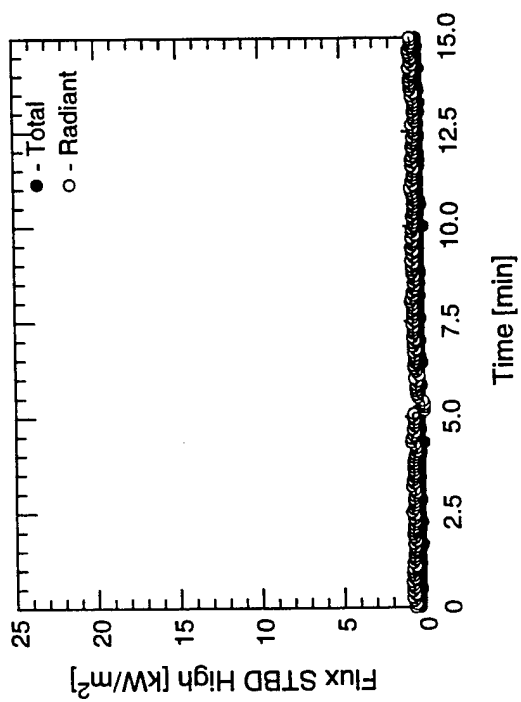
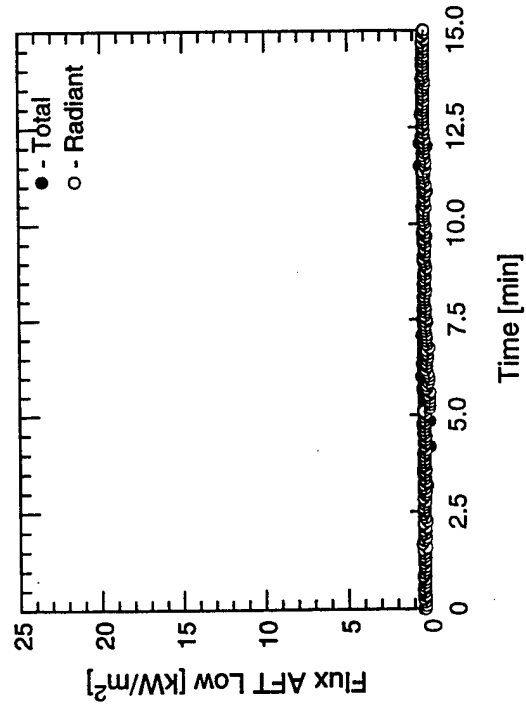
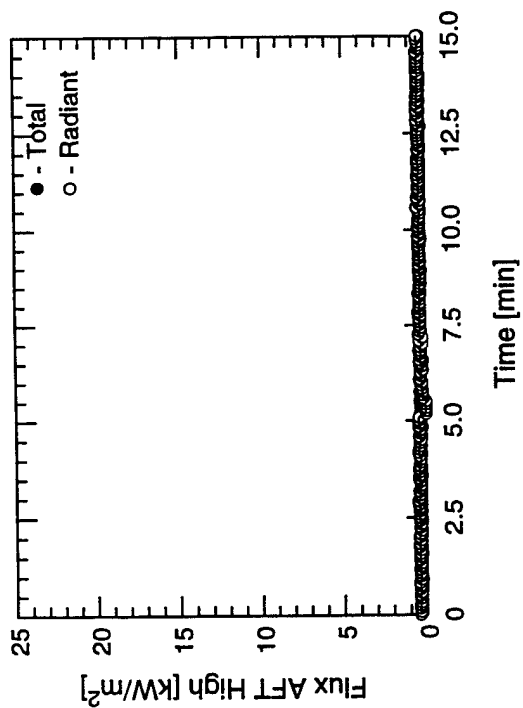
Test #25



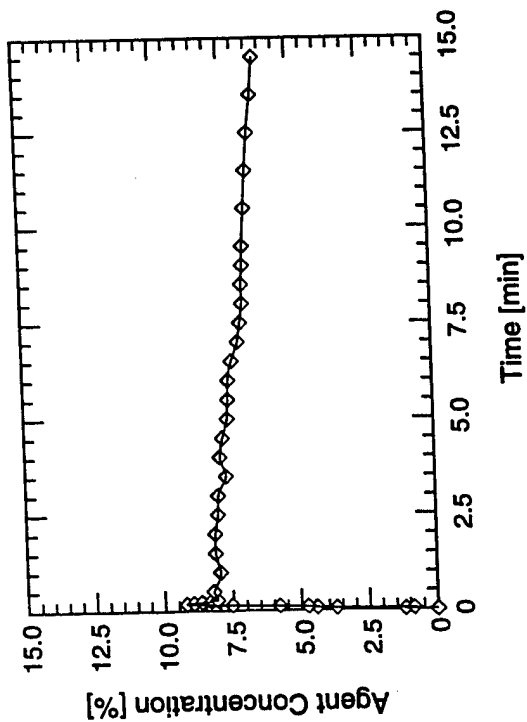
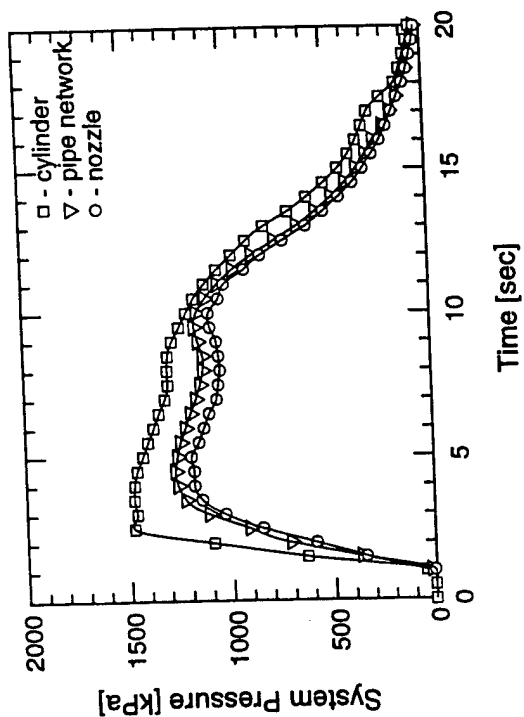
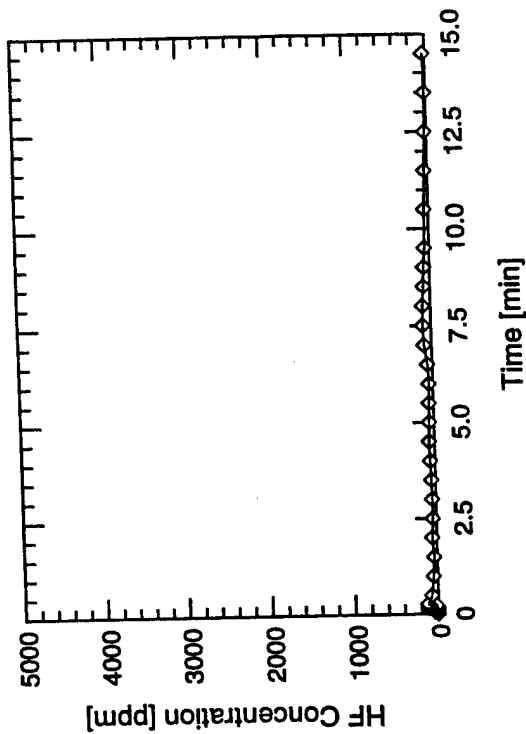
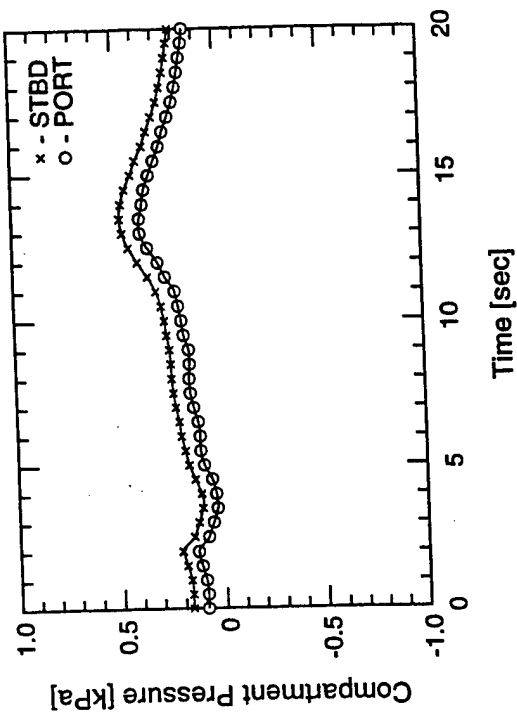
Test #26

Test #26

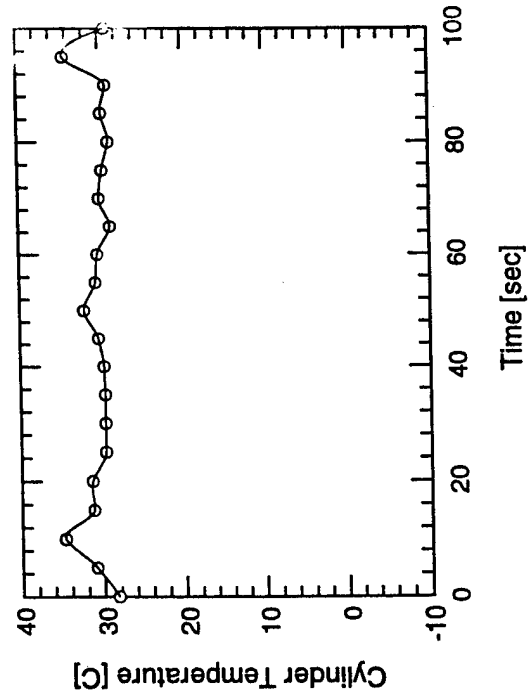
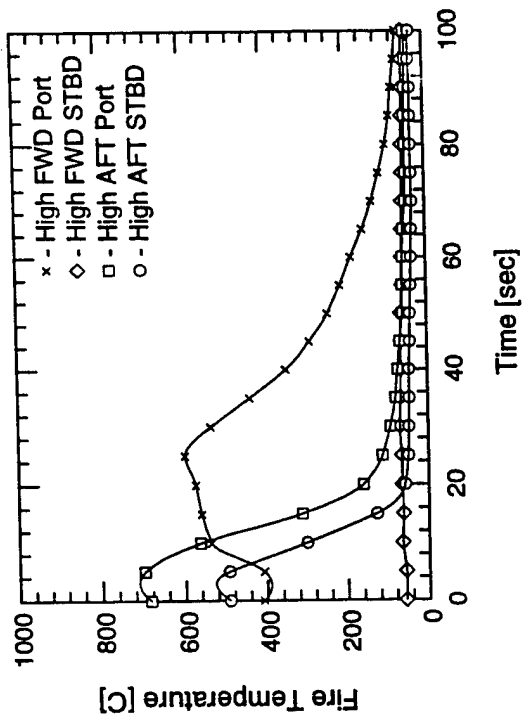
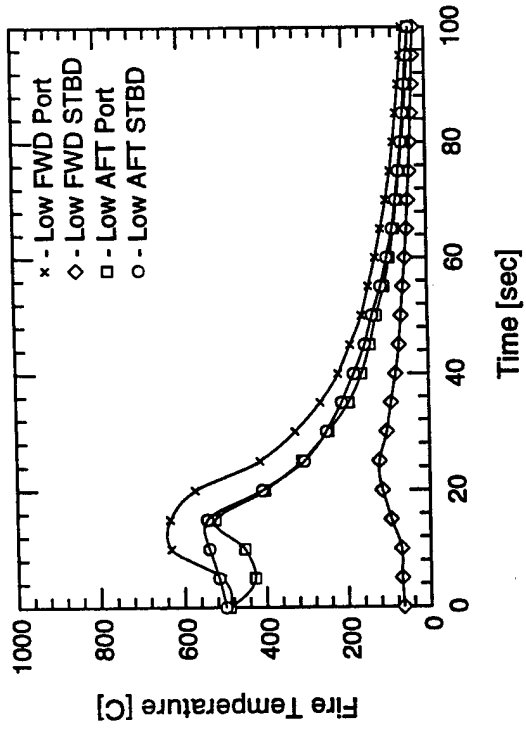




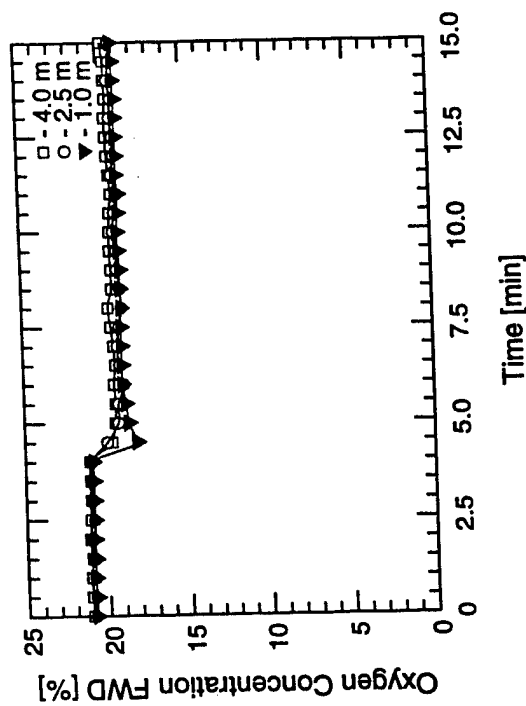
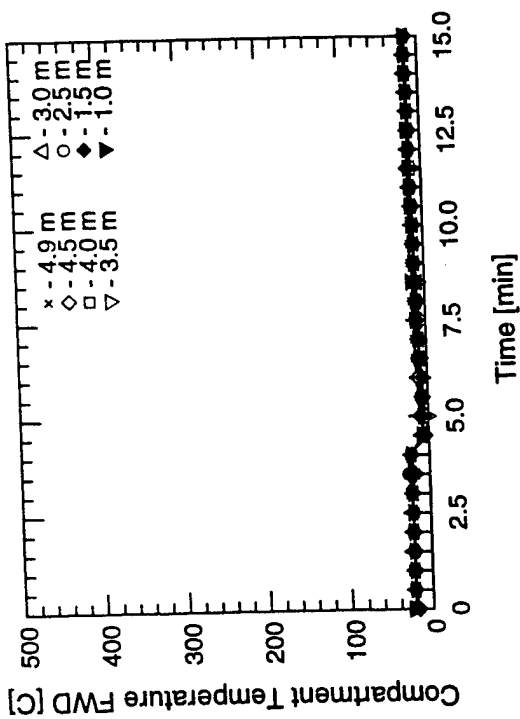
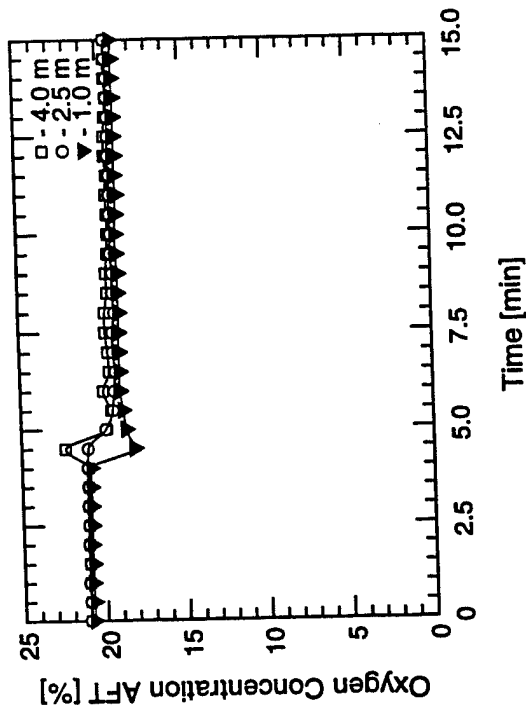
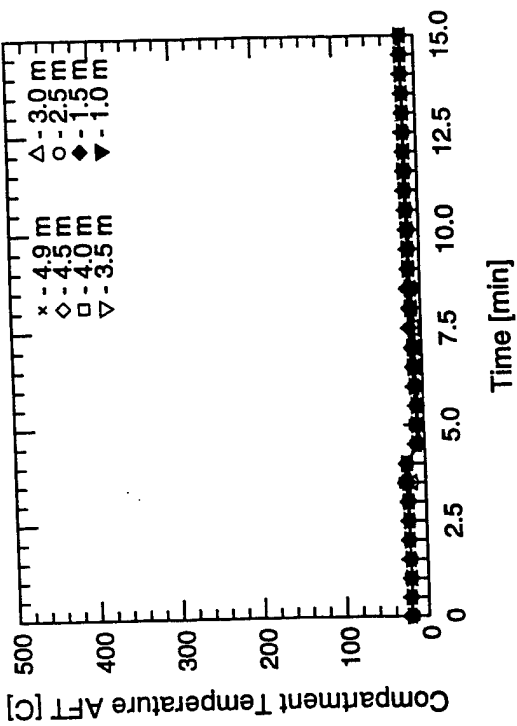
Test #26



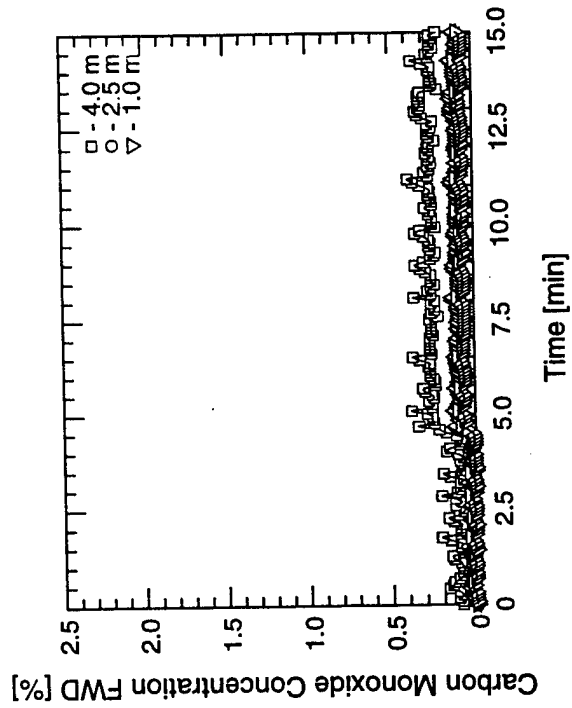
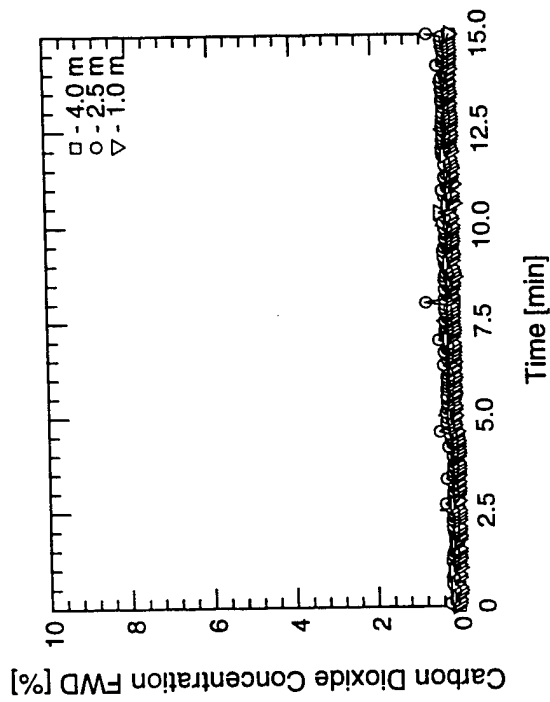
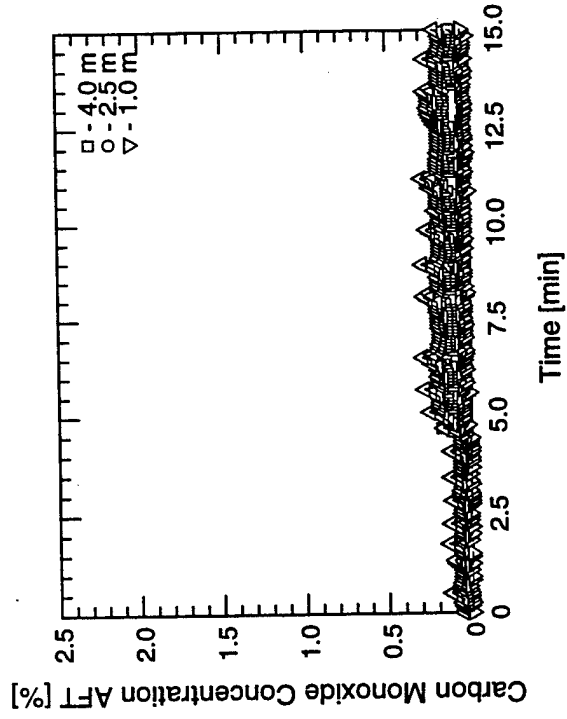
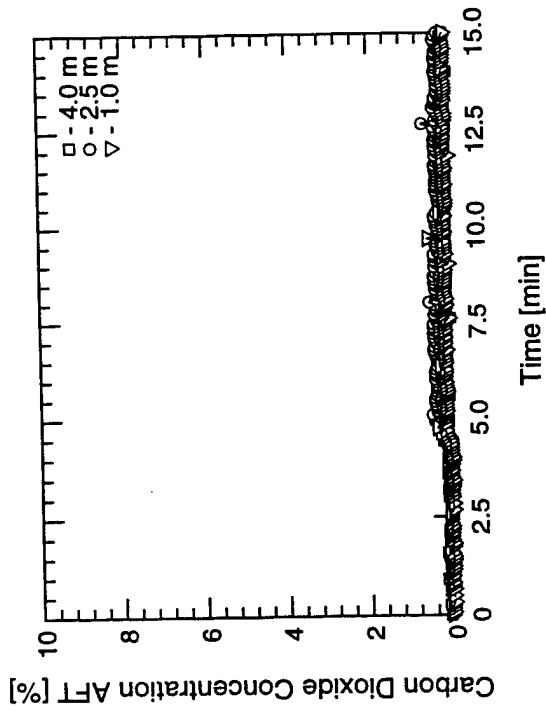
Test #26



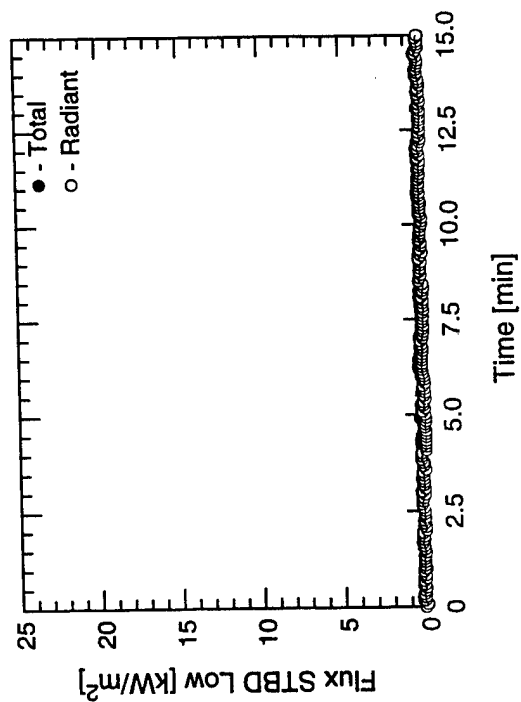
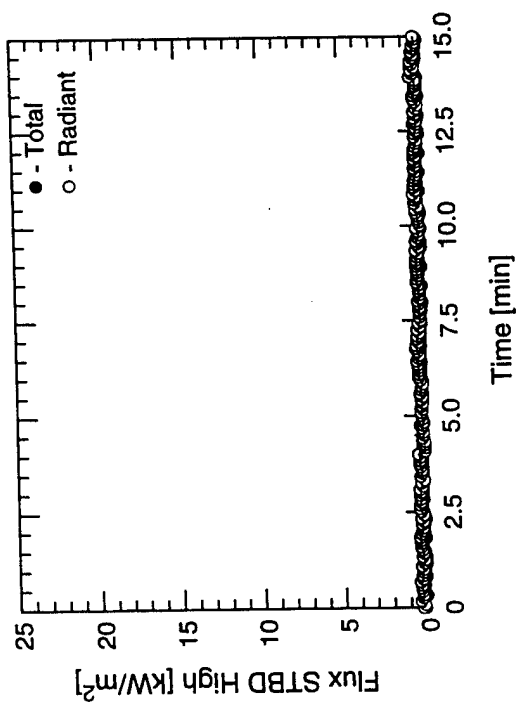
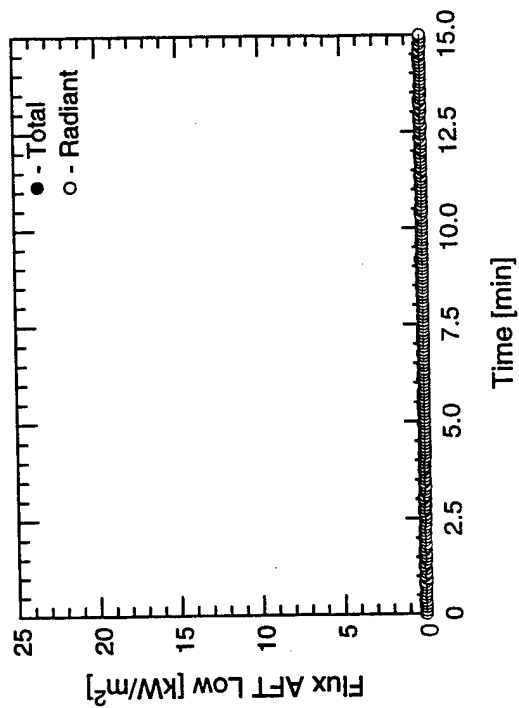
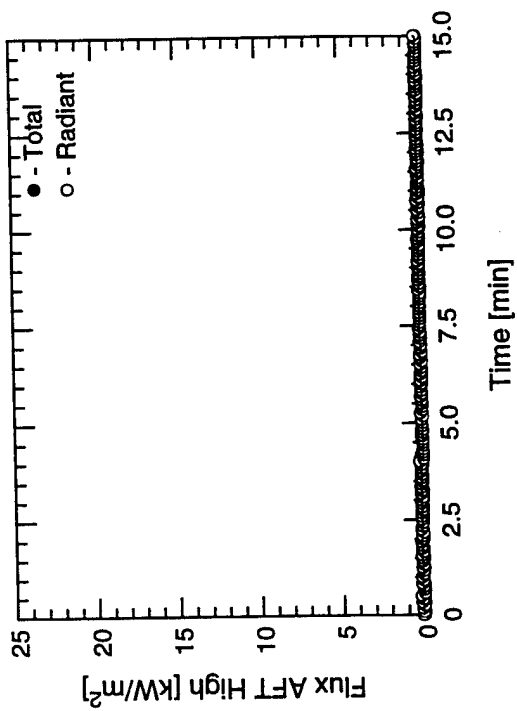
Test #26



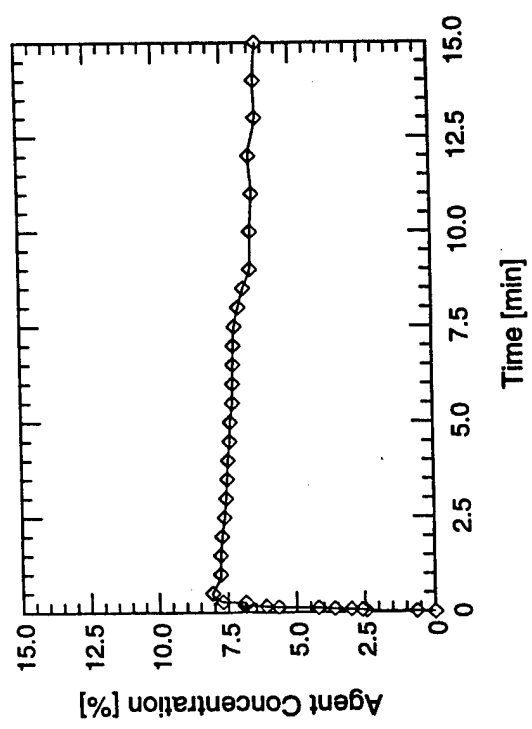
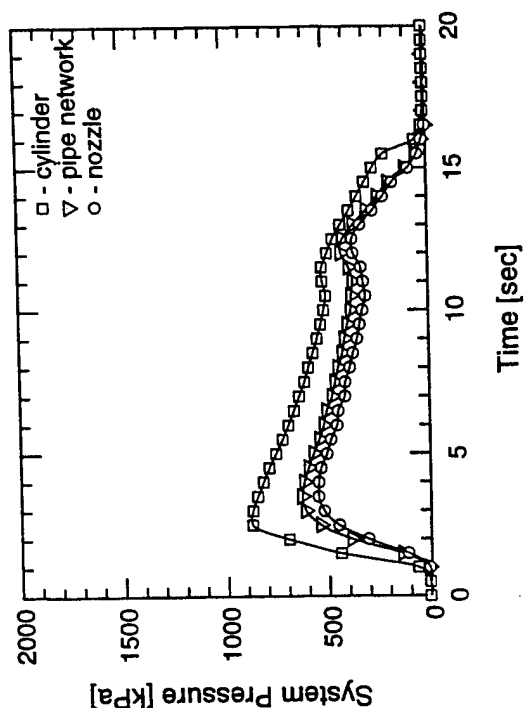
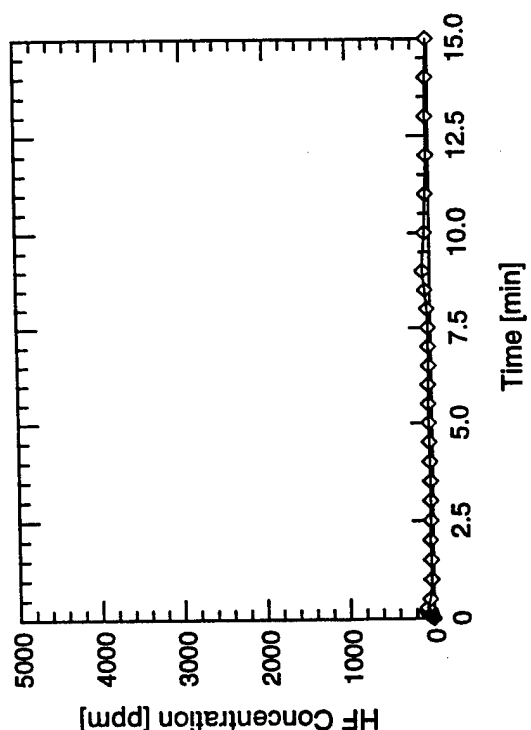
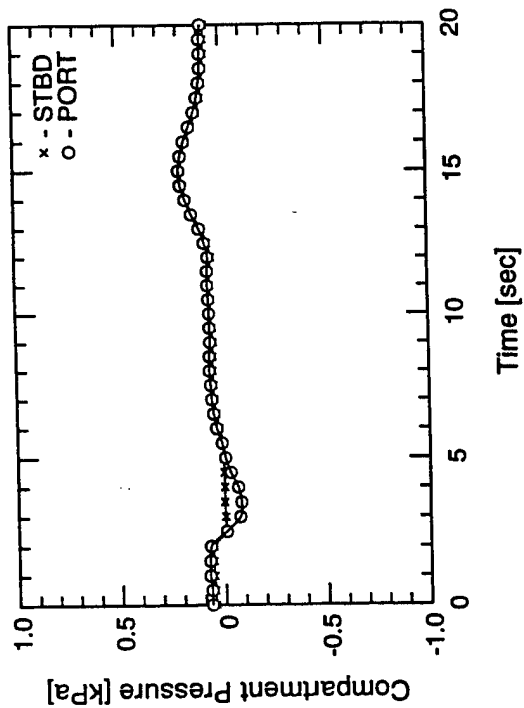
Test #27



Test #27



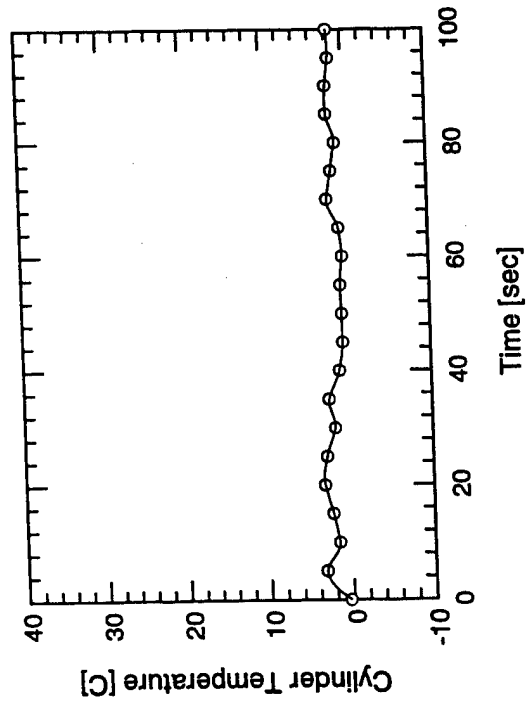
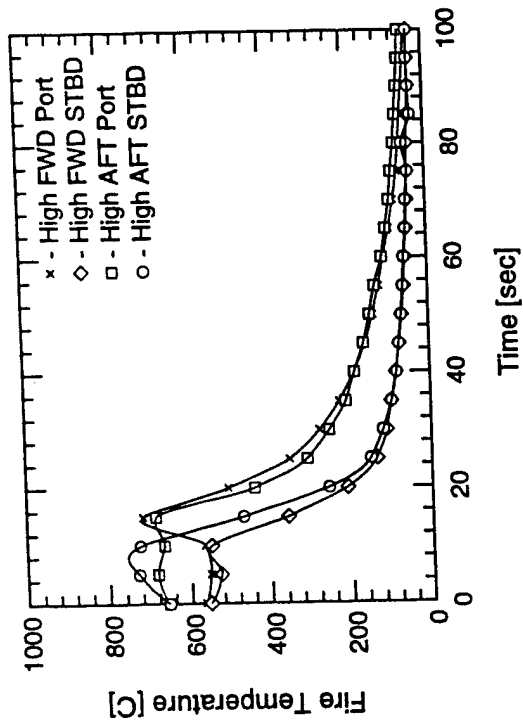
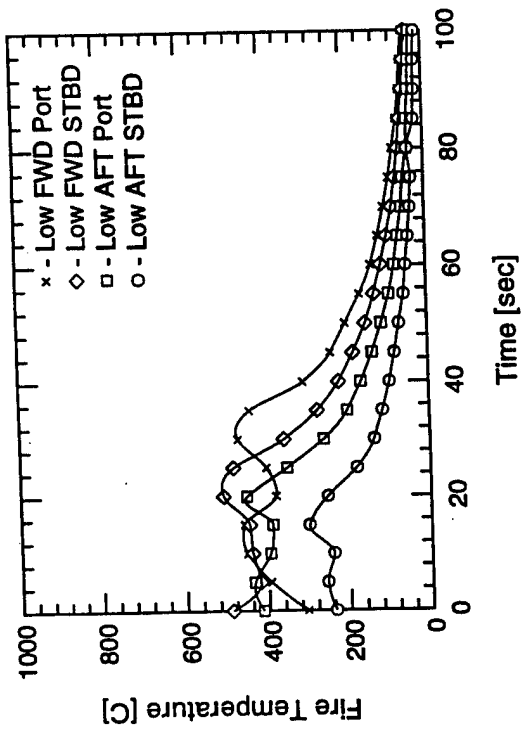
Test #27

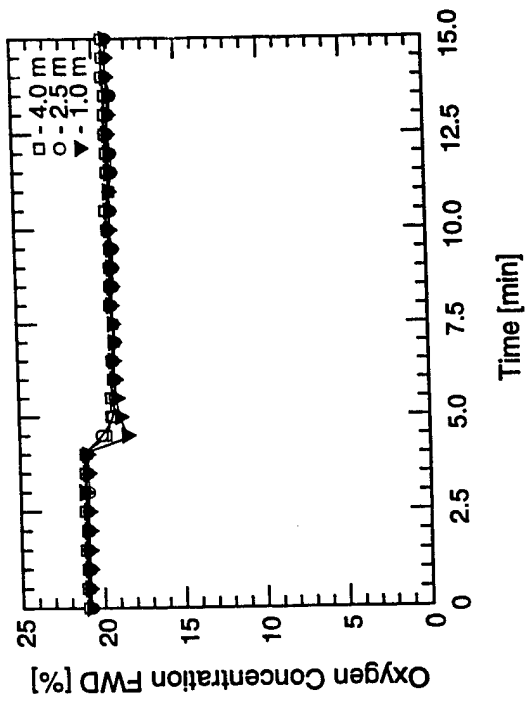
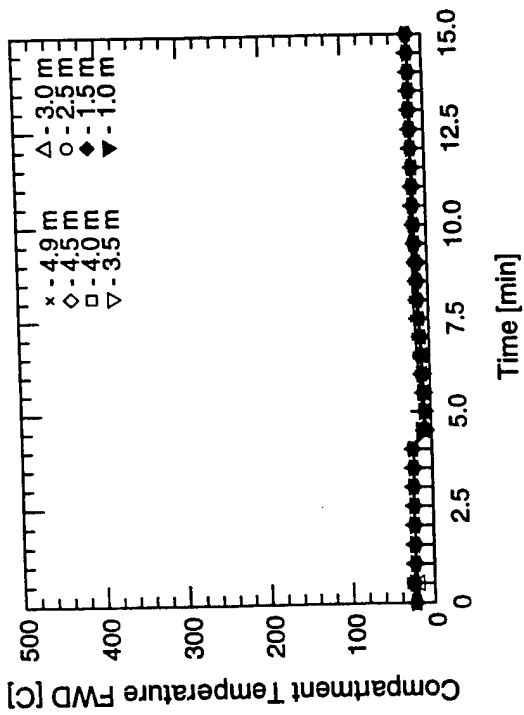
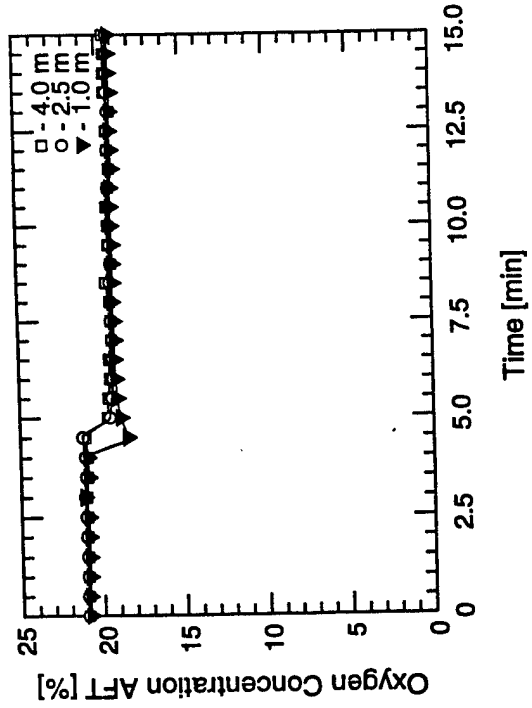
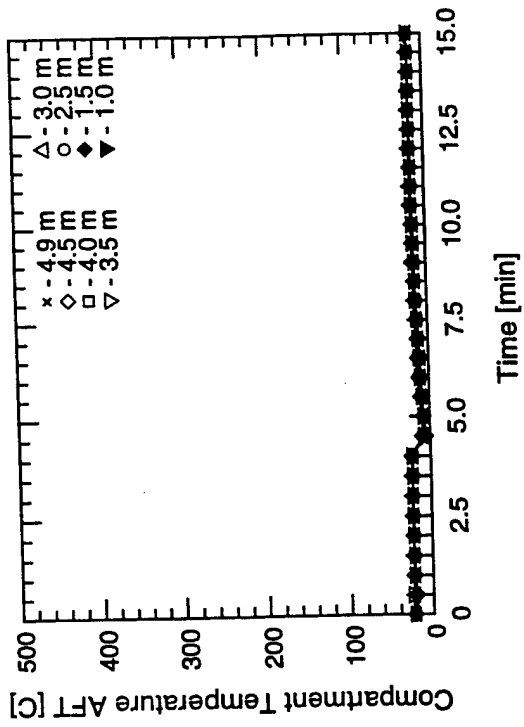


Test #27

Test #27

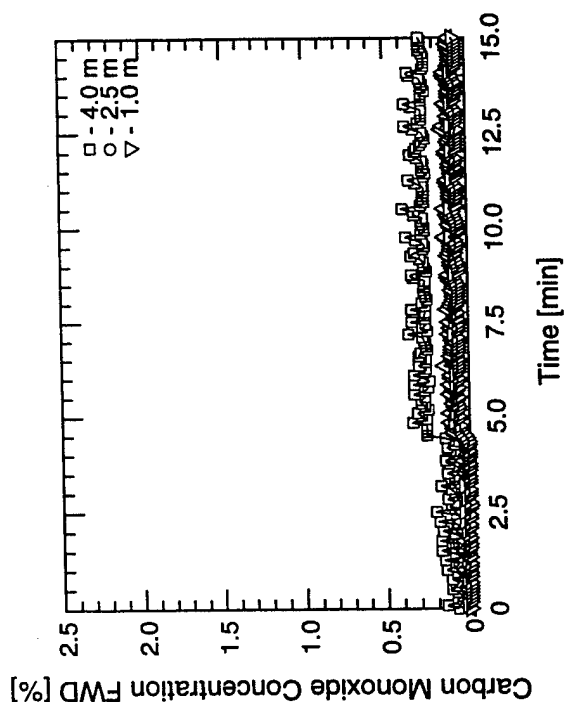
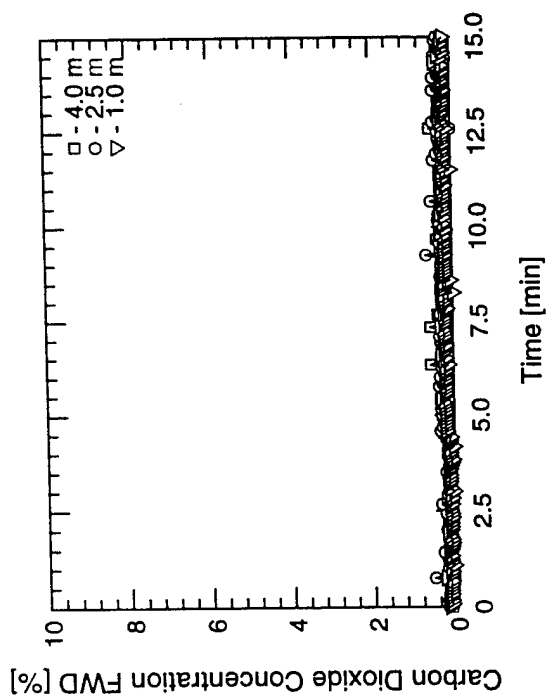
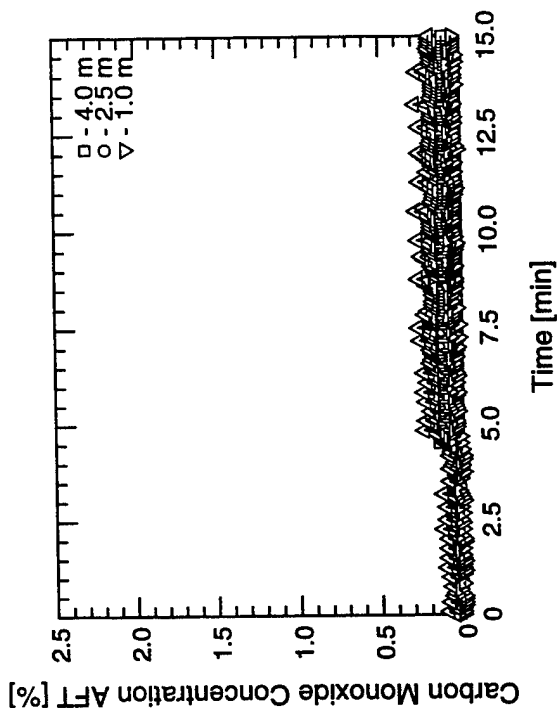
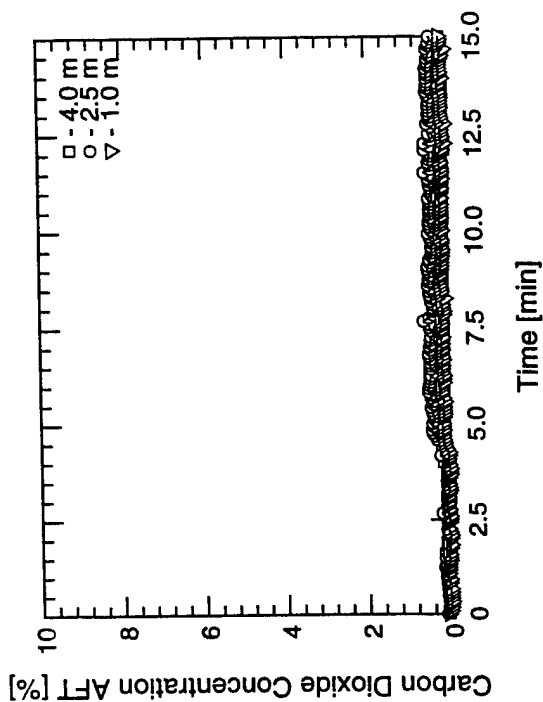
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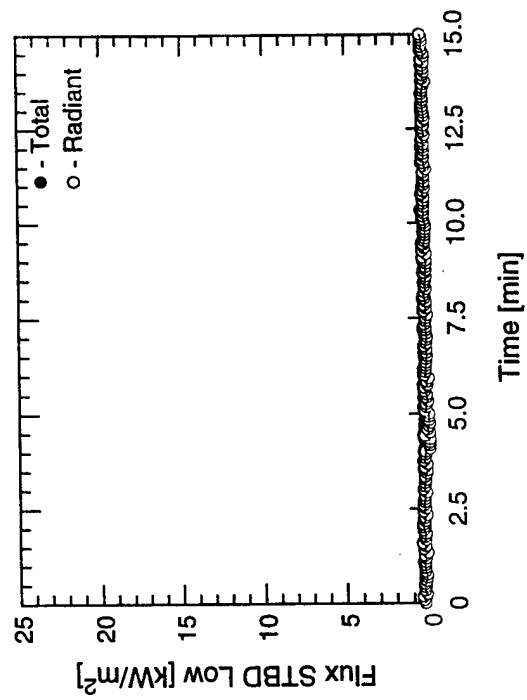
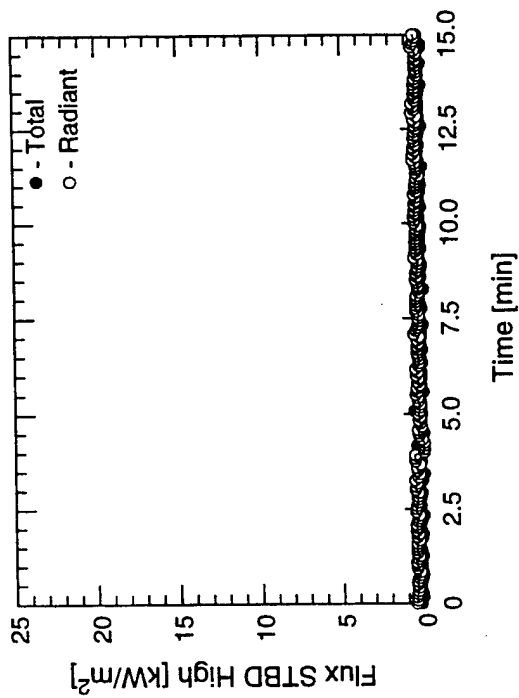
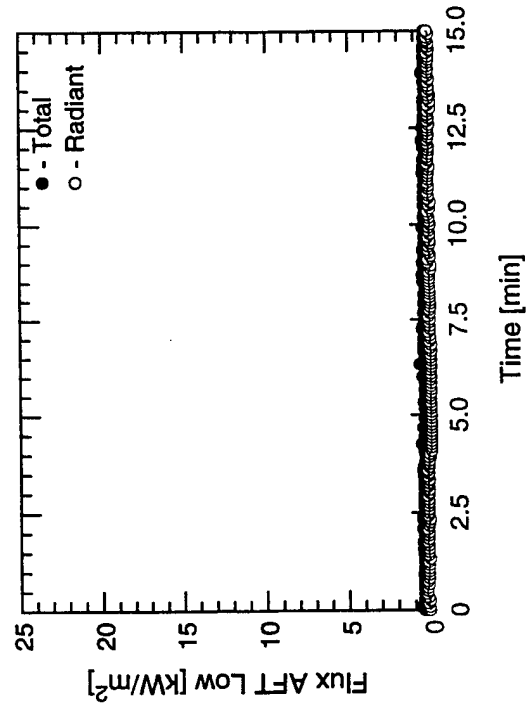
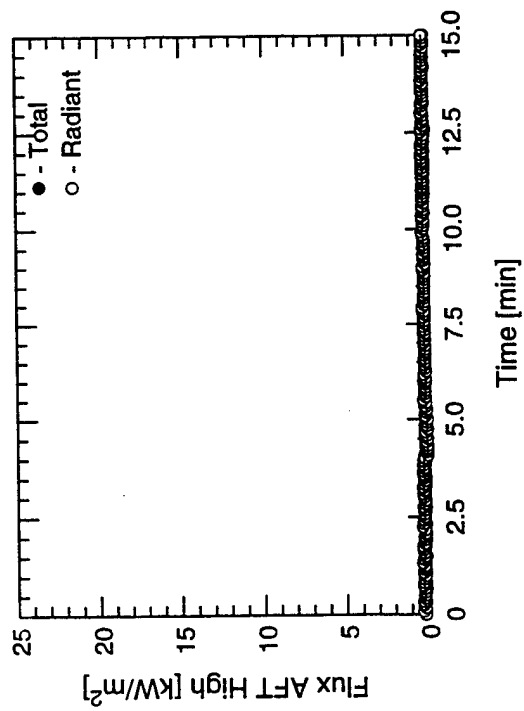




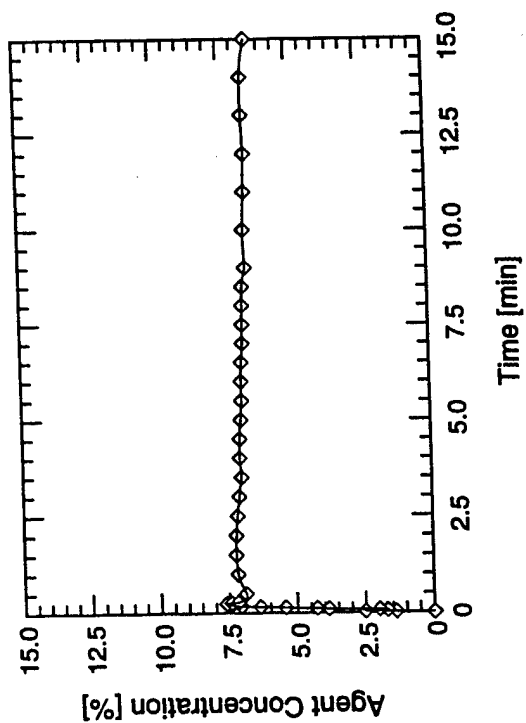
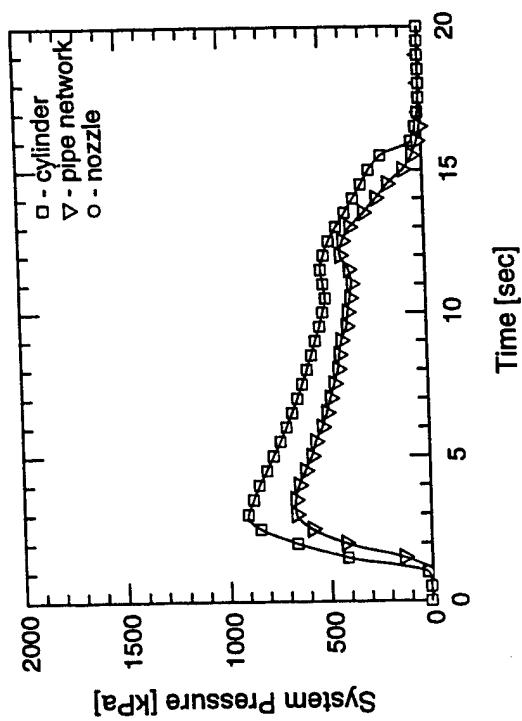
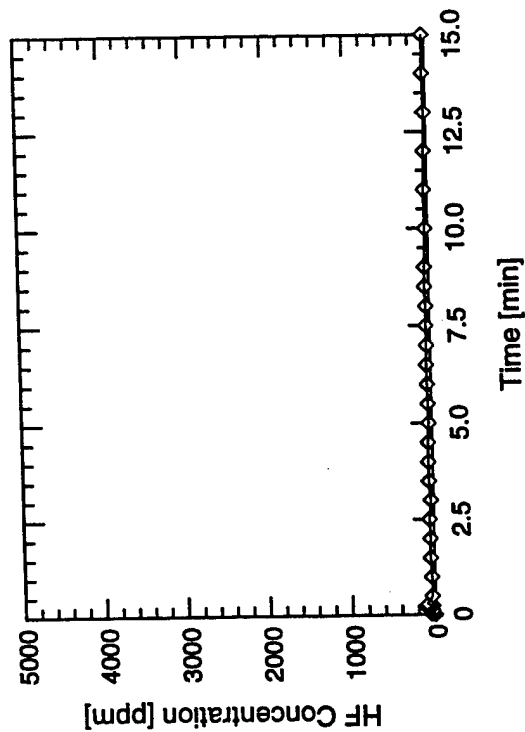
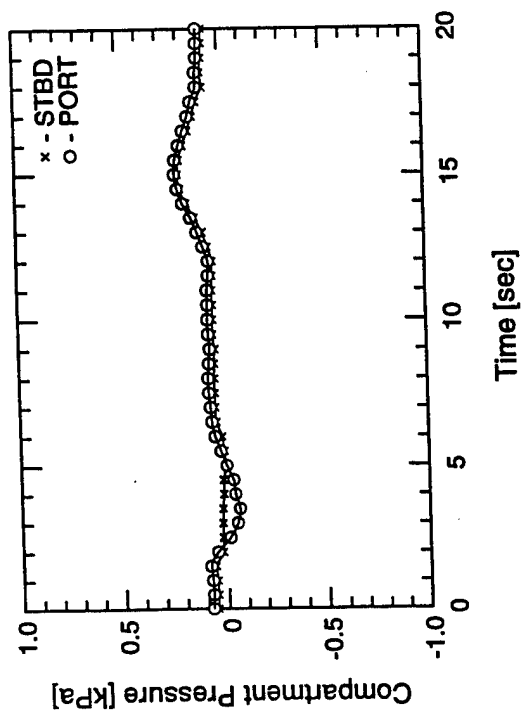
Test #28

Test #28

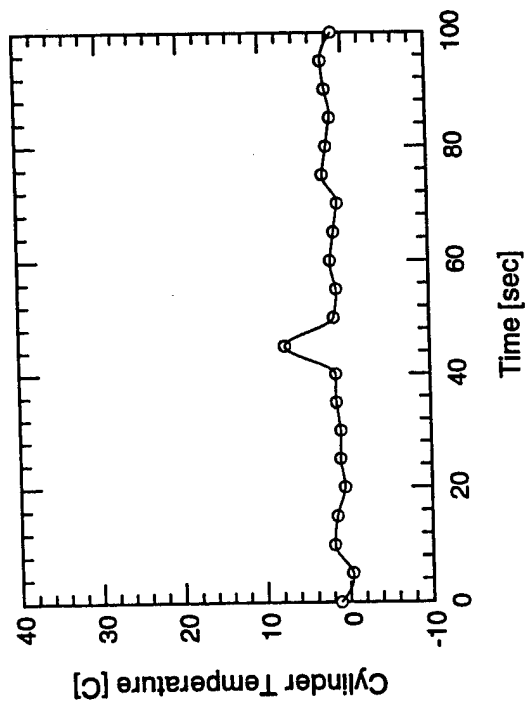
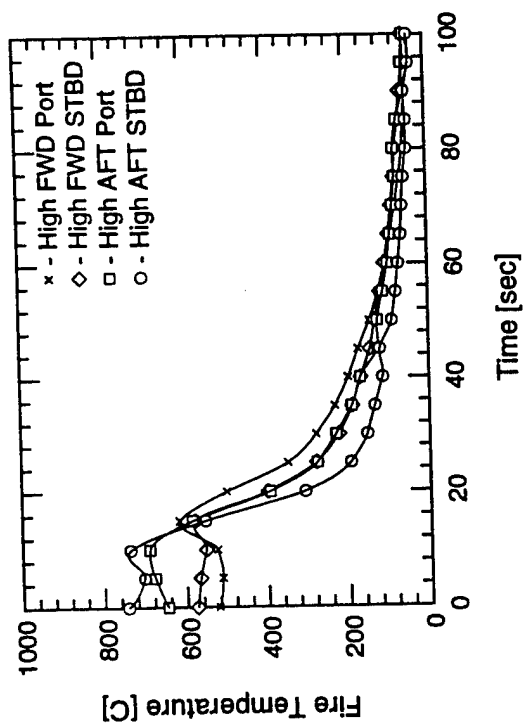
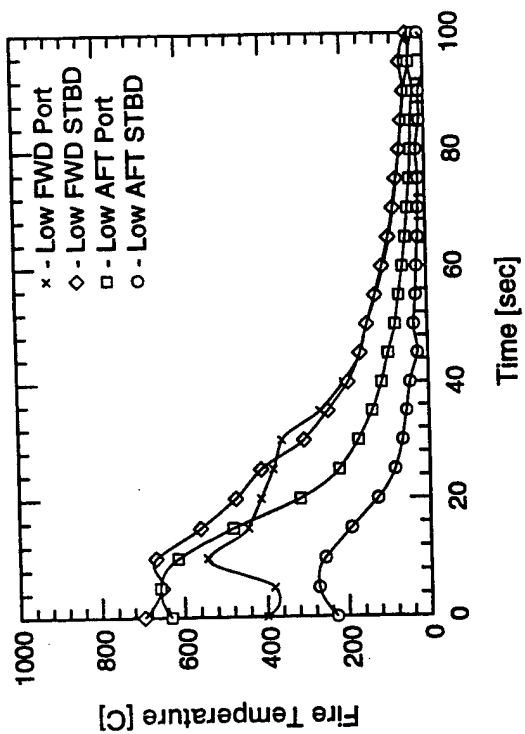




Test #28

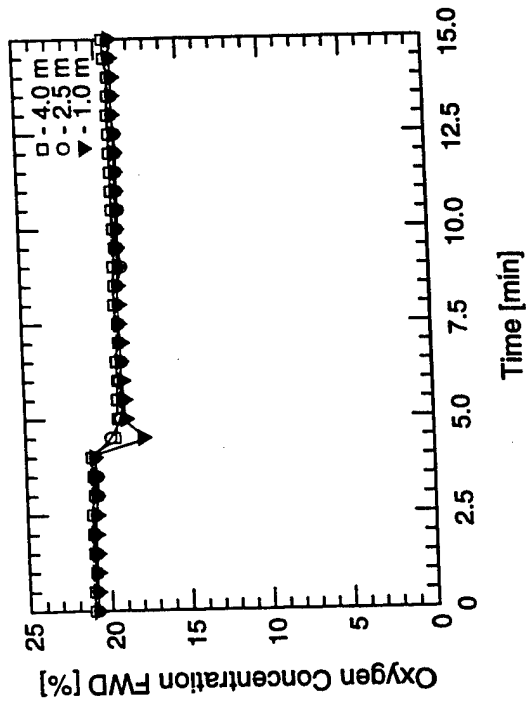
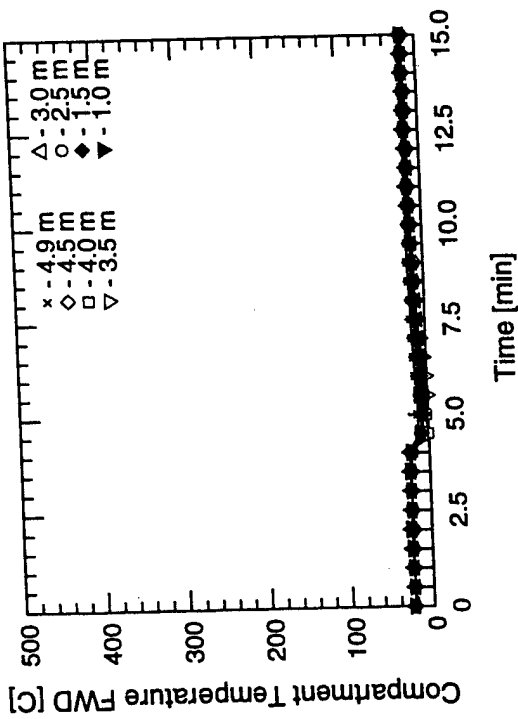
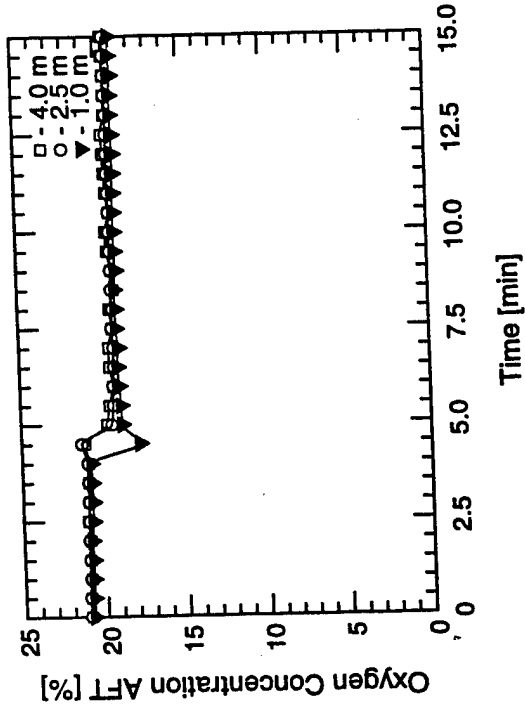
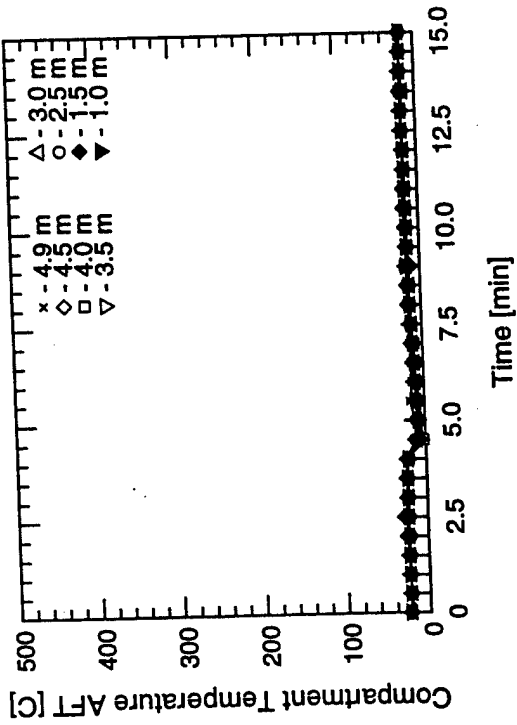


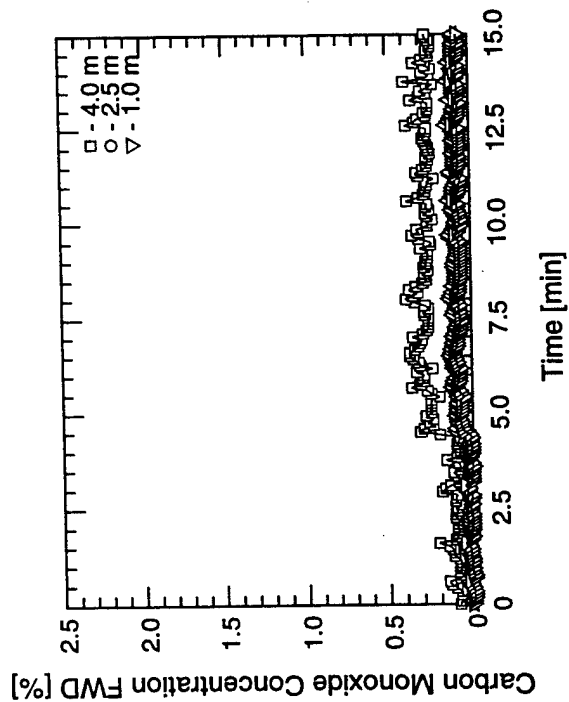
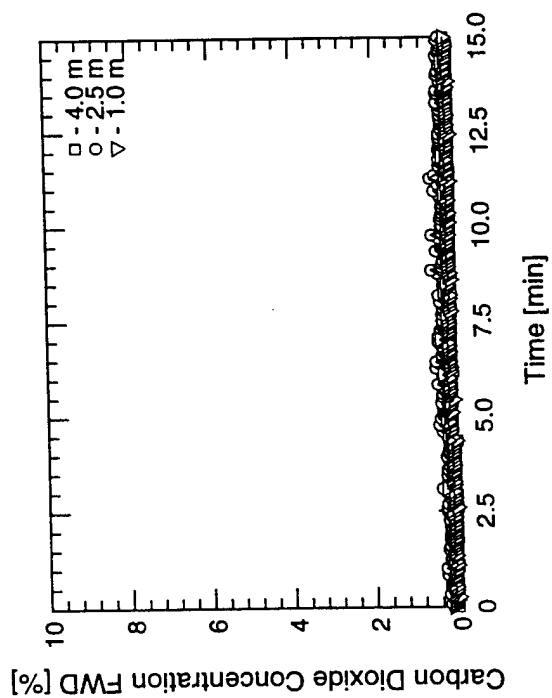
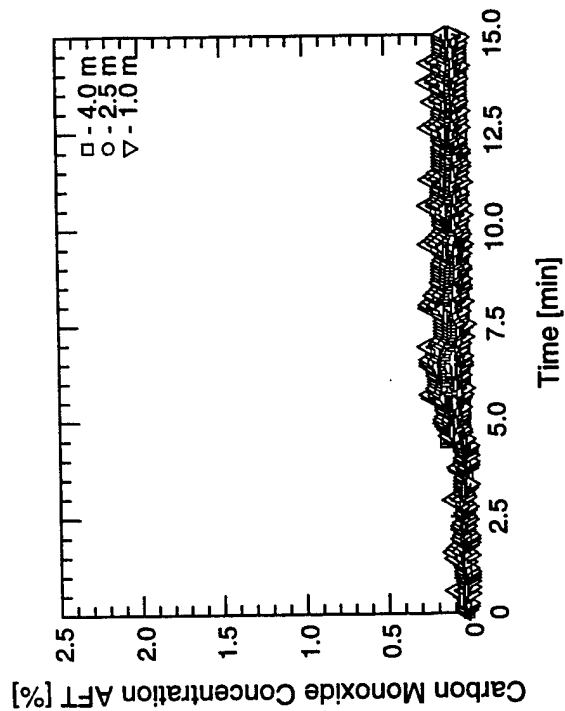
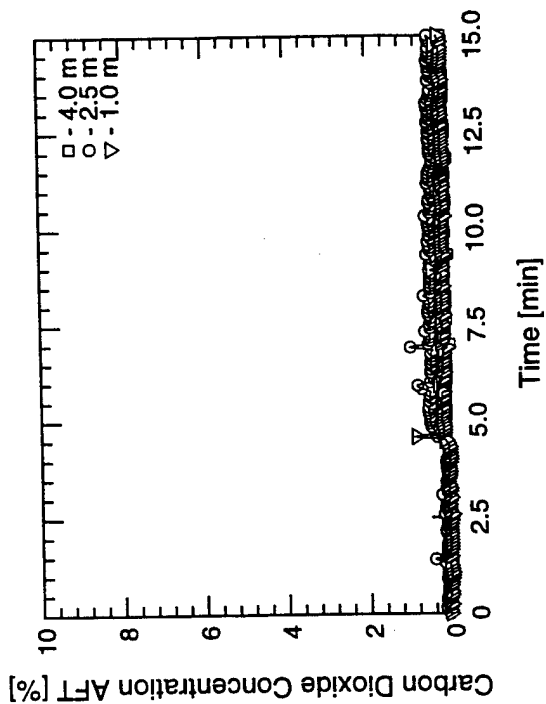
Test #28



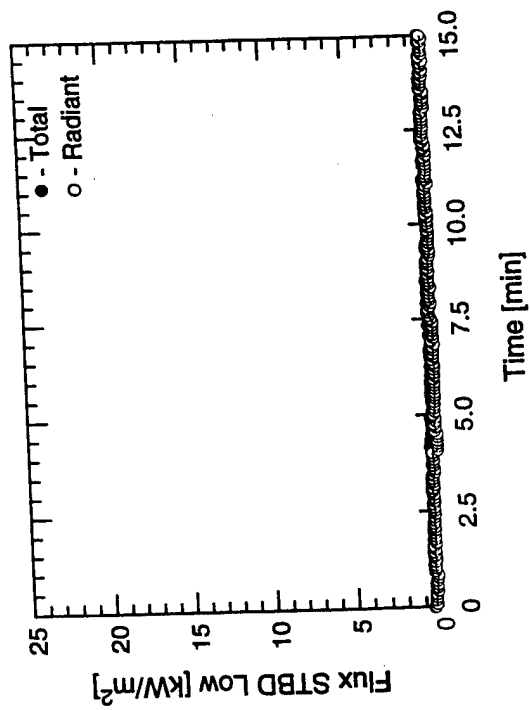
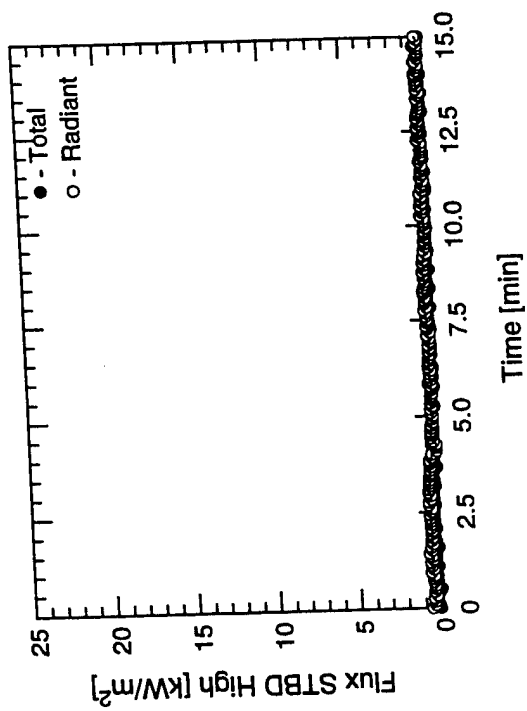
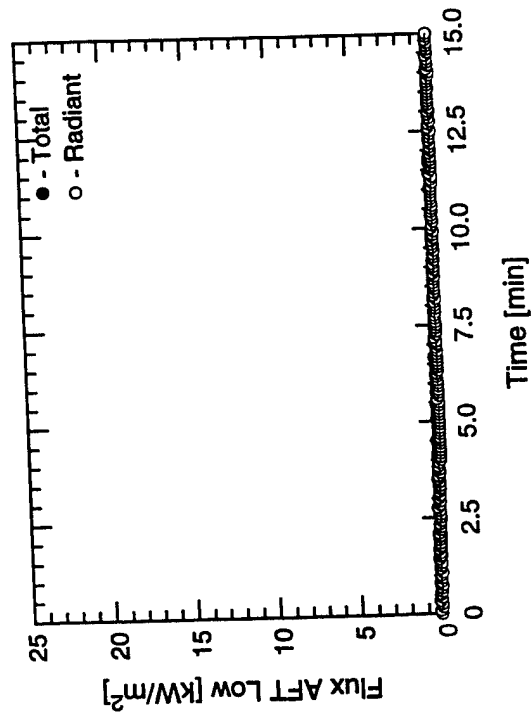
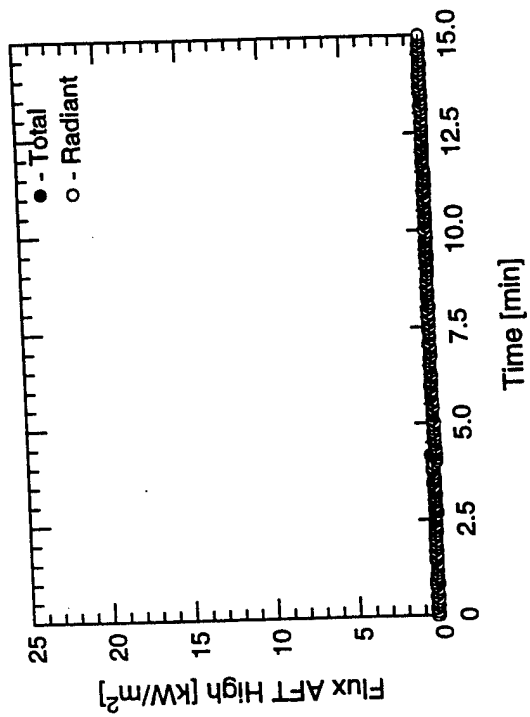
Test #28

Test #29

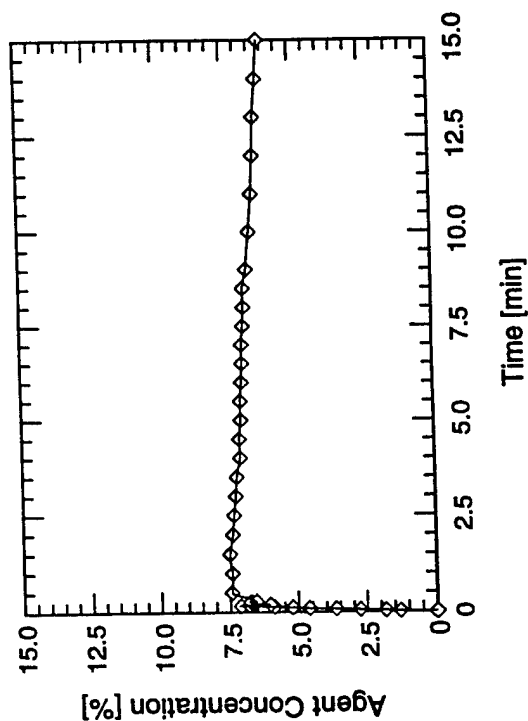
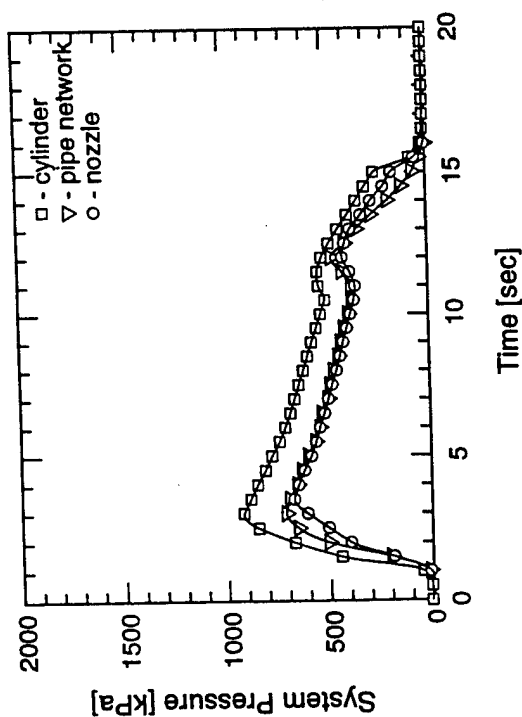
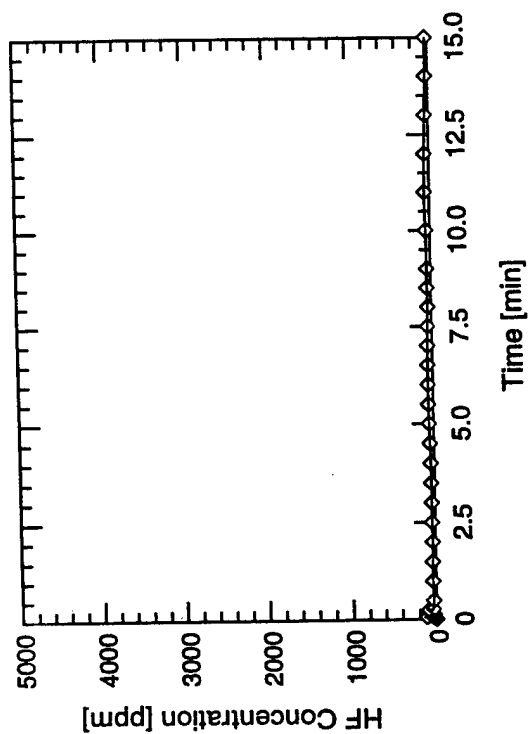
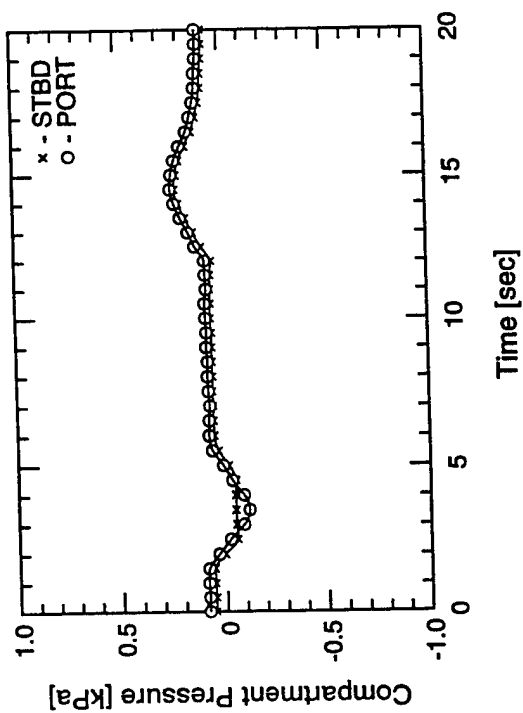




Test #29

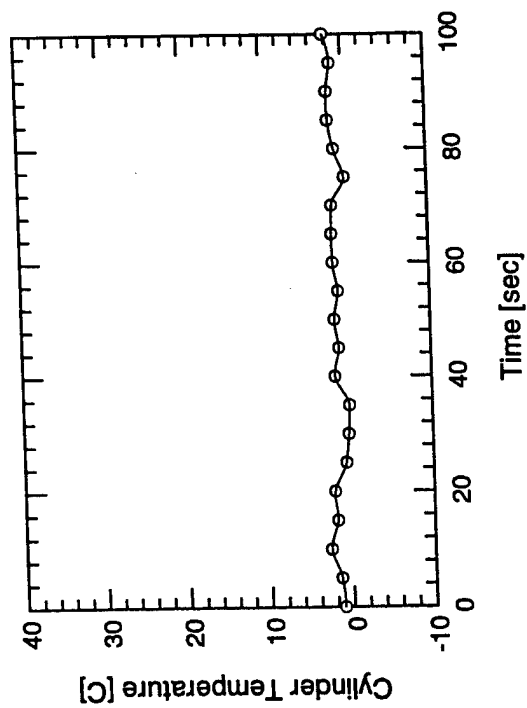
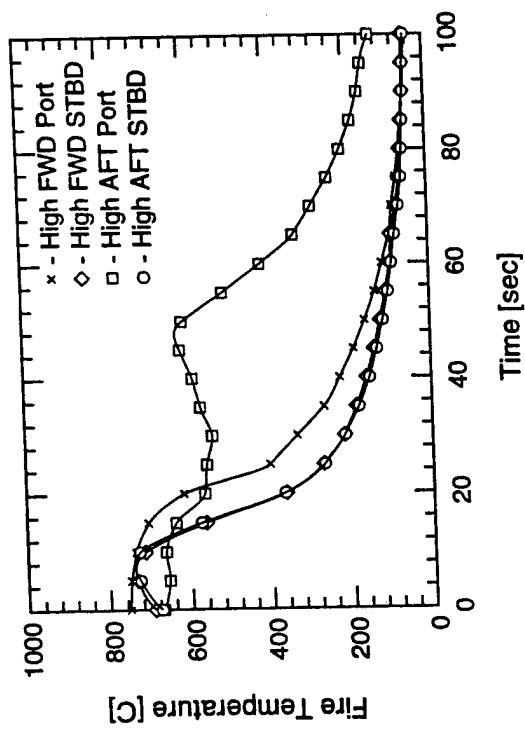
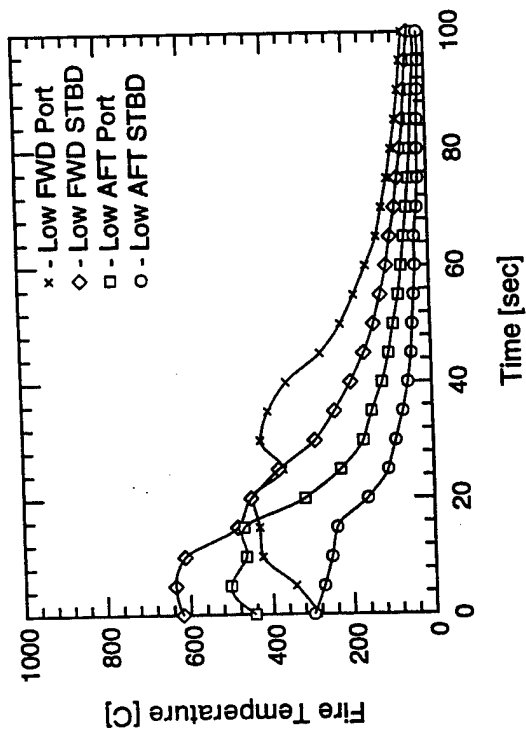


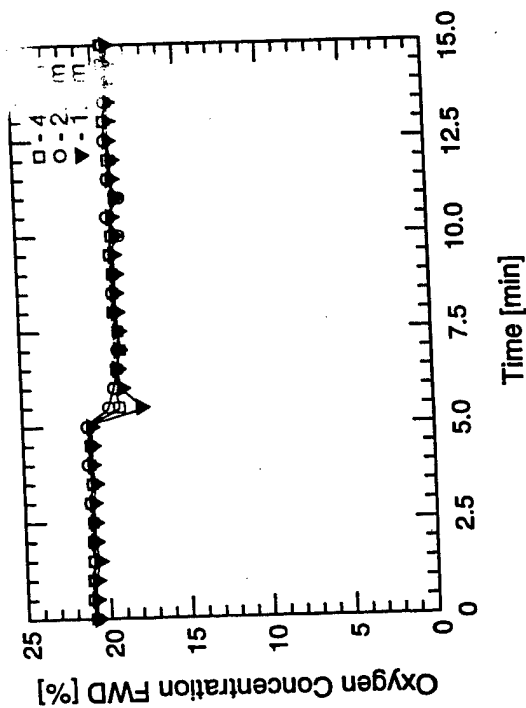
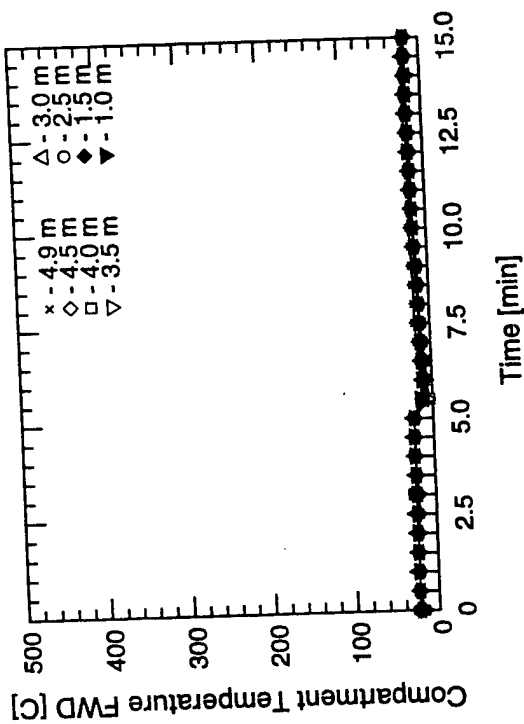
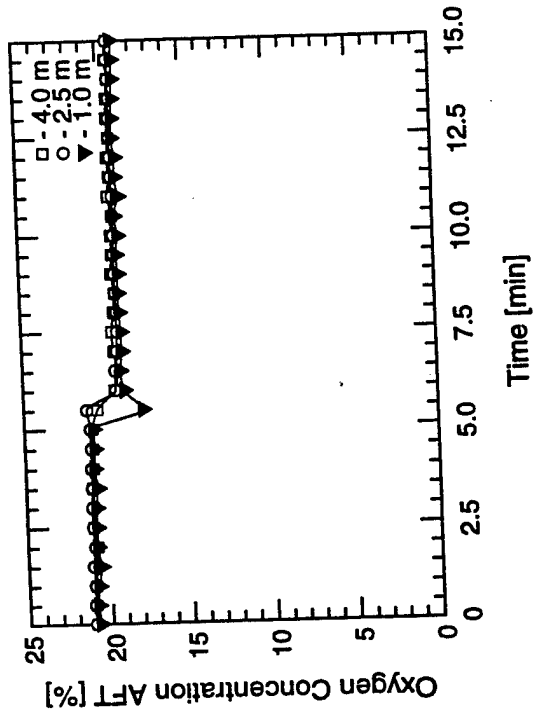
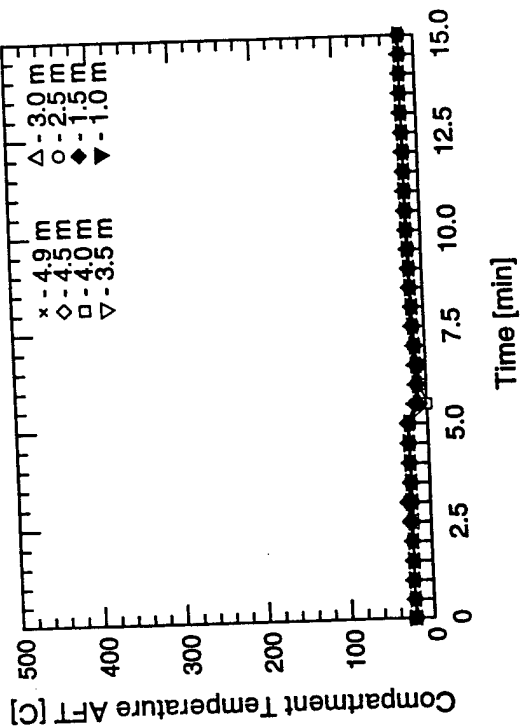
Test #29



Test #29

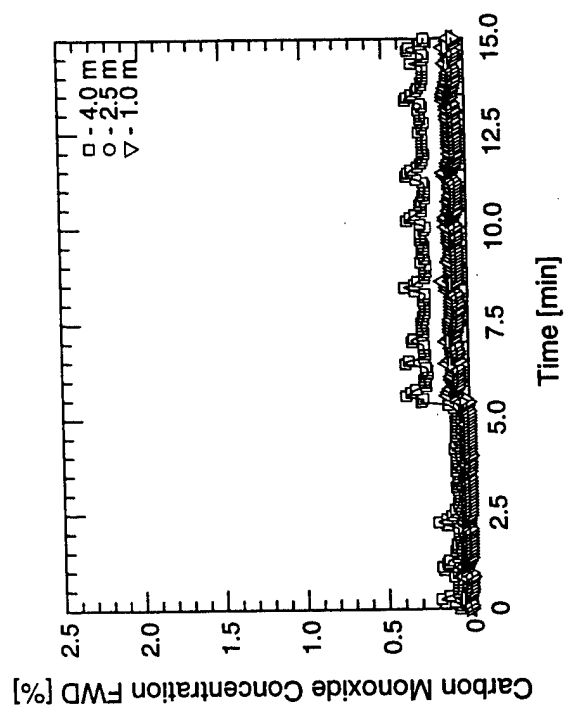
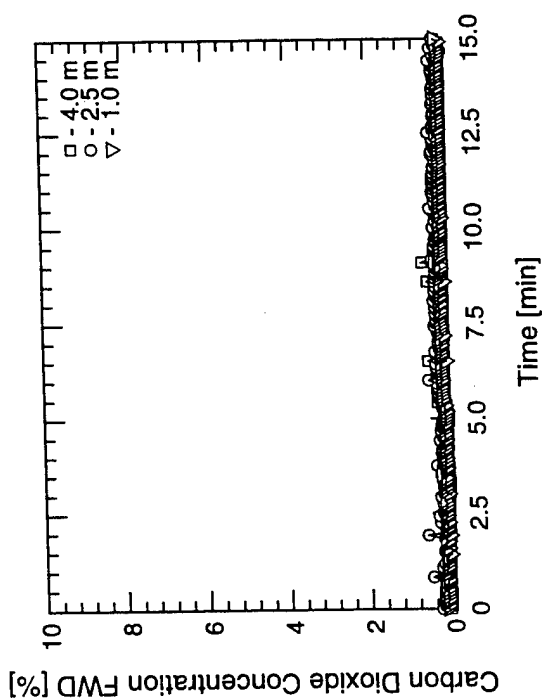
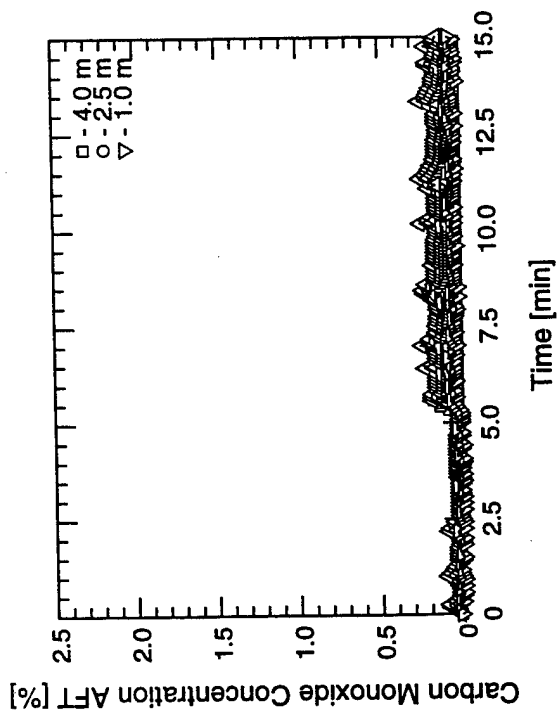
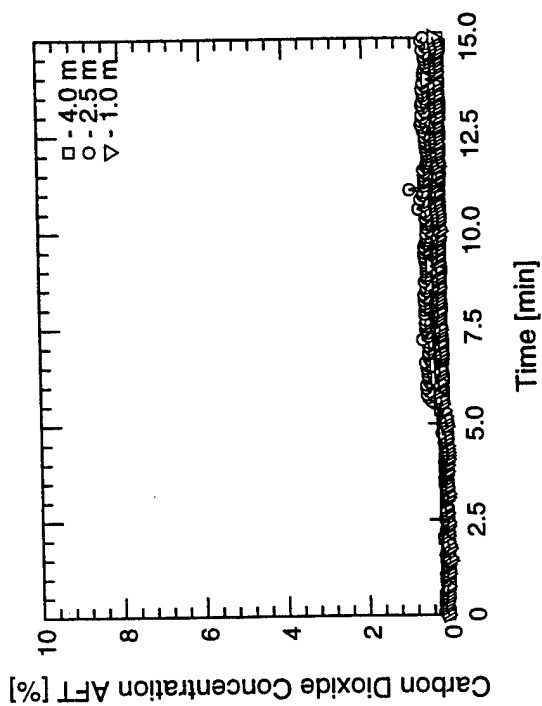
Test #29

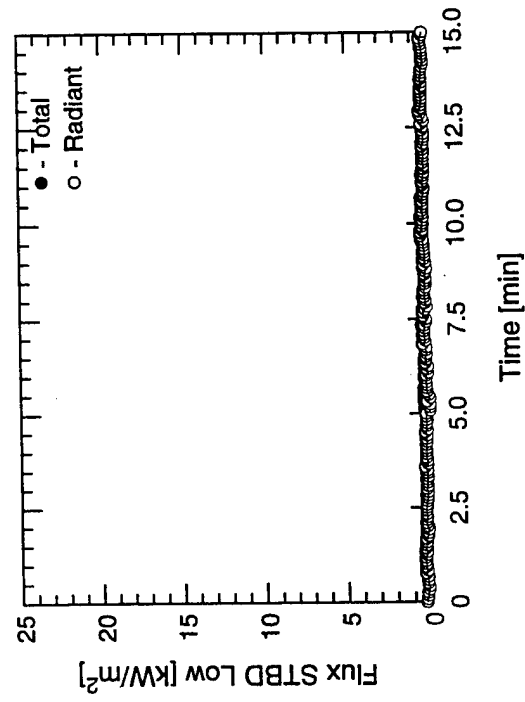
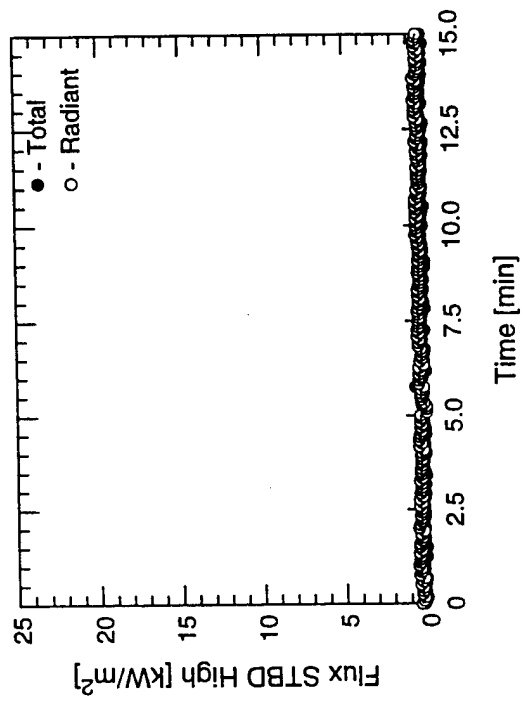
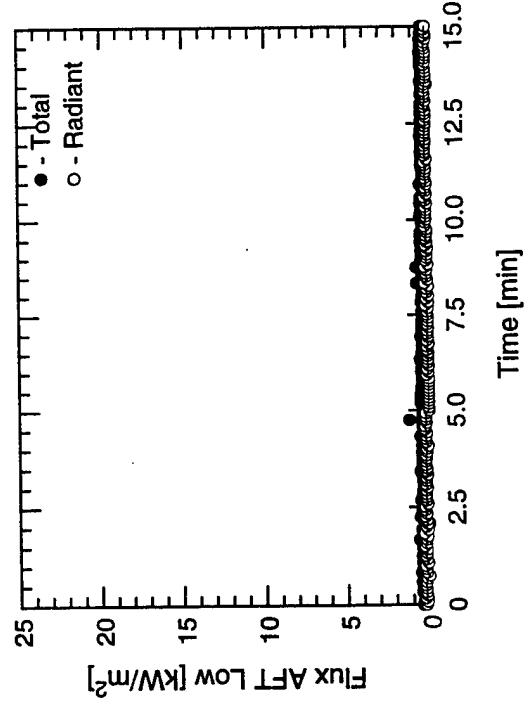
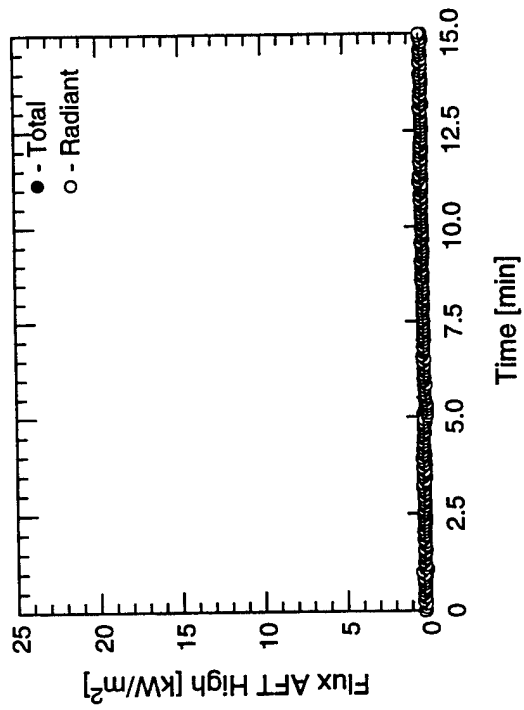




Test #30

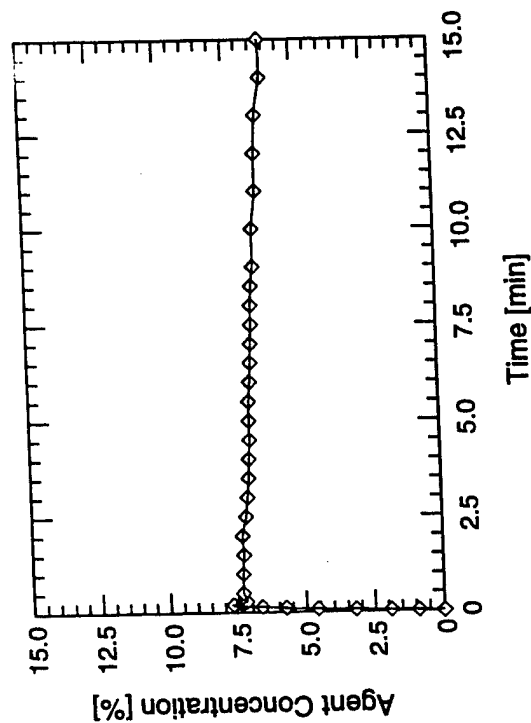
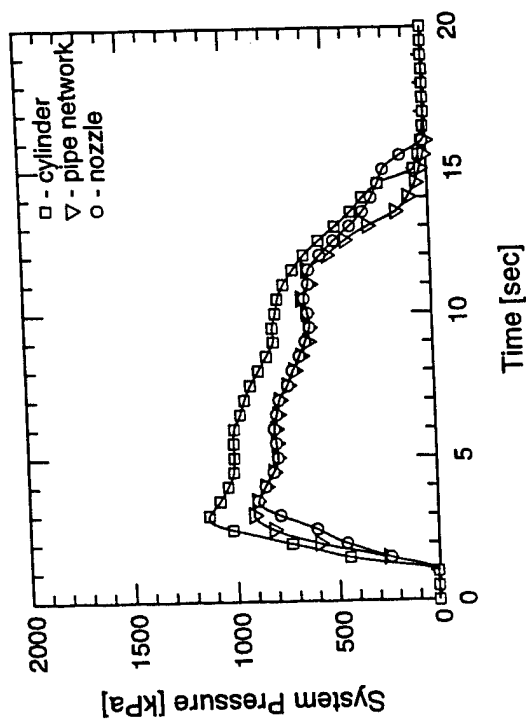
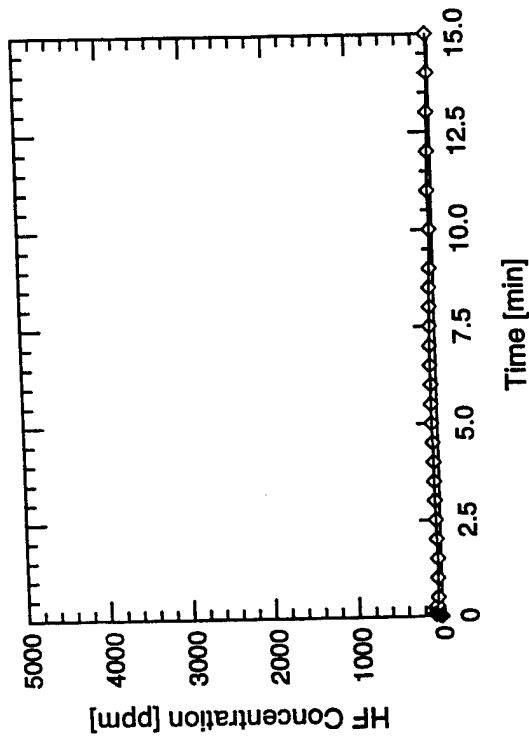
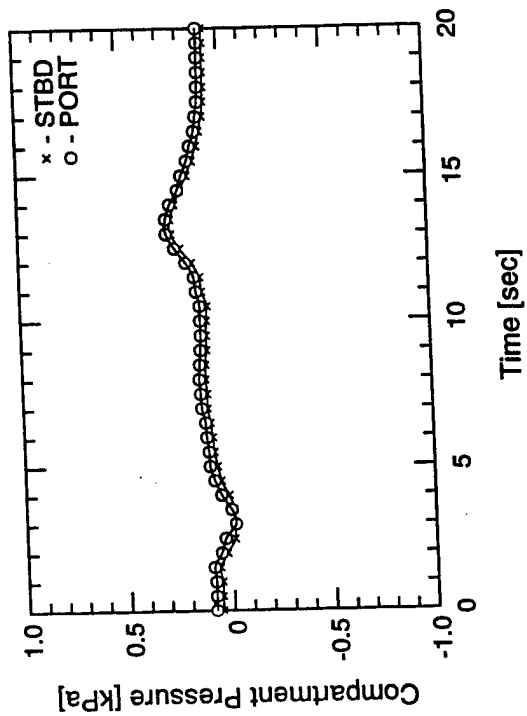
Test #30

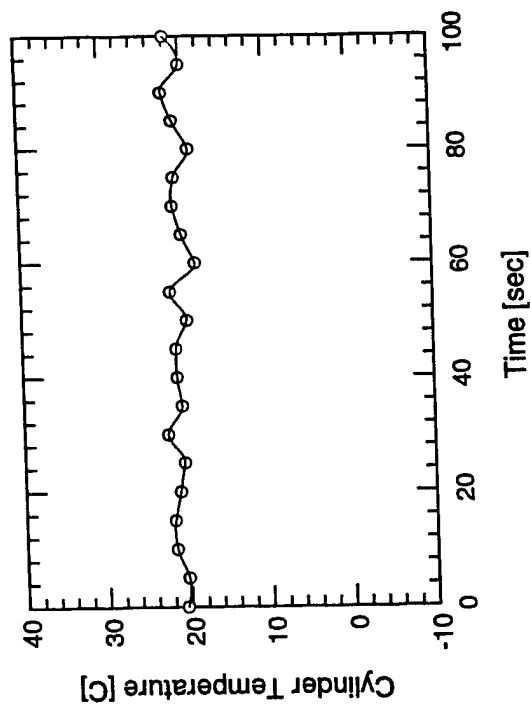
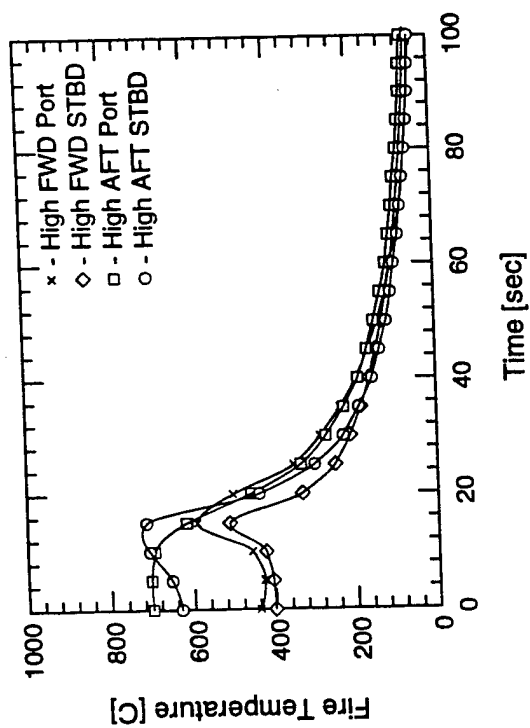
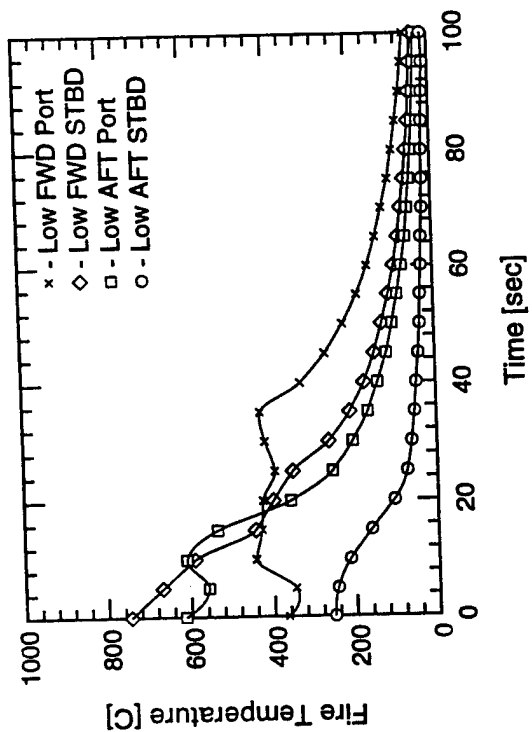




Test #30

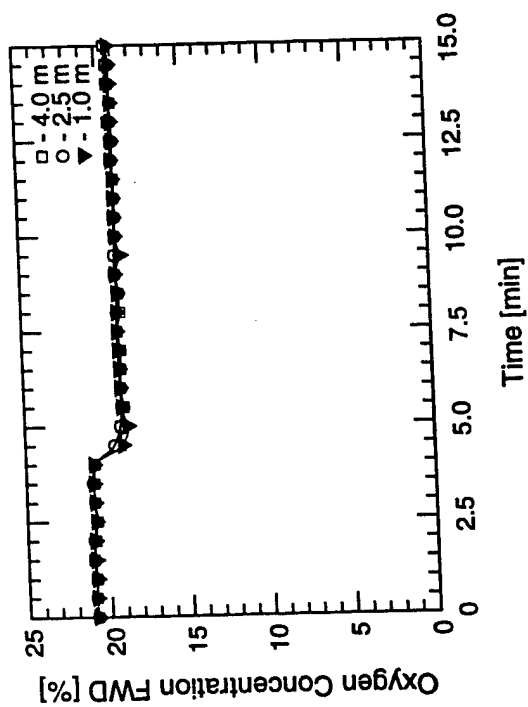
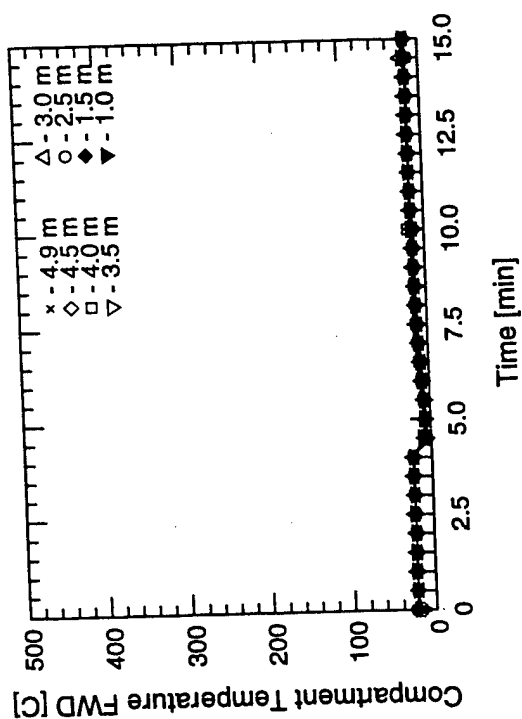
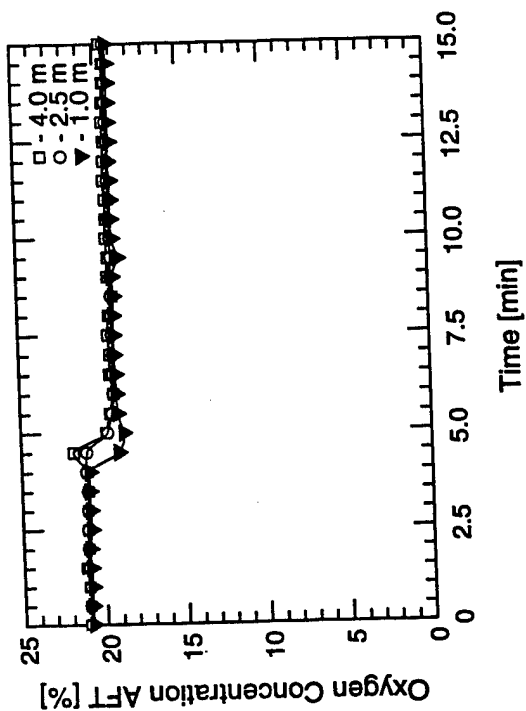
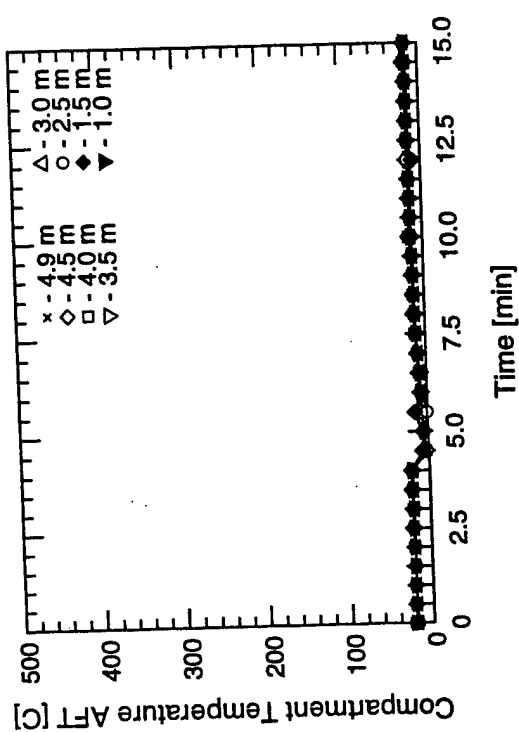
Test #30

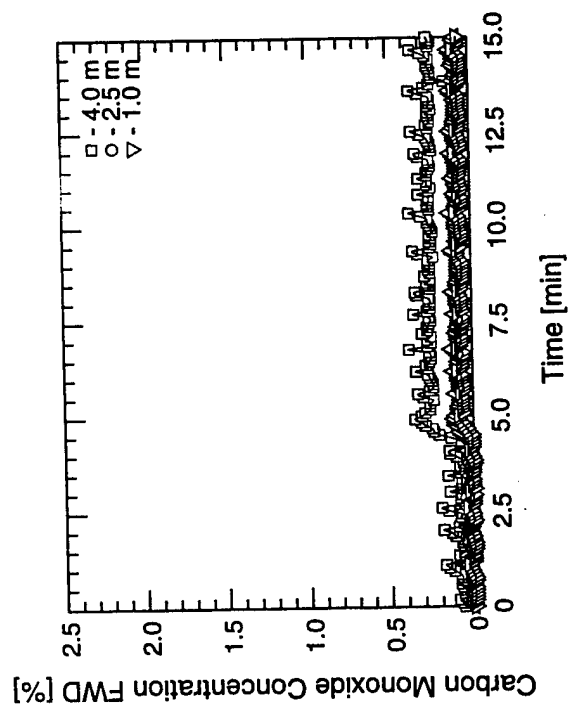
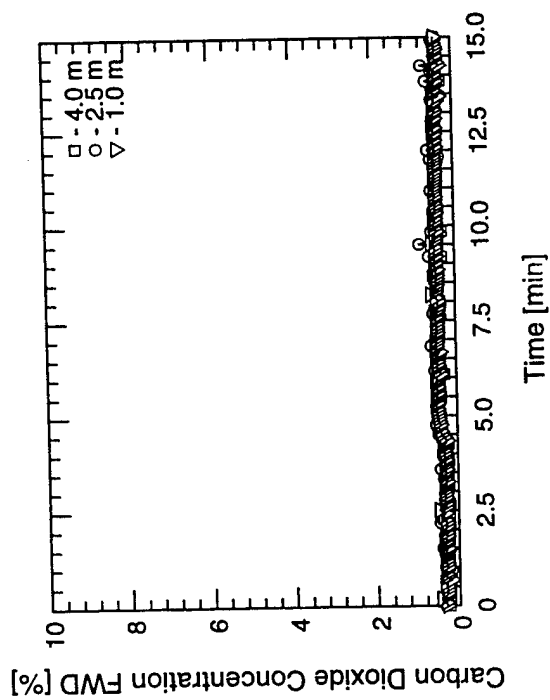
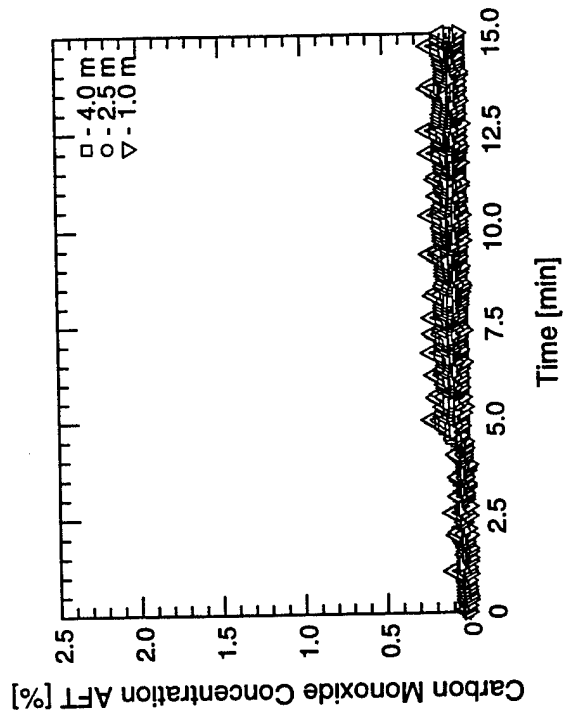
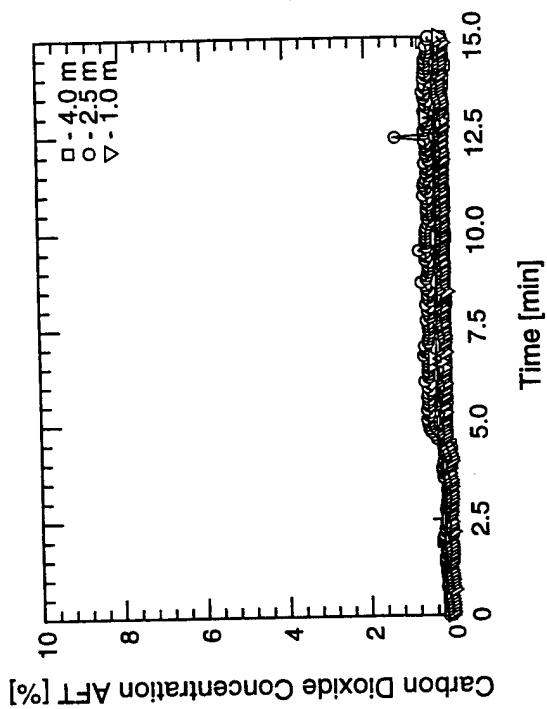




Test #30

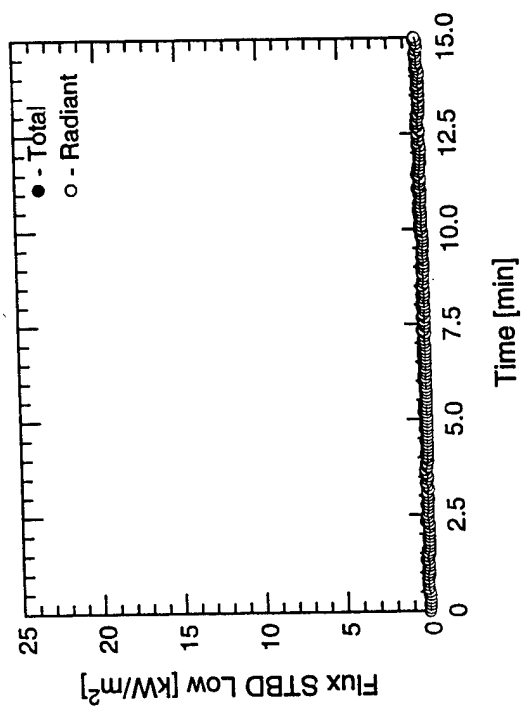
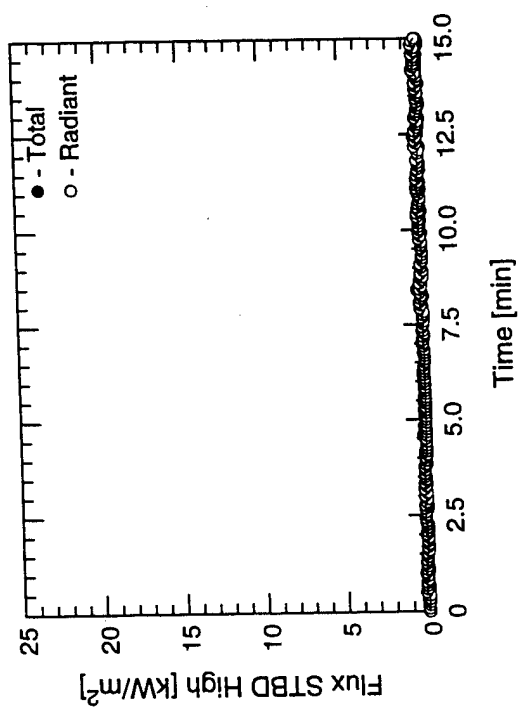
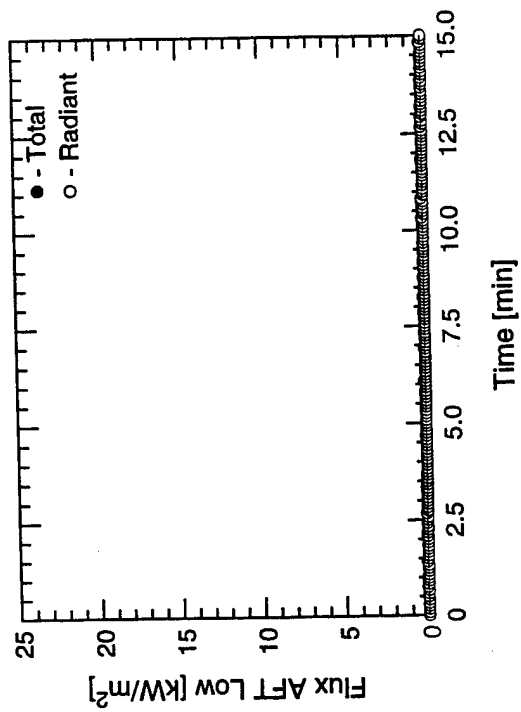
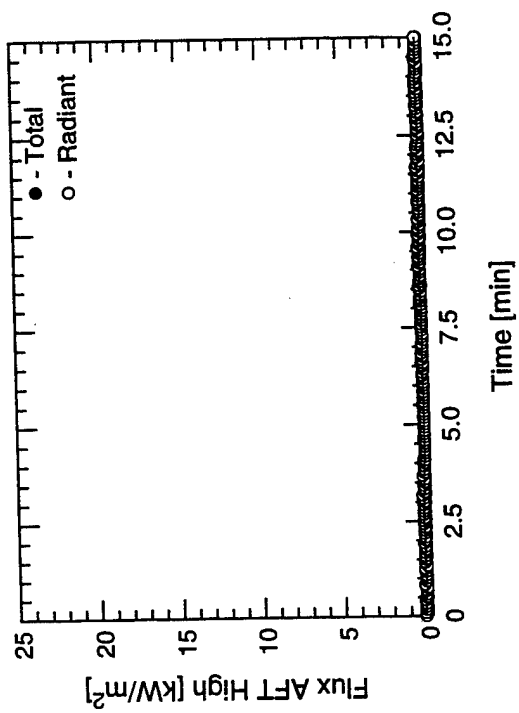
Test #31

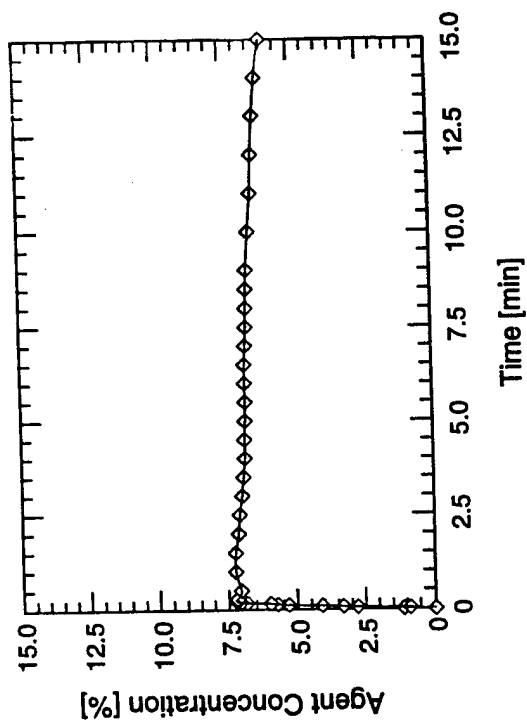
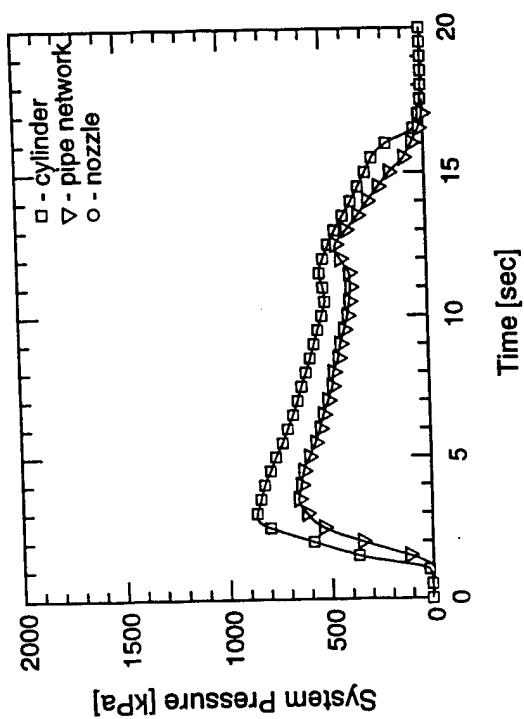
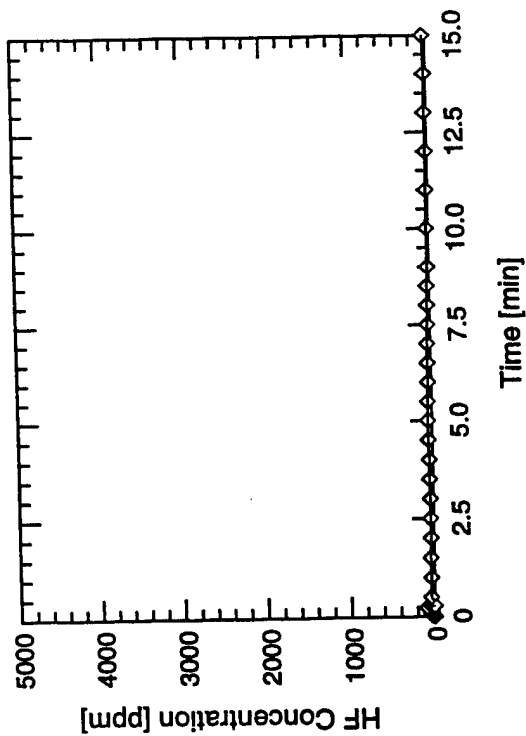
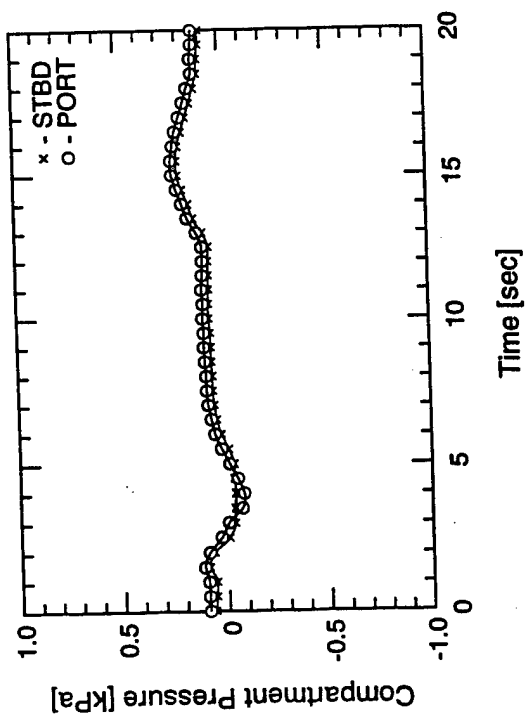




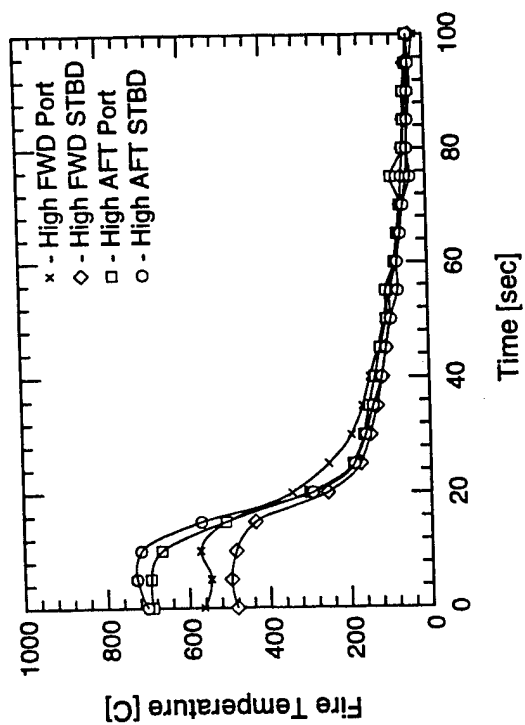
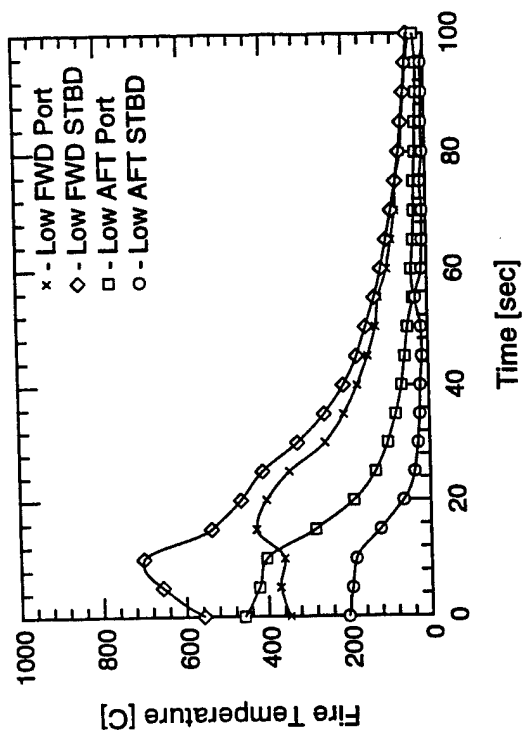
Test #31

Test #31

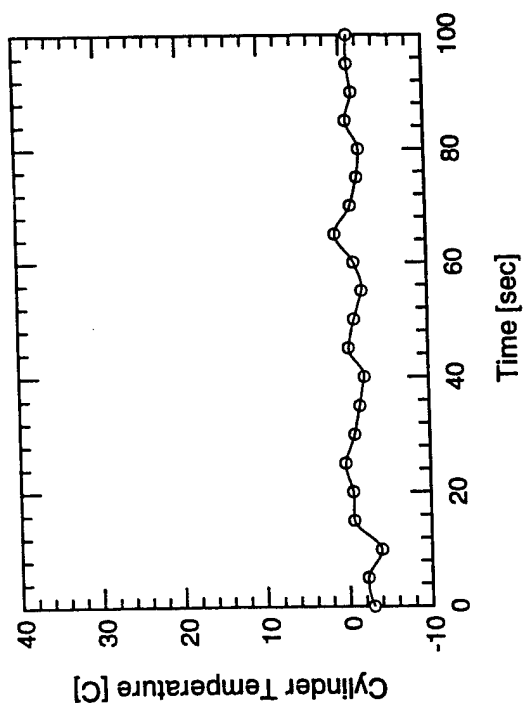




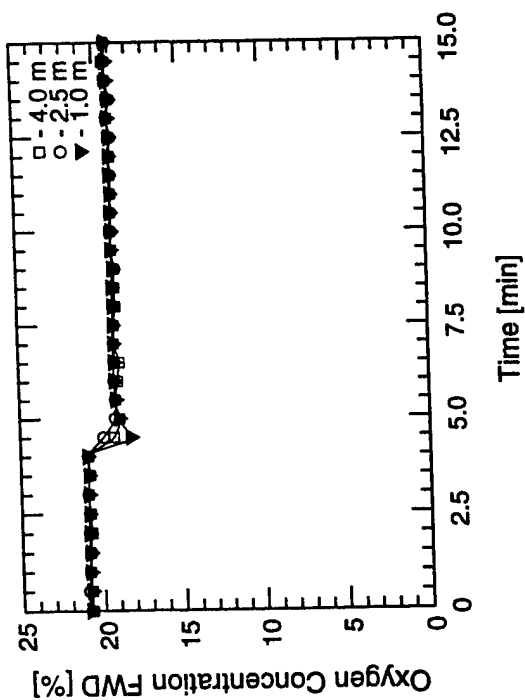
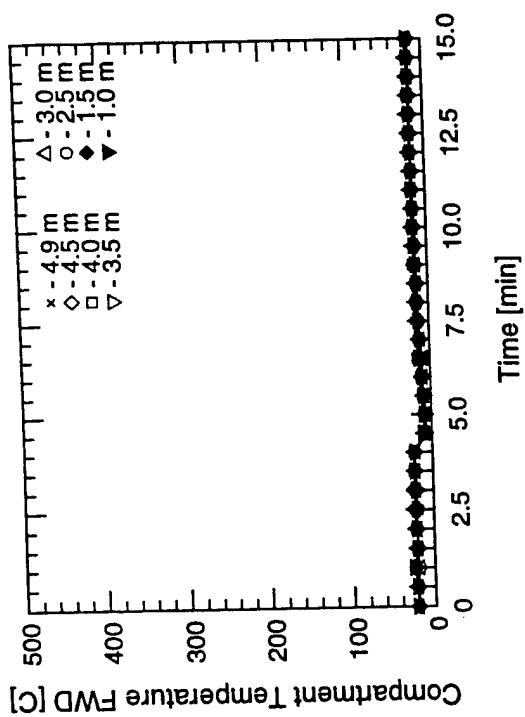
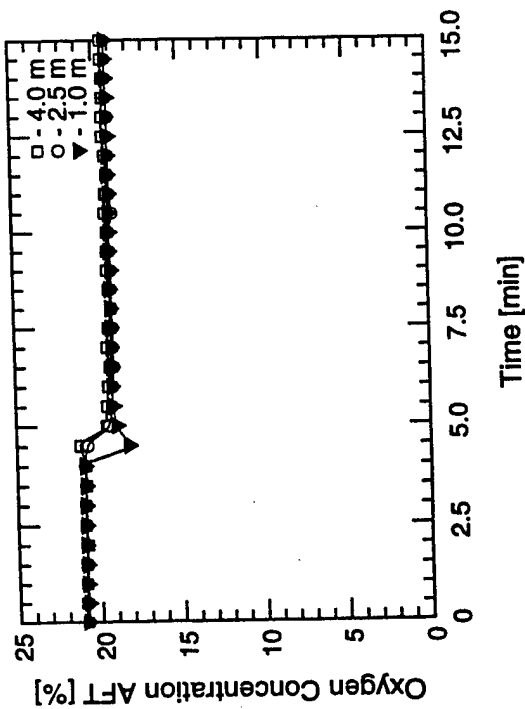
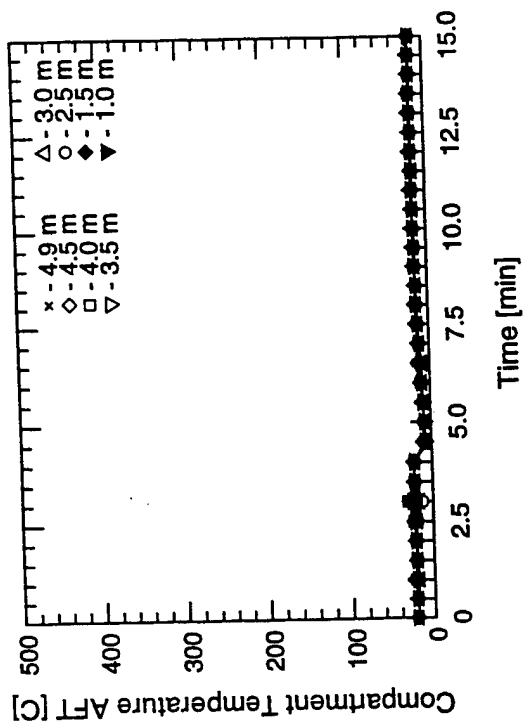
Test #31



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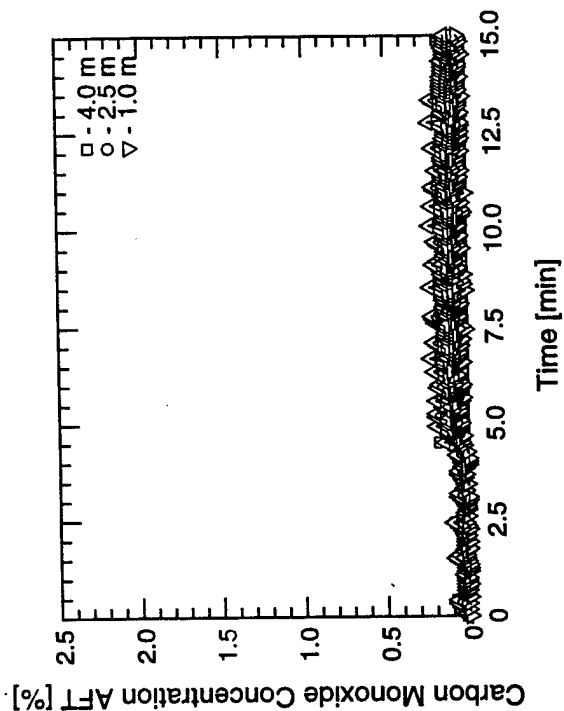
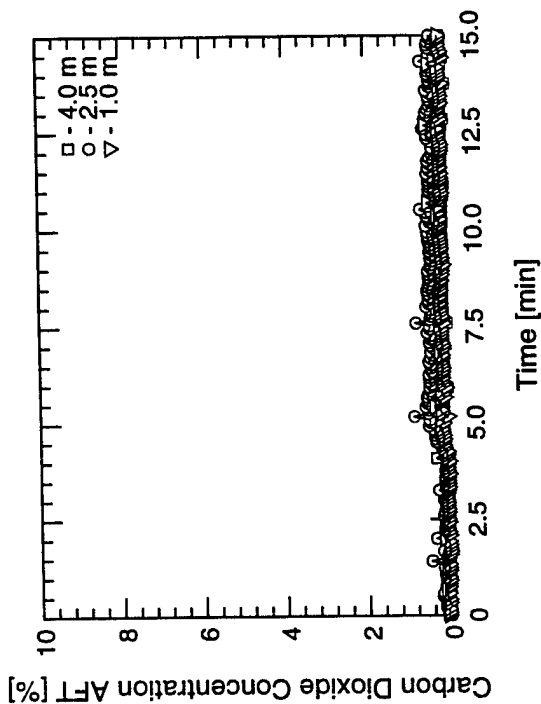
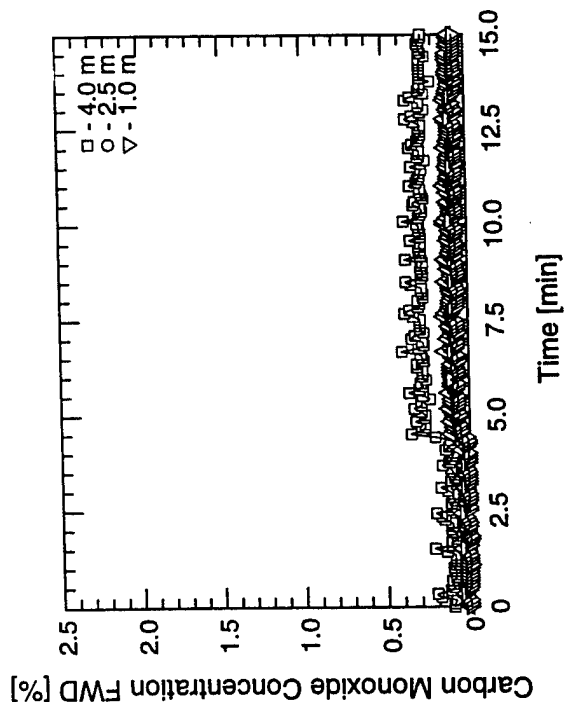
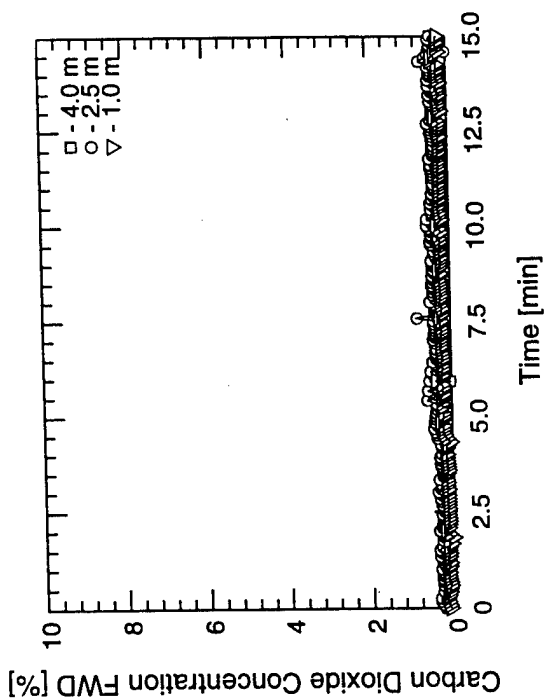
Test #31

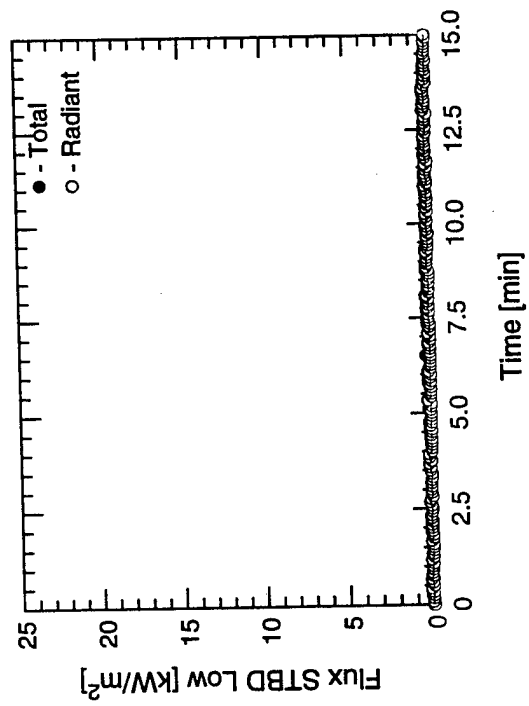
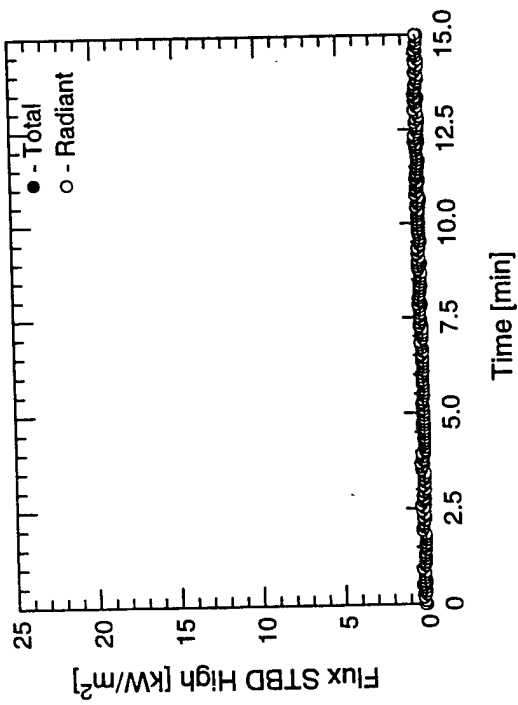
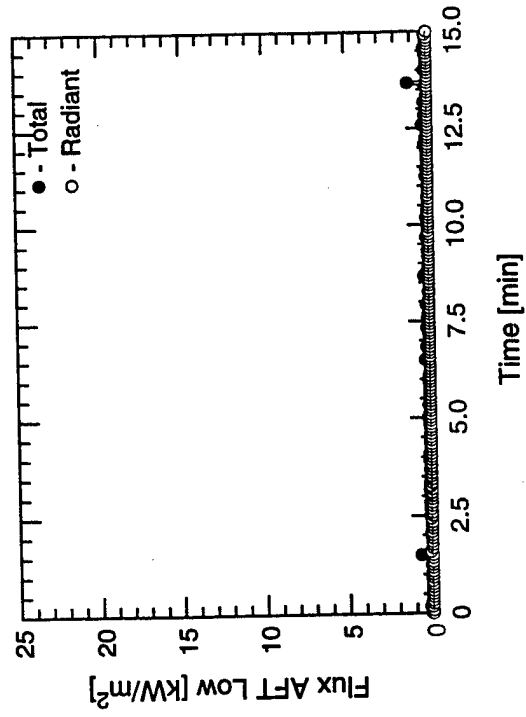
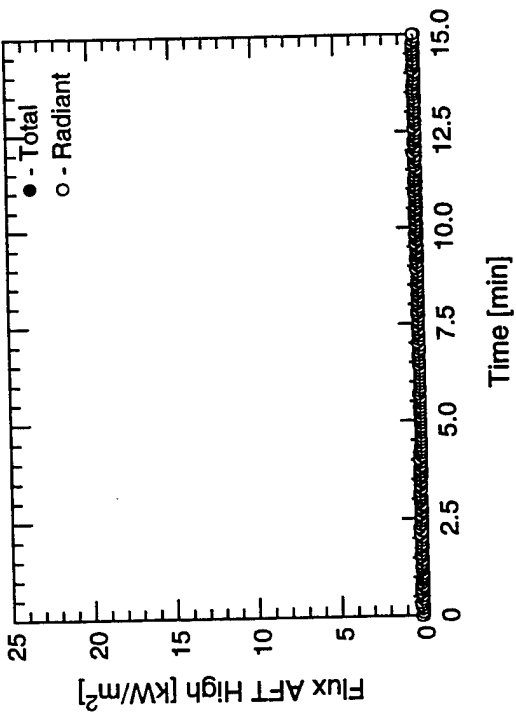


Test #32

Test #32

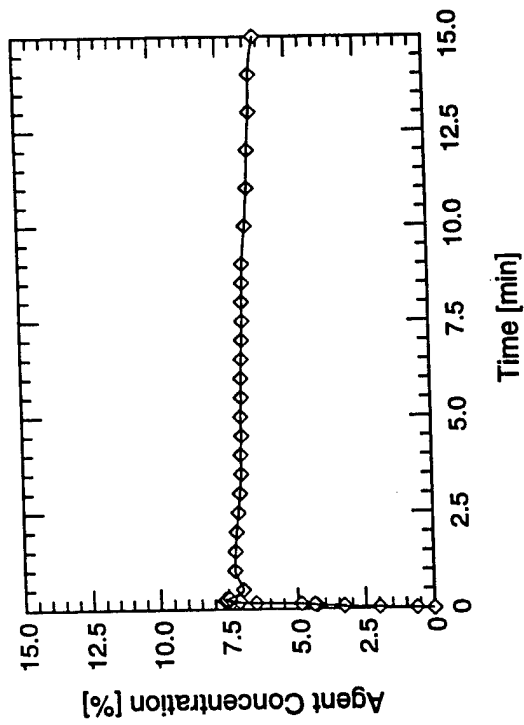
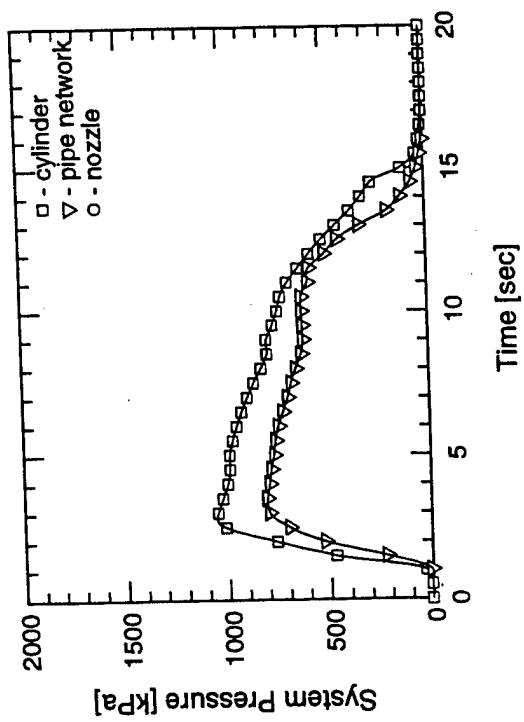
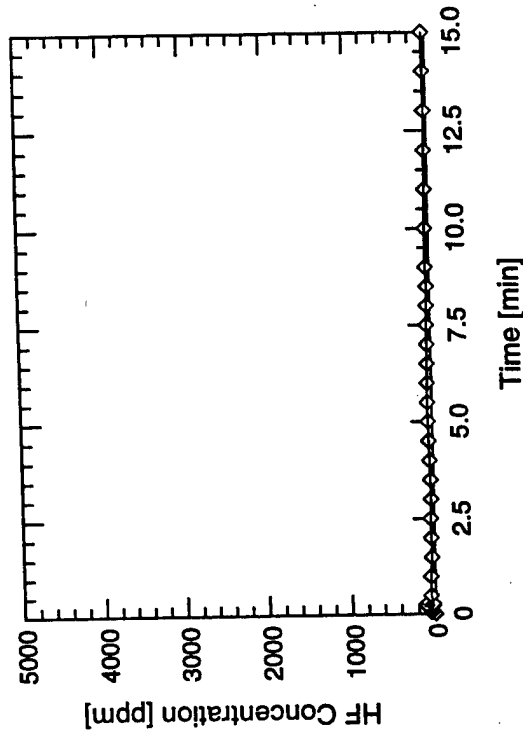
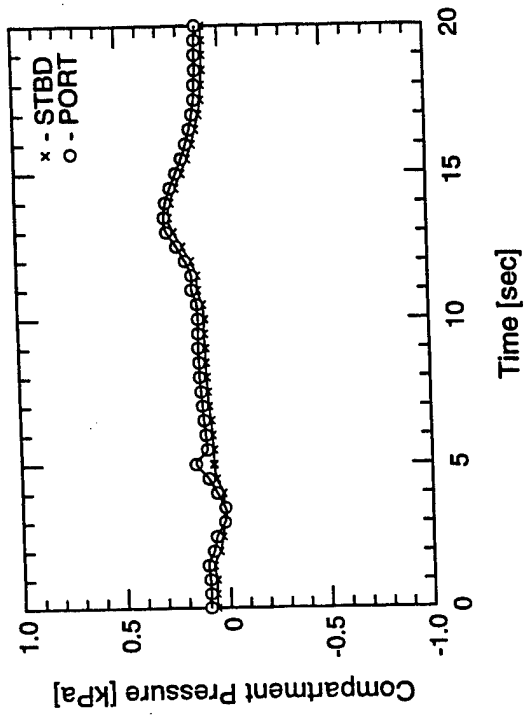
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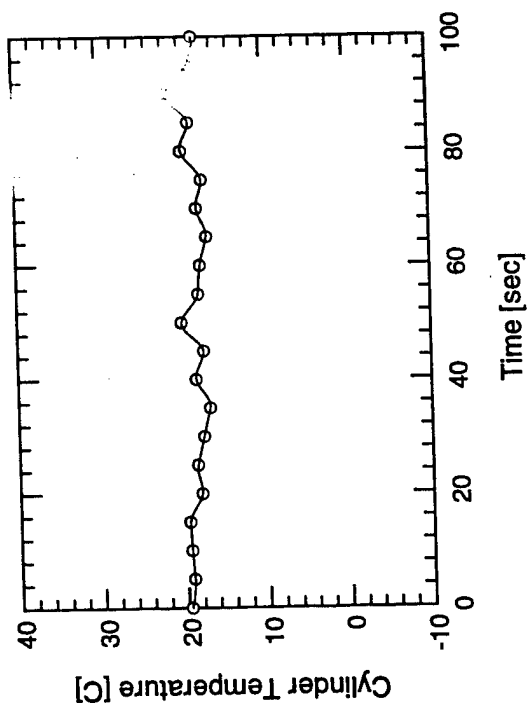
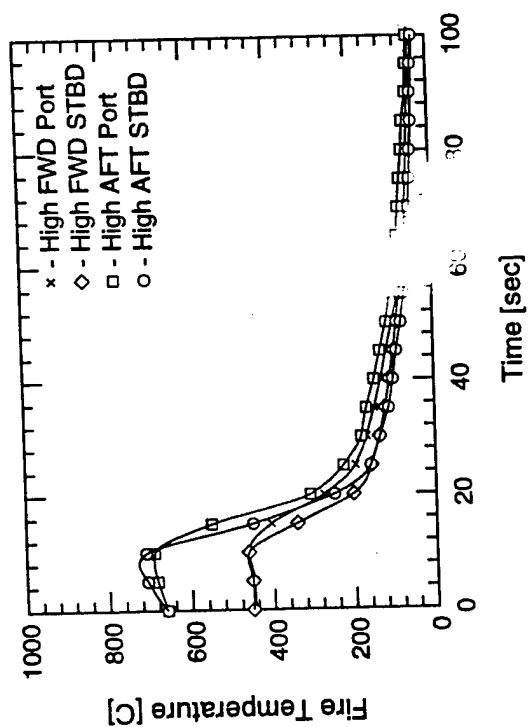
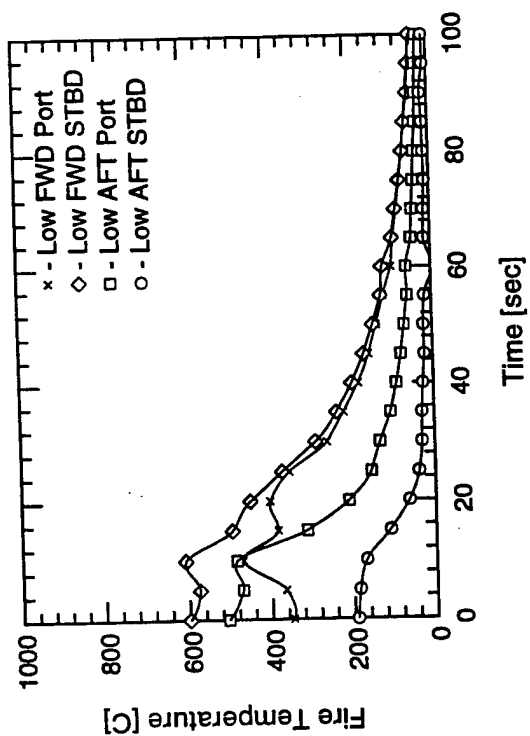




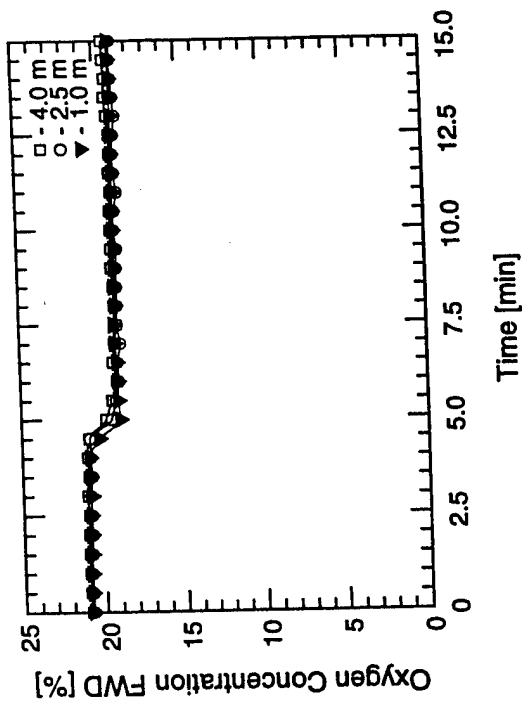
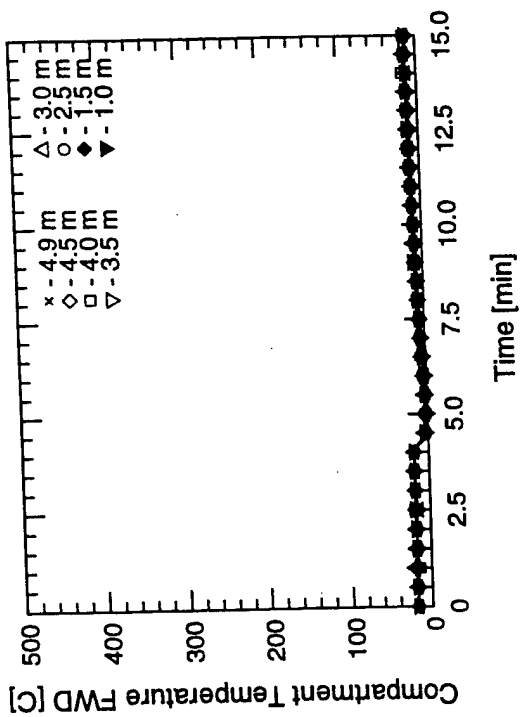
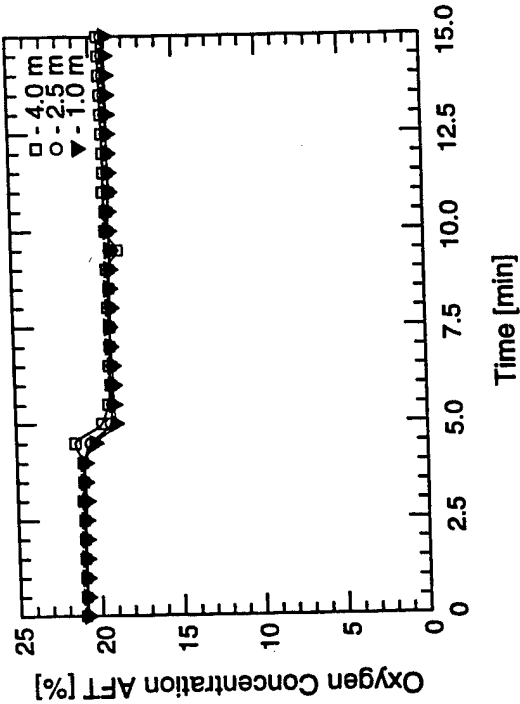
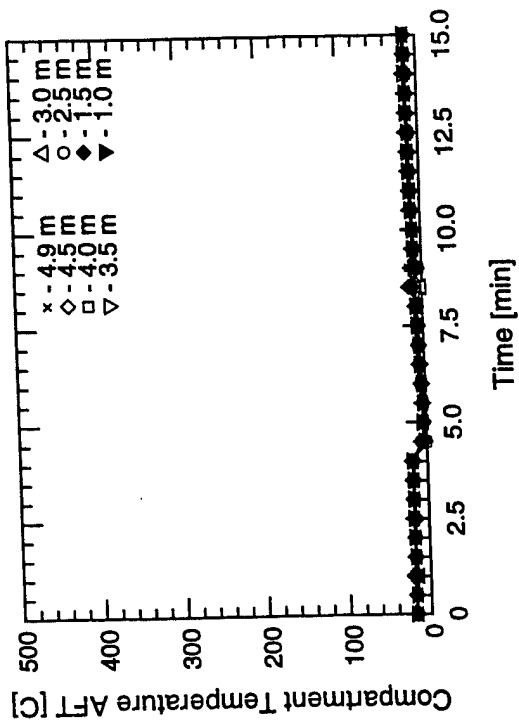
Test #32

Test #32

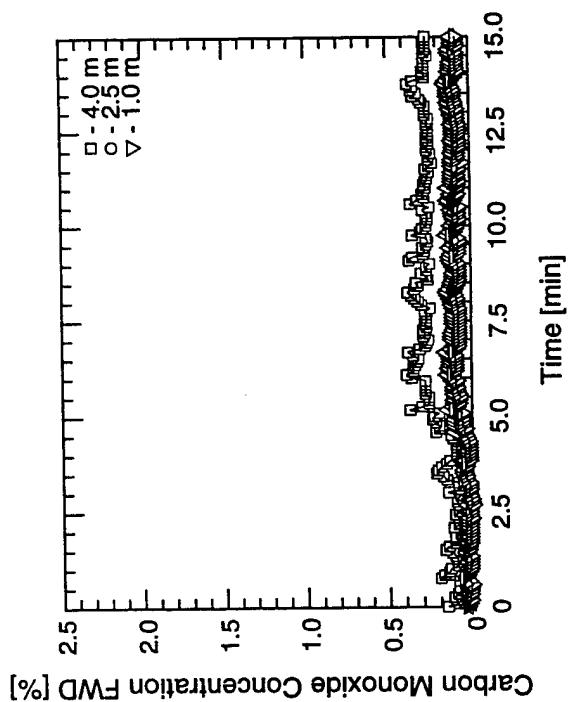
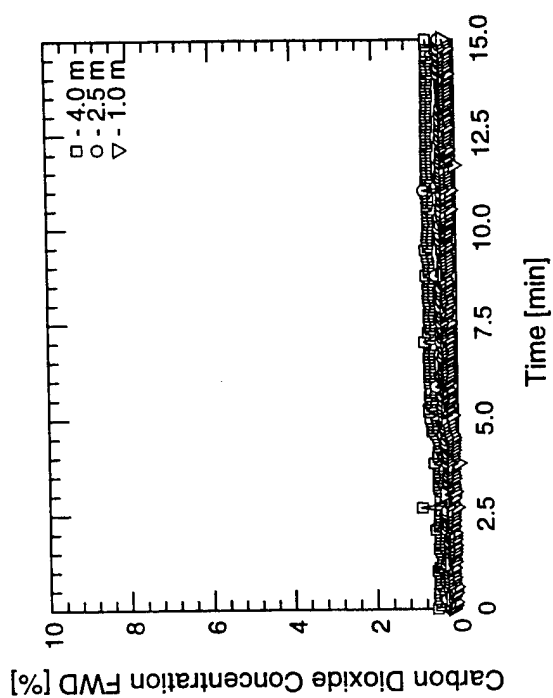
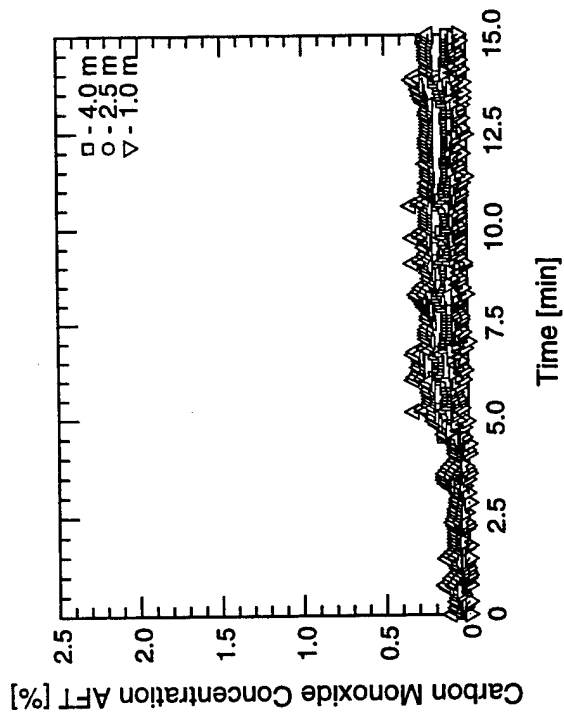
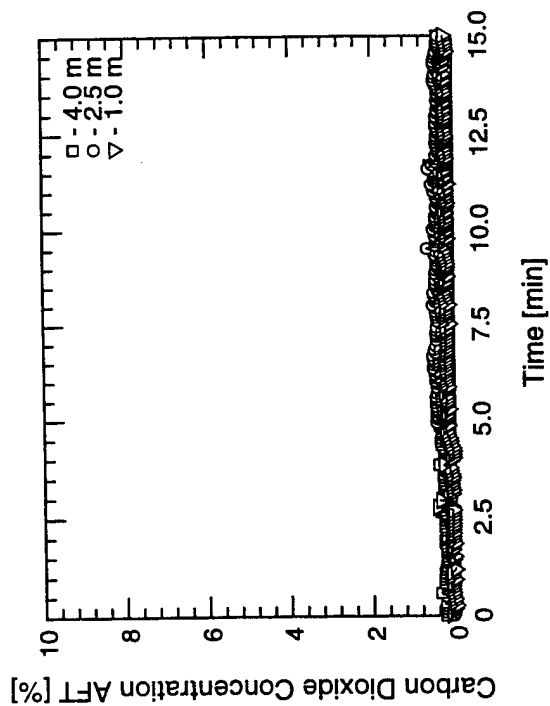




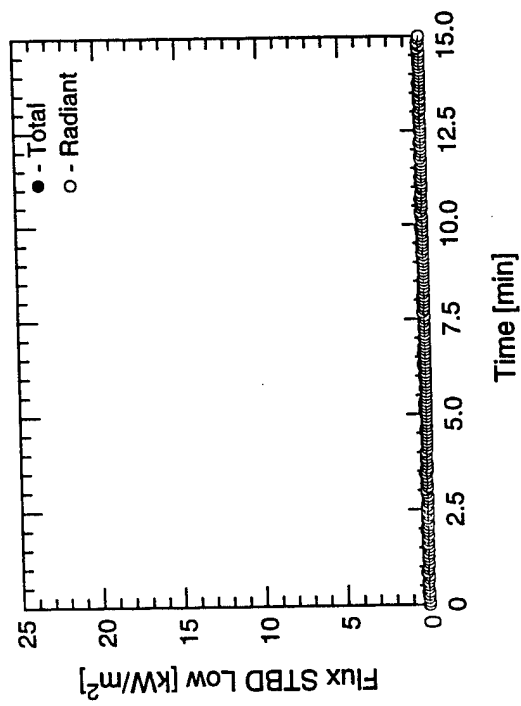
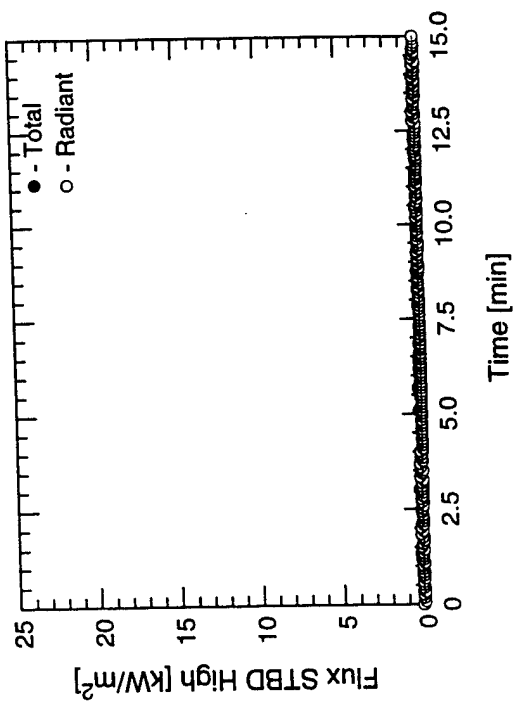
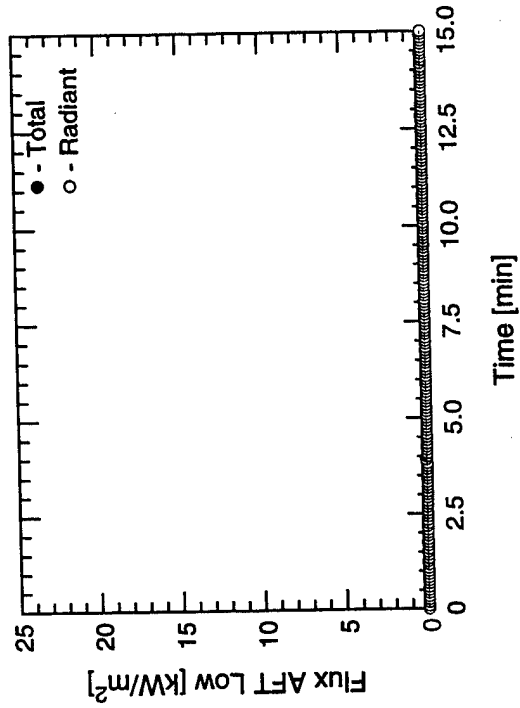
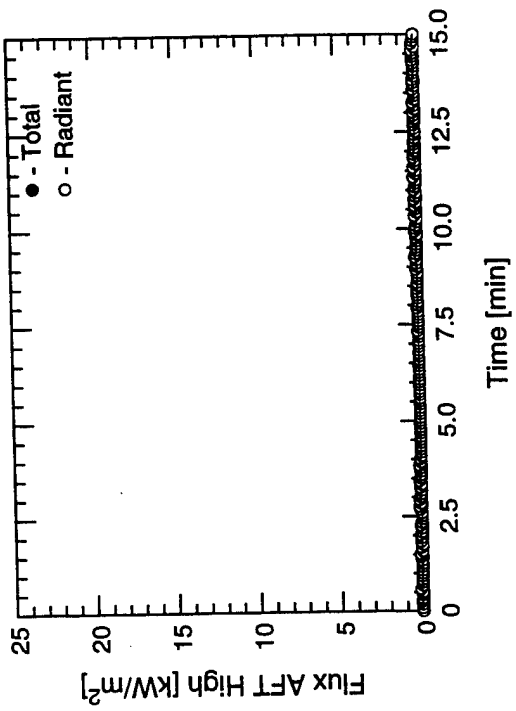
Test #32



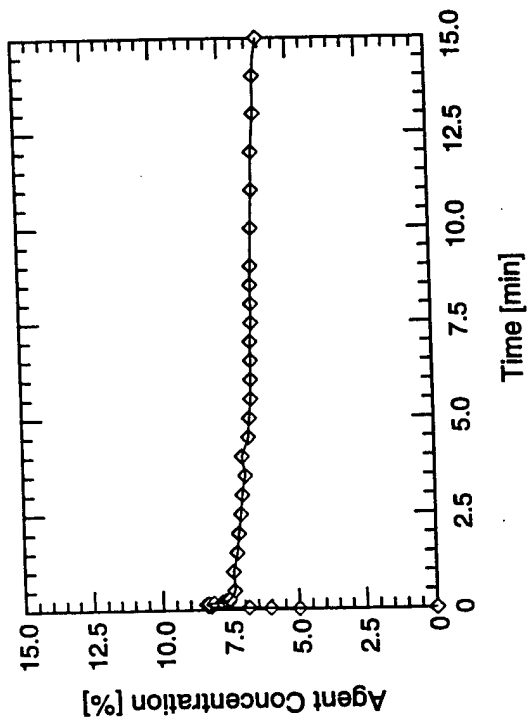
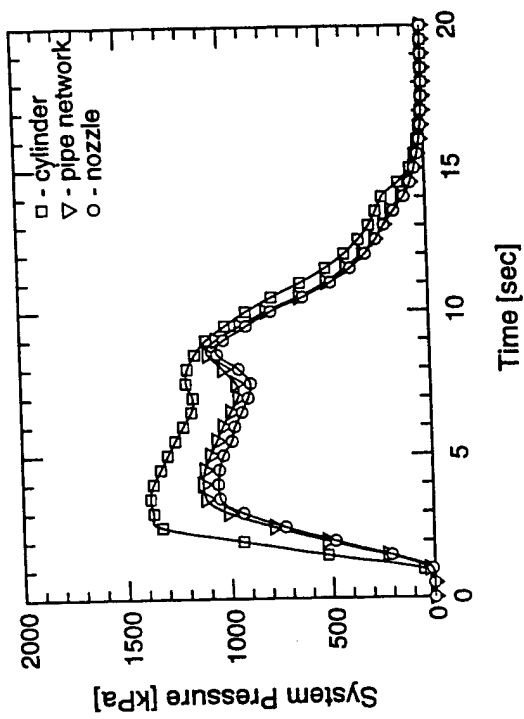
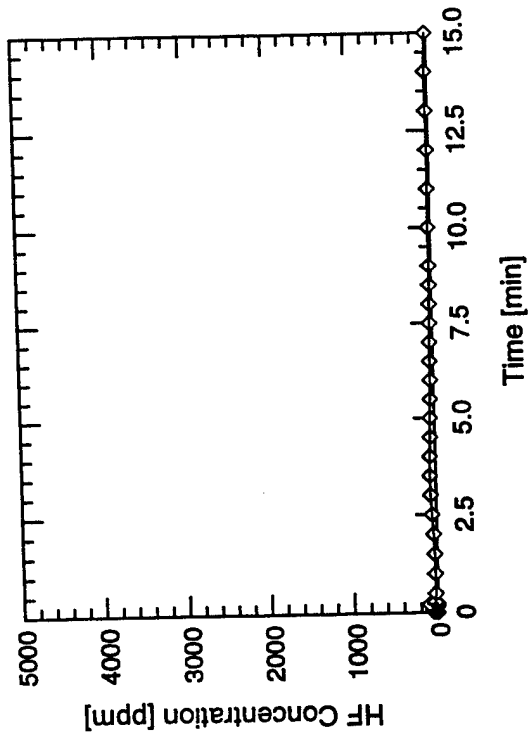
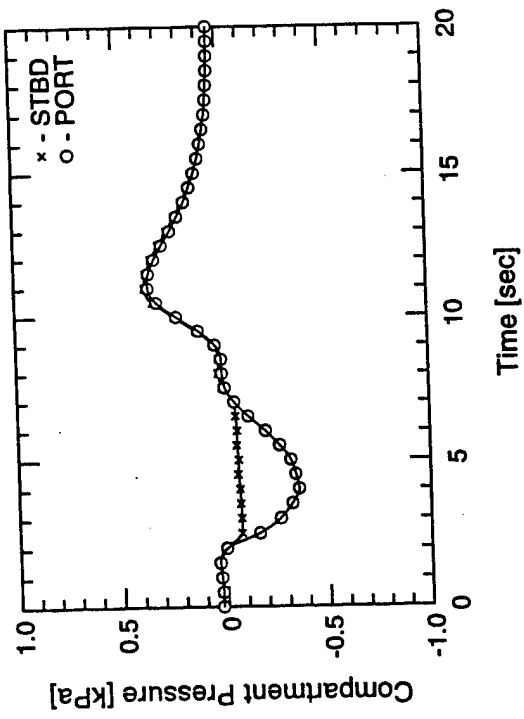
Test #33



Test #33

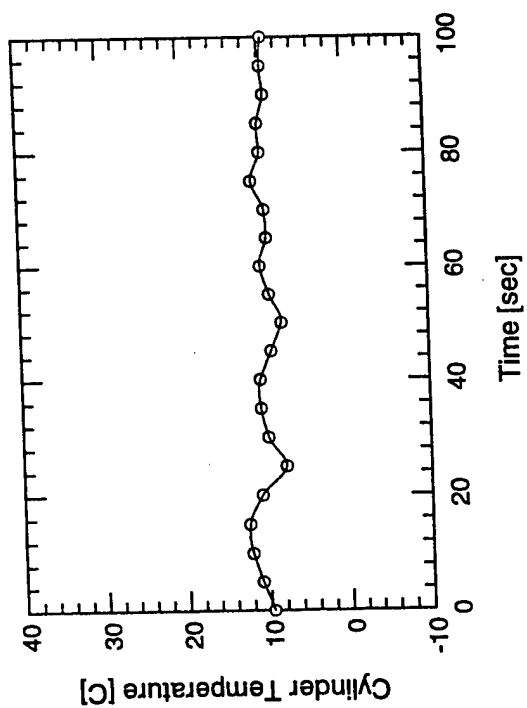
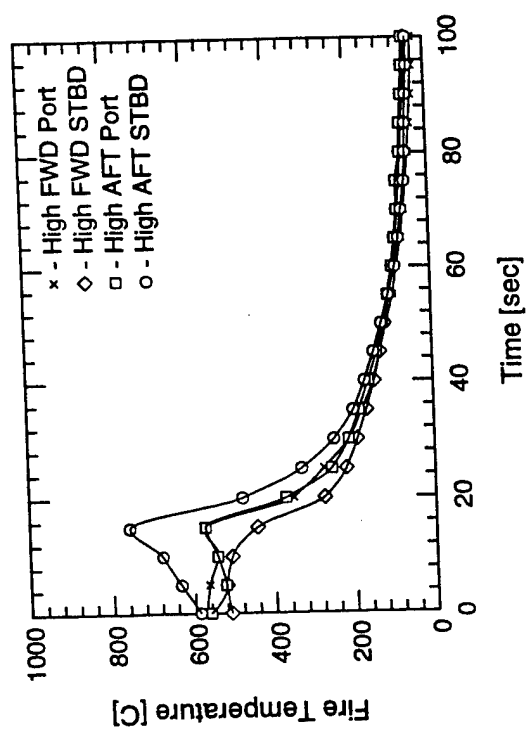
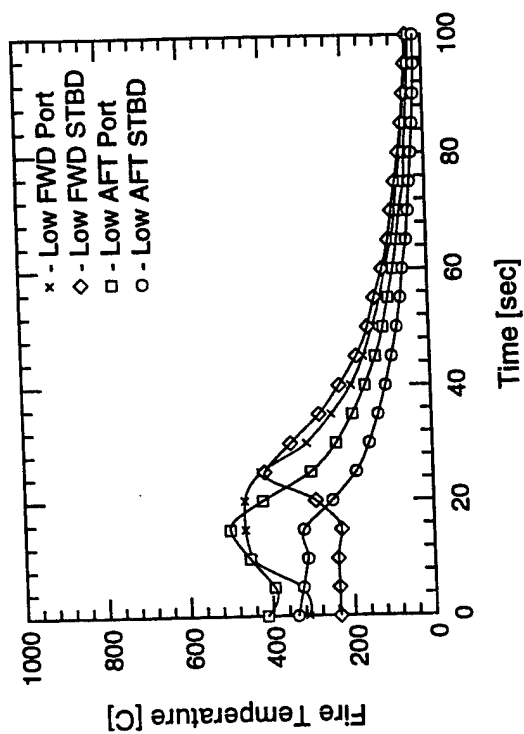


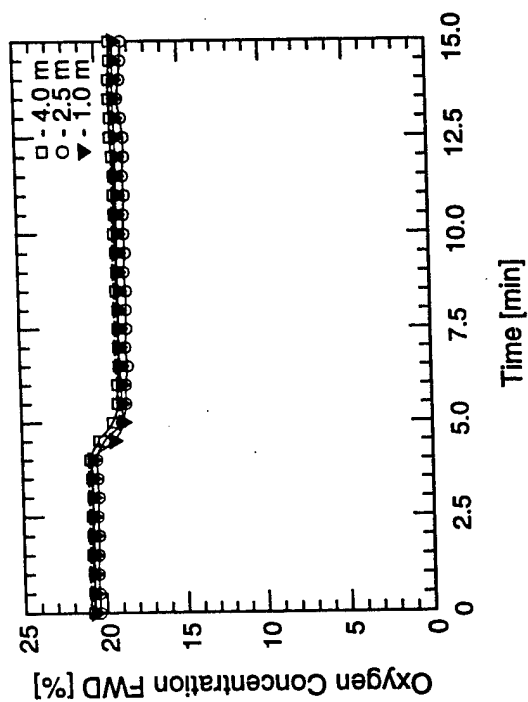
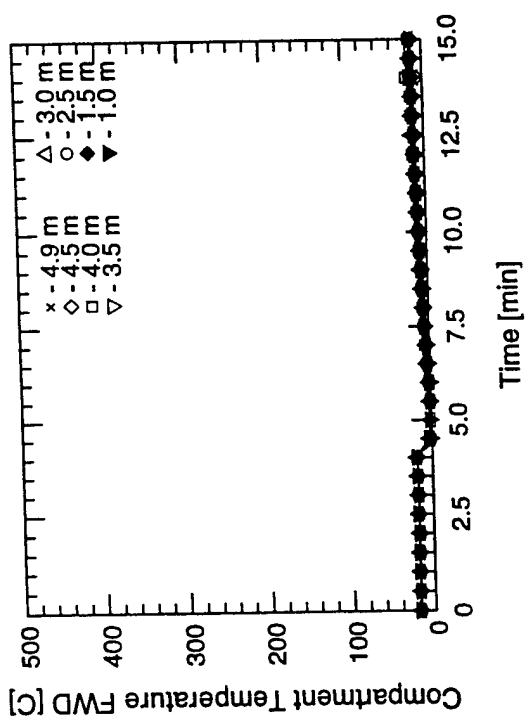
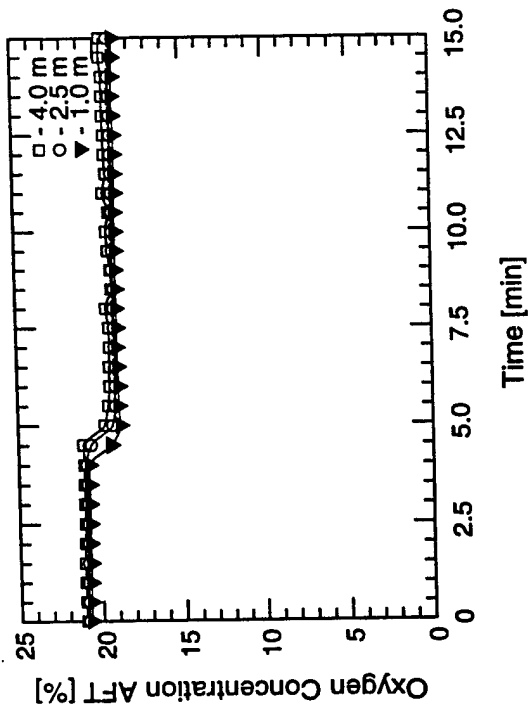
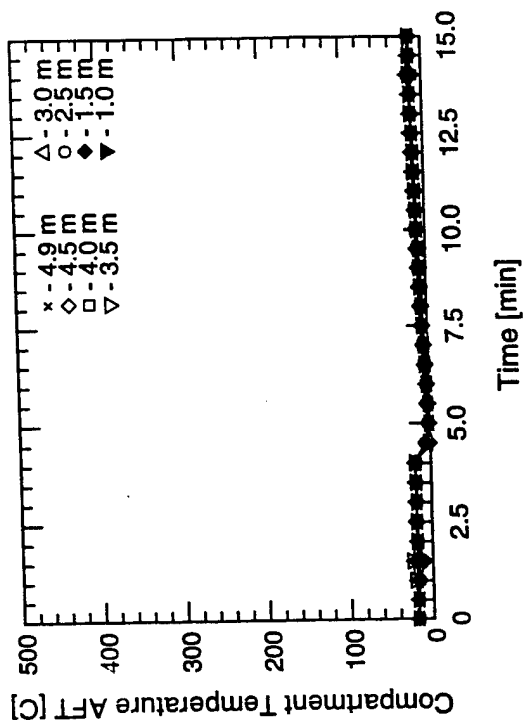
Test #33



Test #33

Test #33

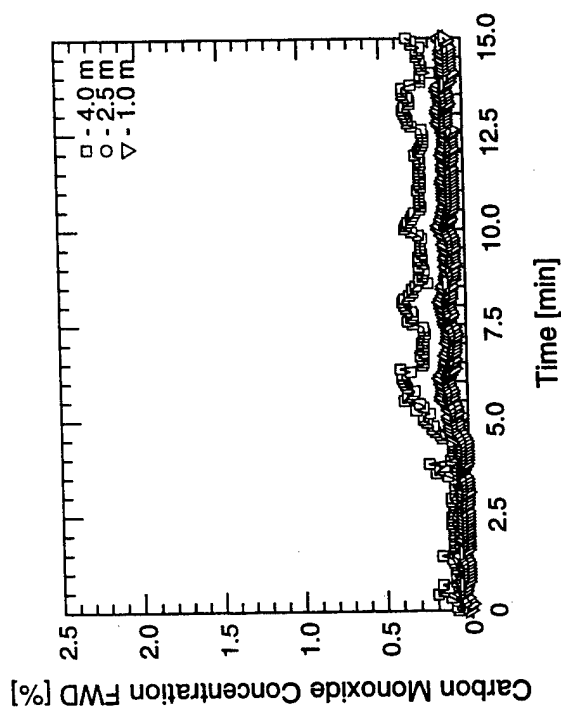
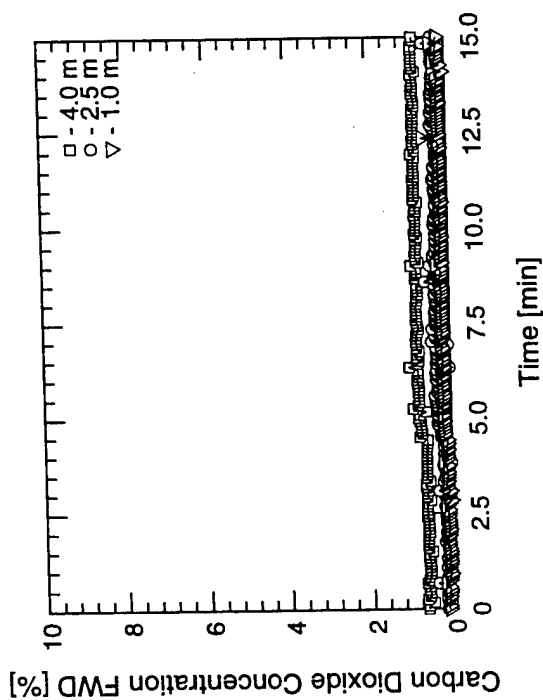
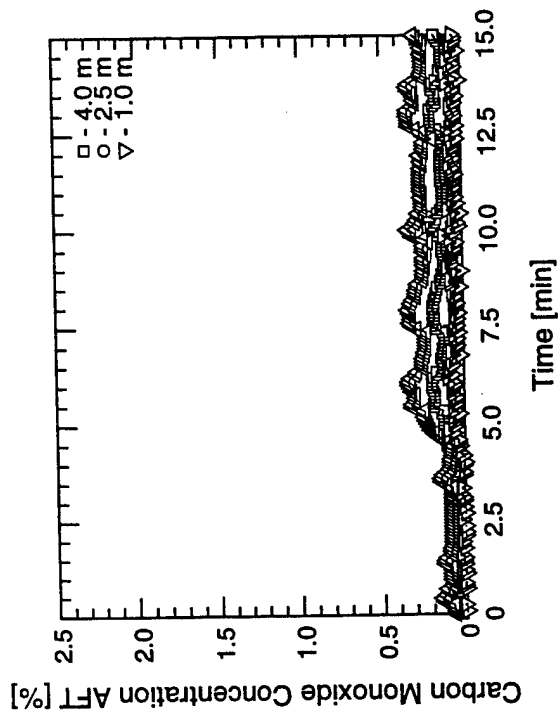
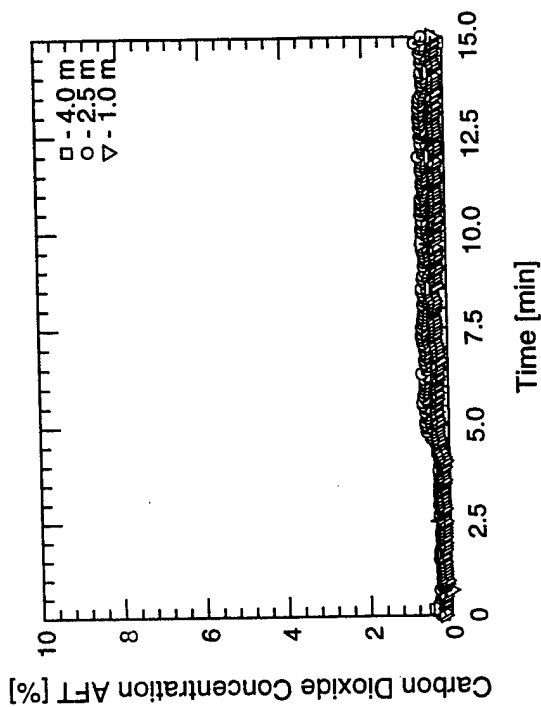


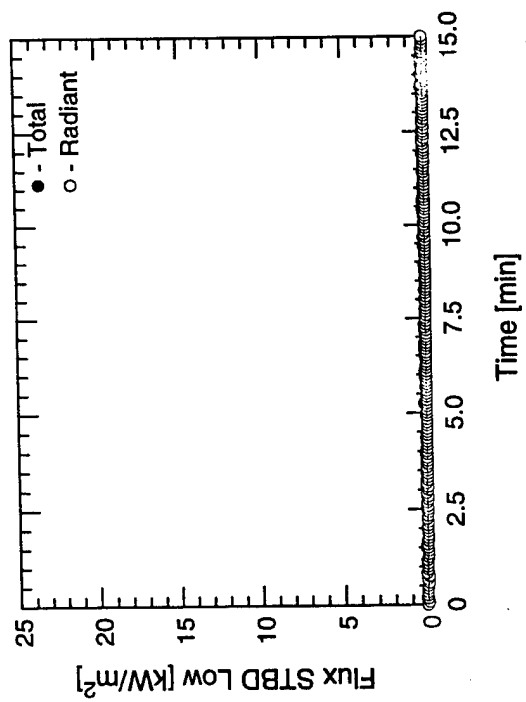
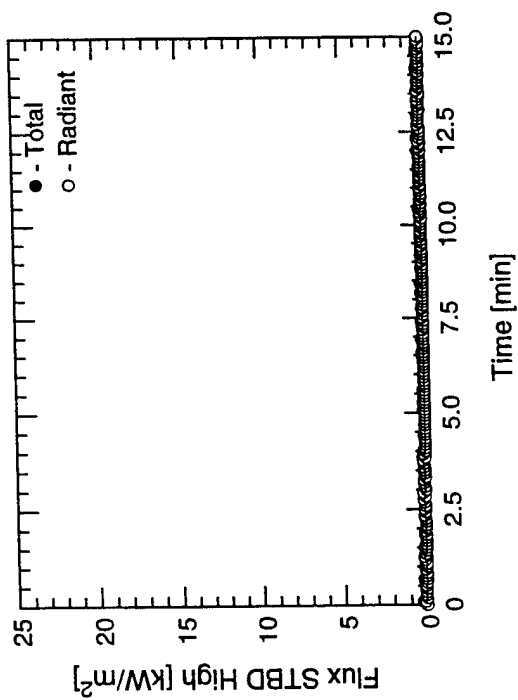
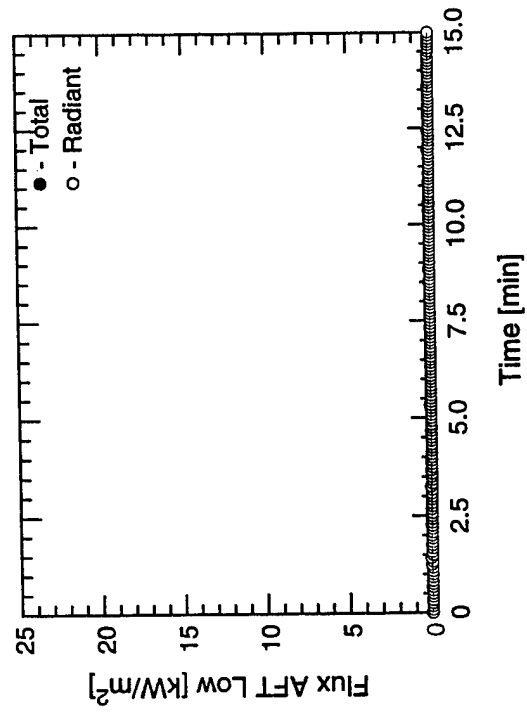
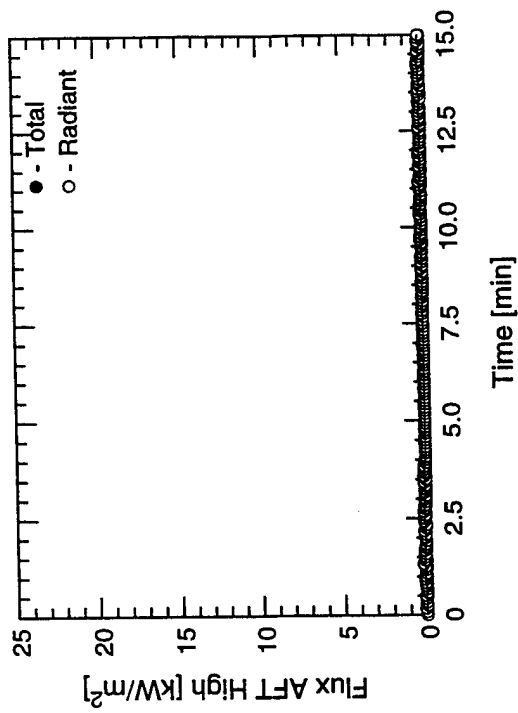


Test #34

Test #34

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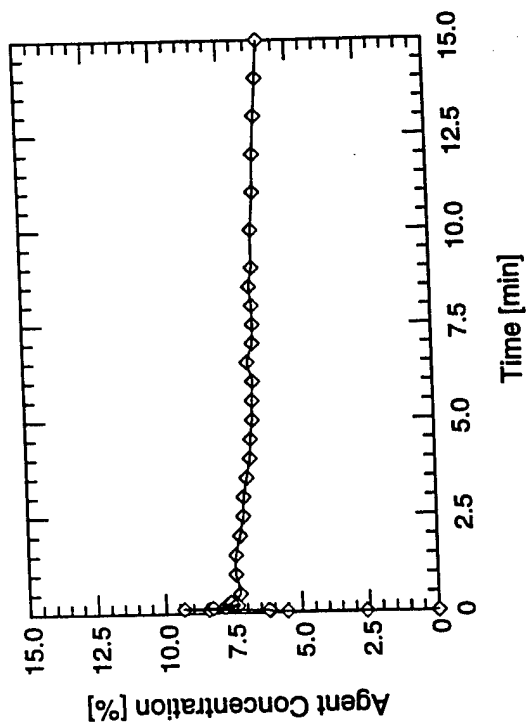
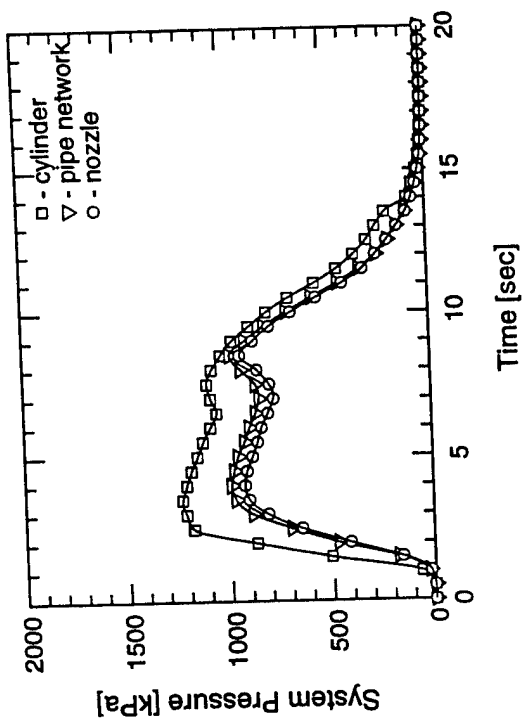
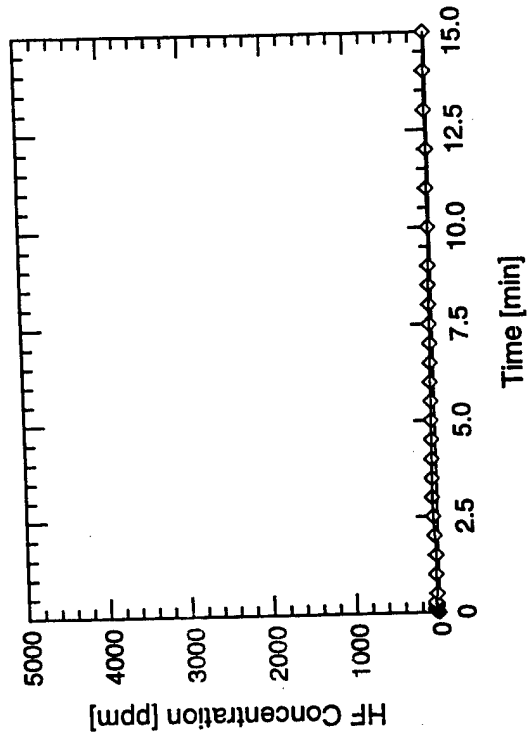
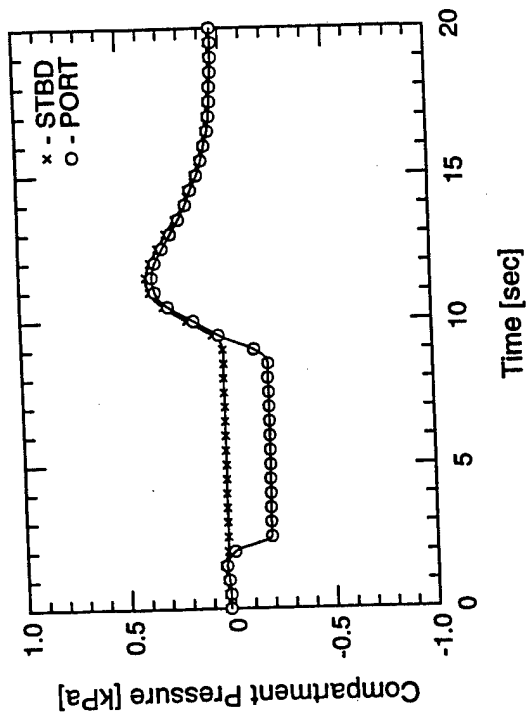


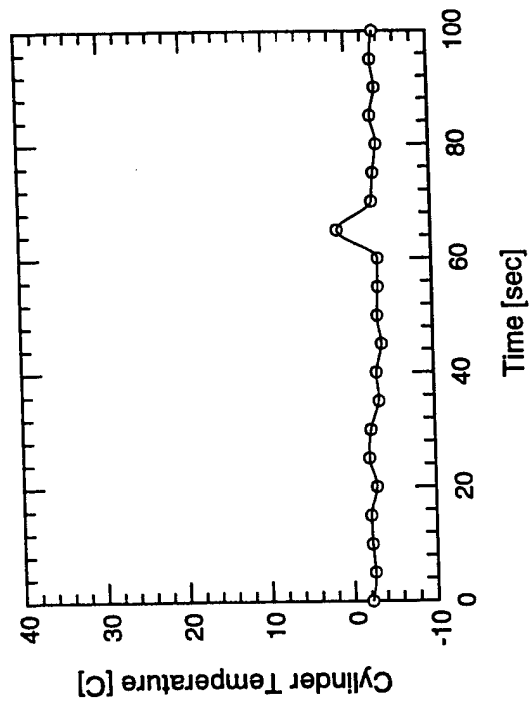
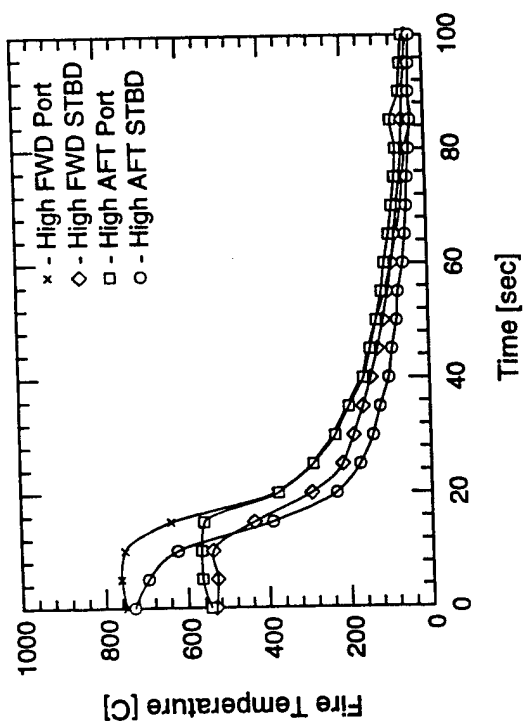
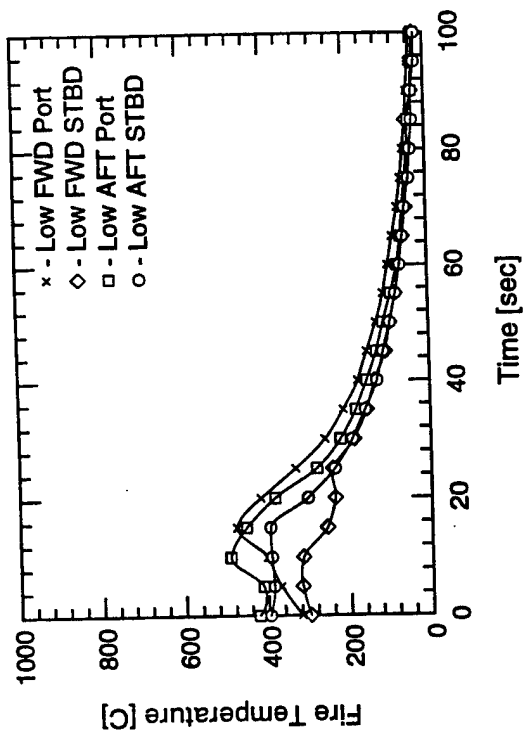


Test #34

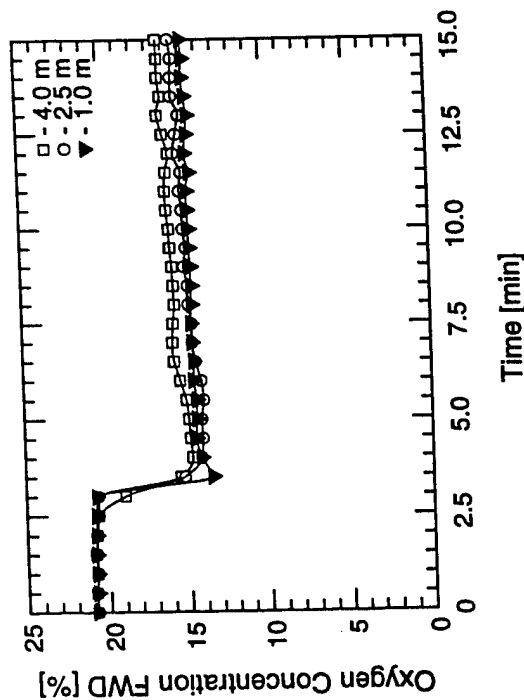
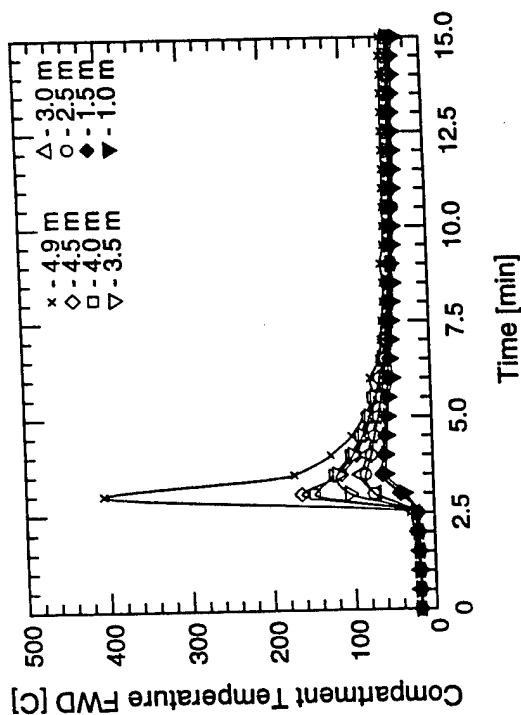
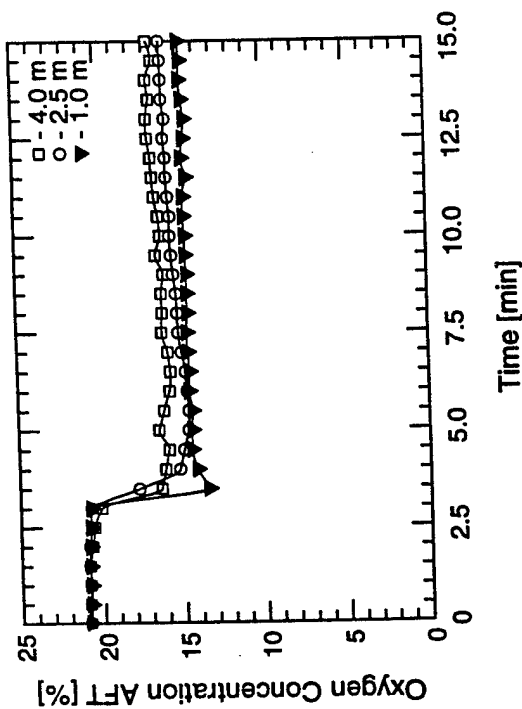
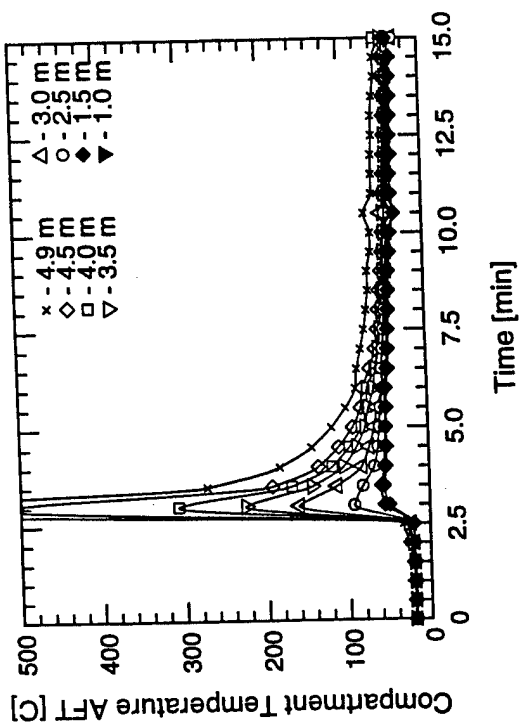
Test #34

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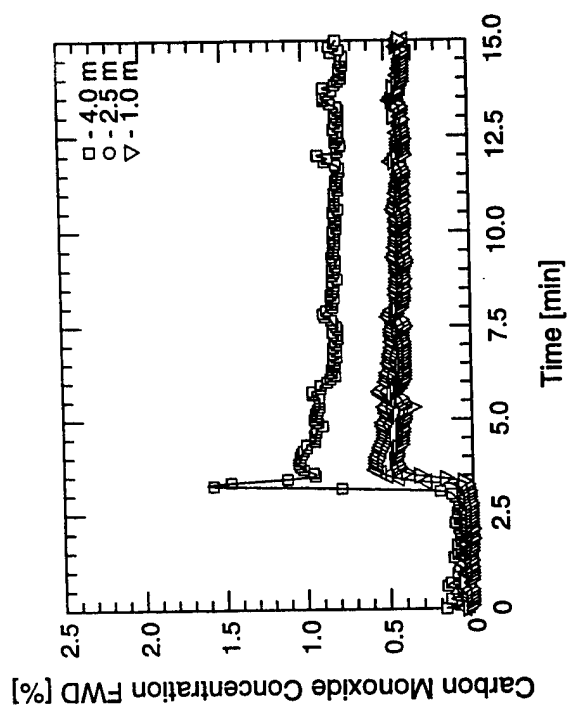
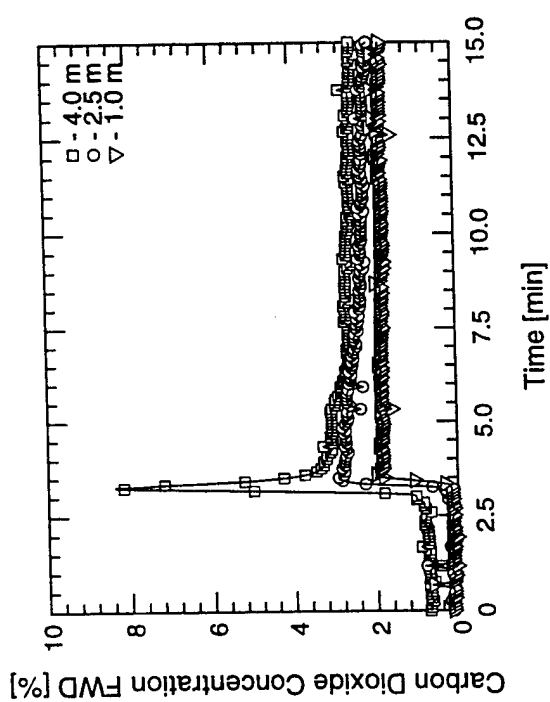
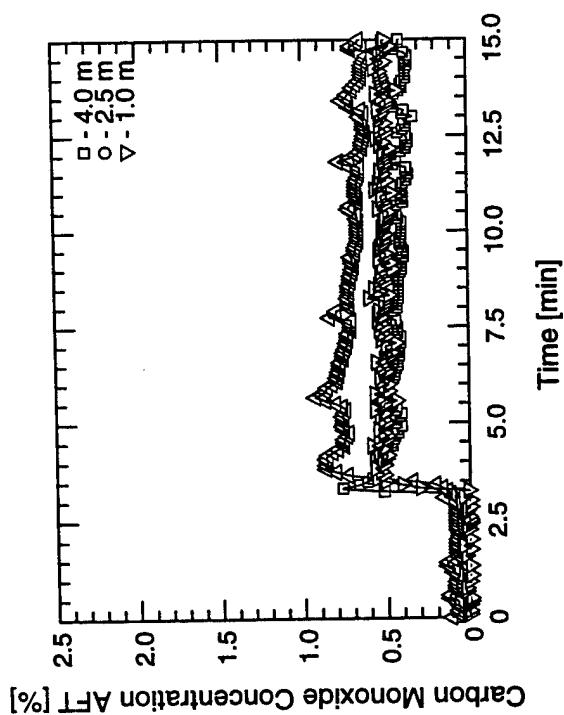
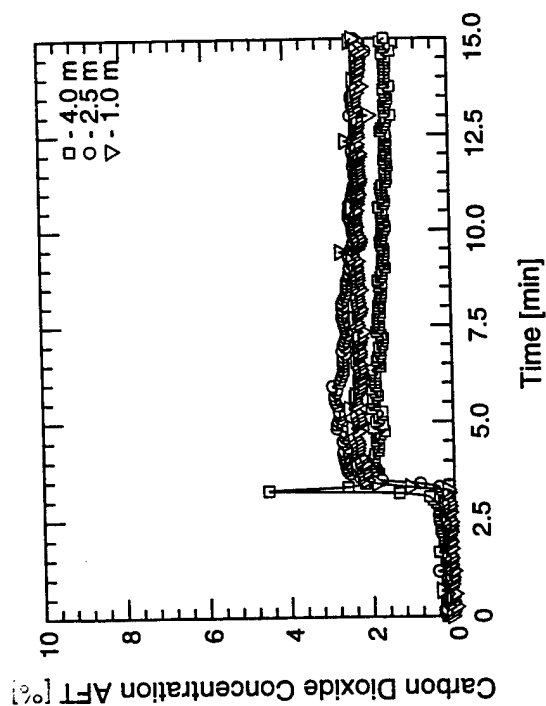




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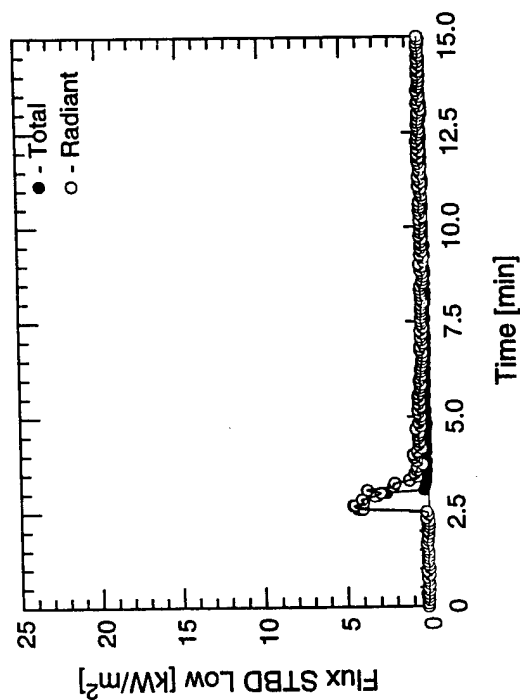
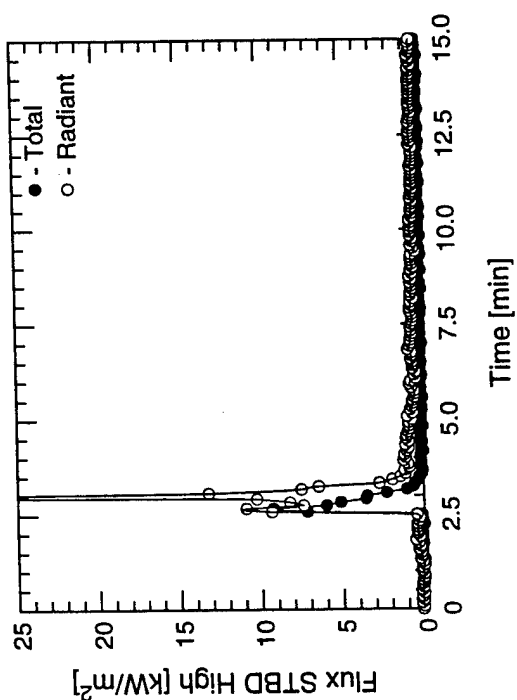
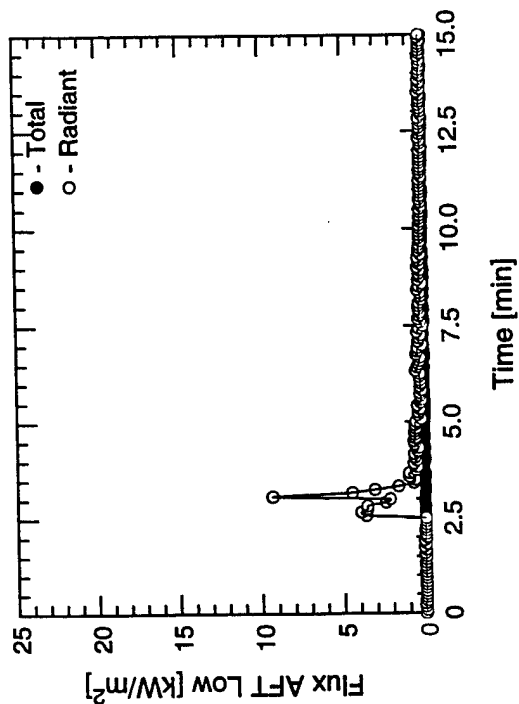
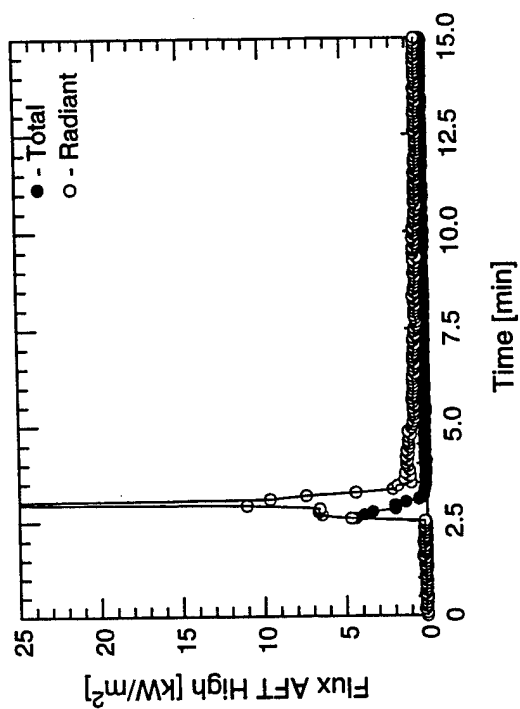


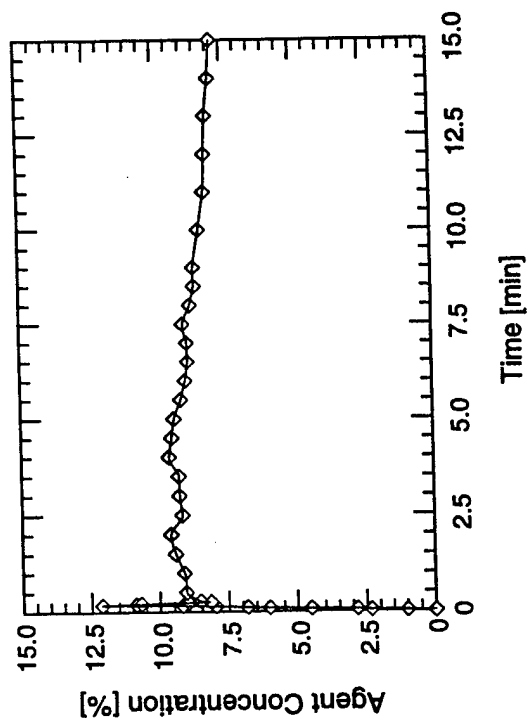
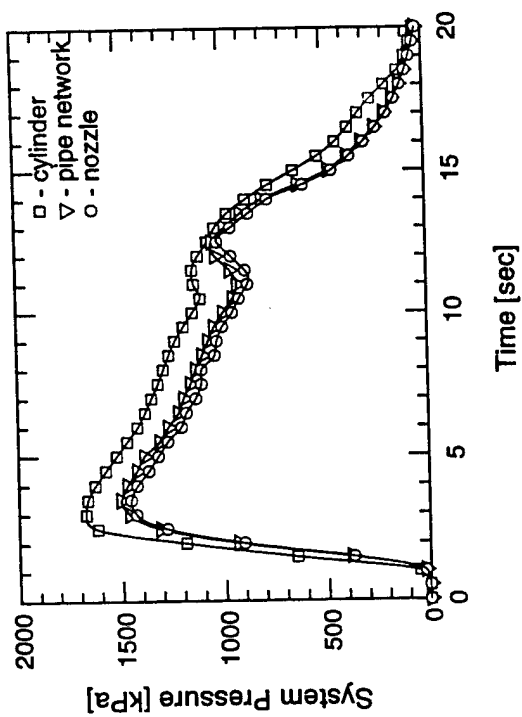
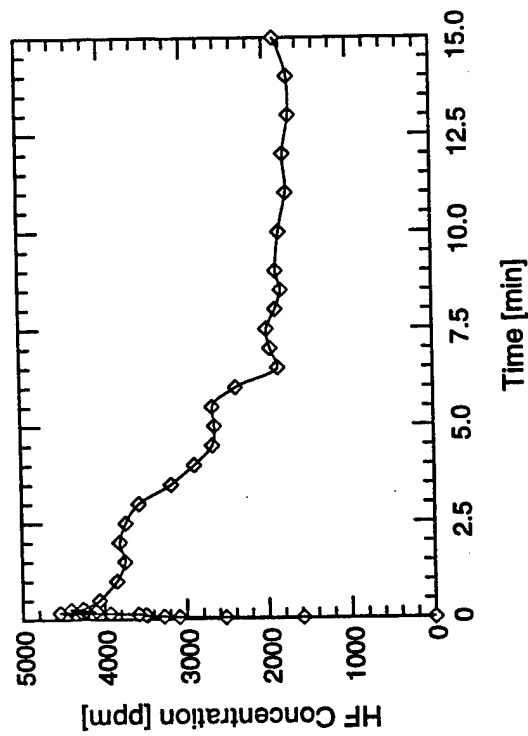
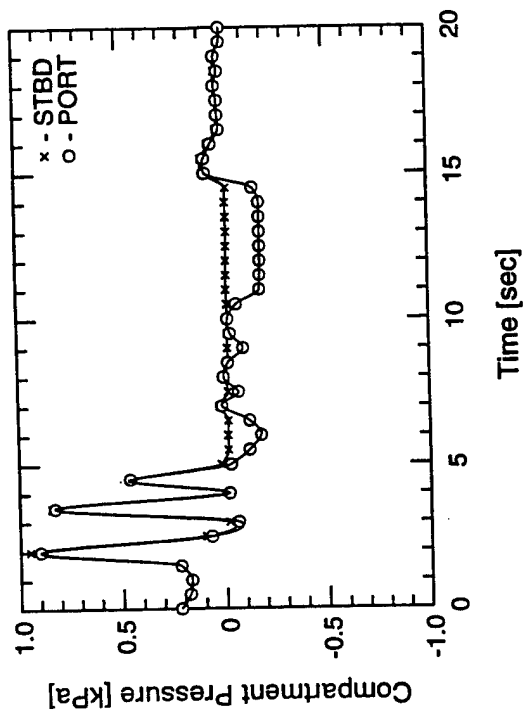
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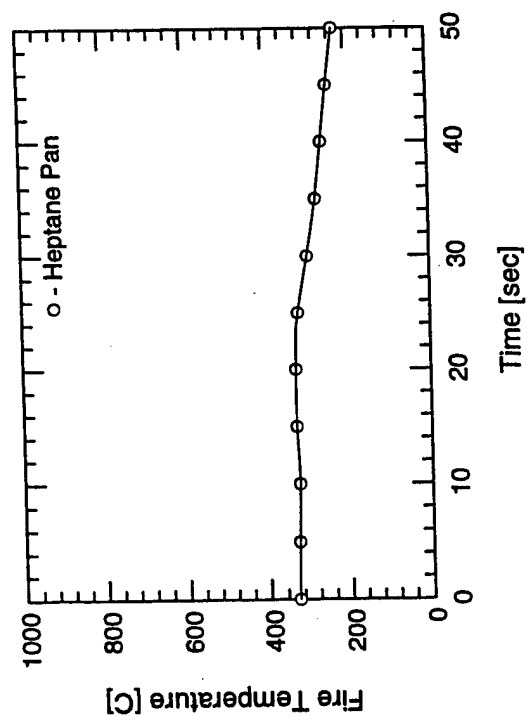
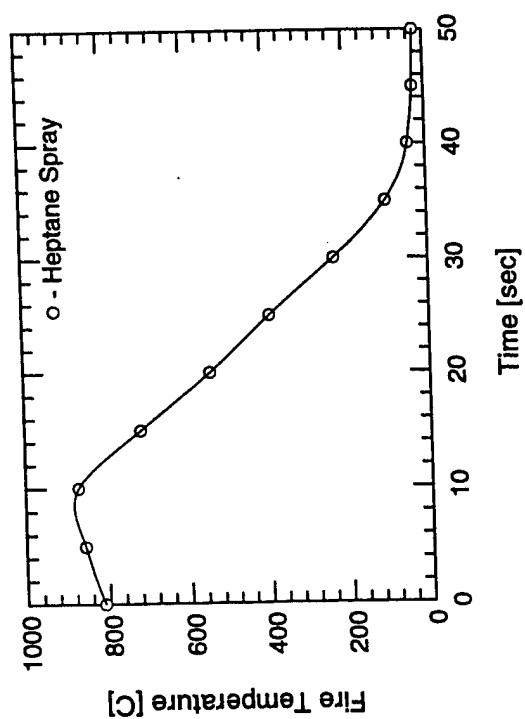
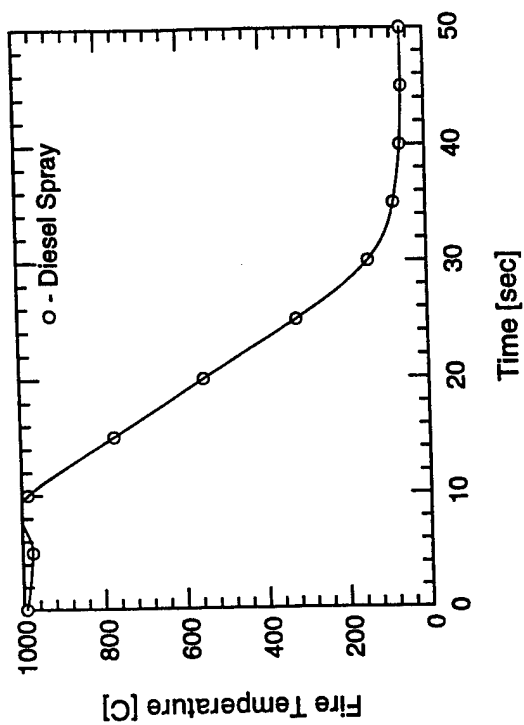
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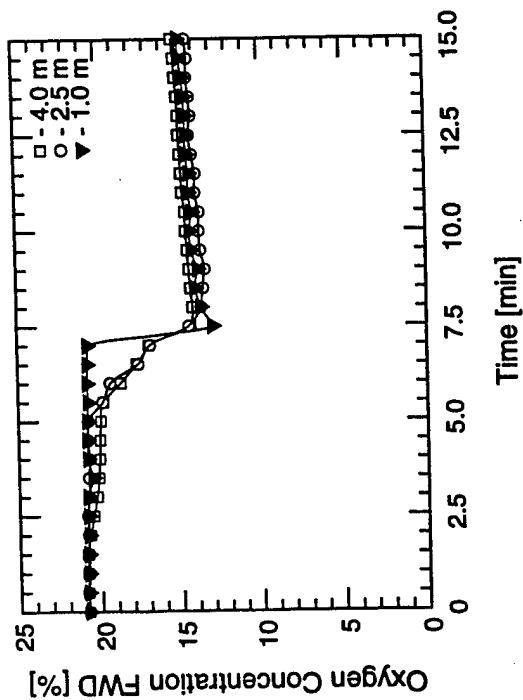
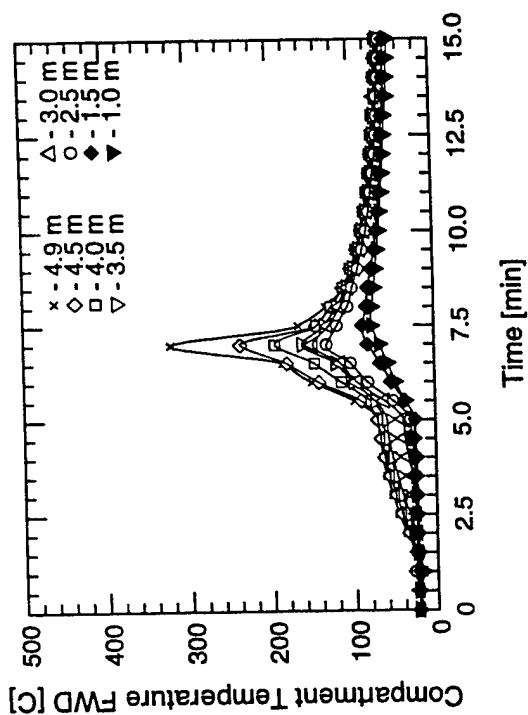
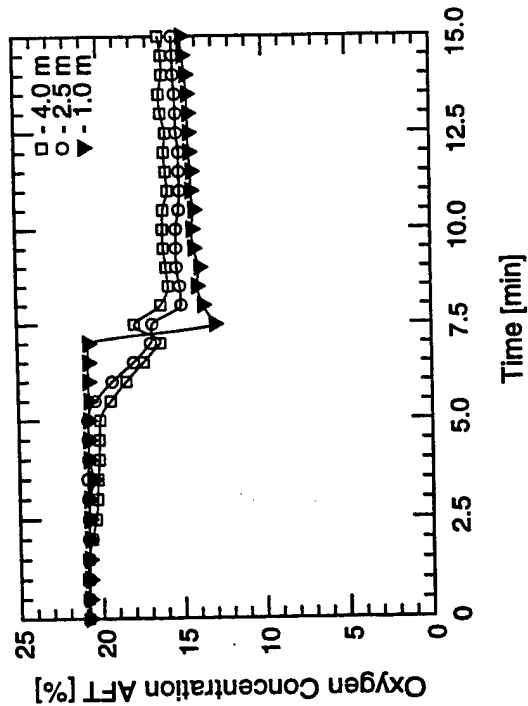
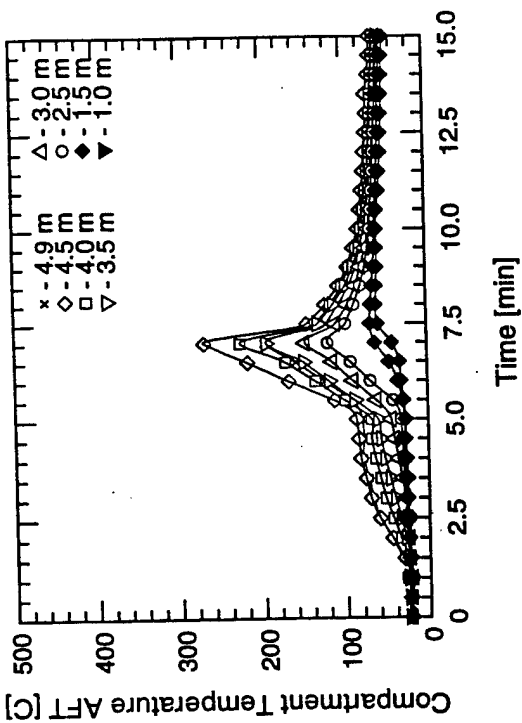




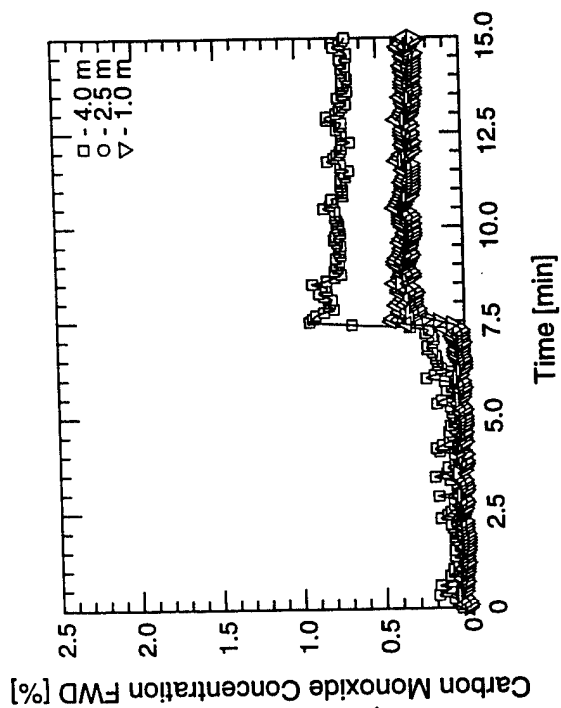
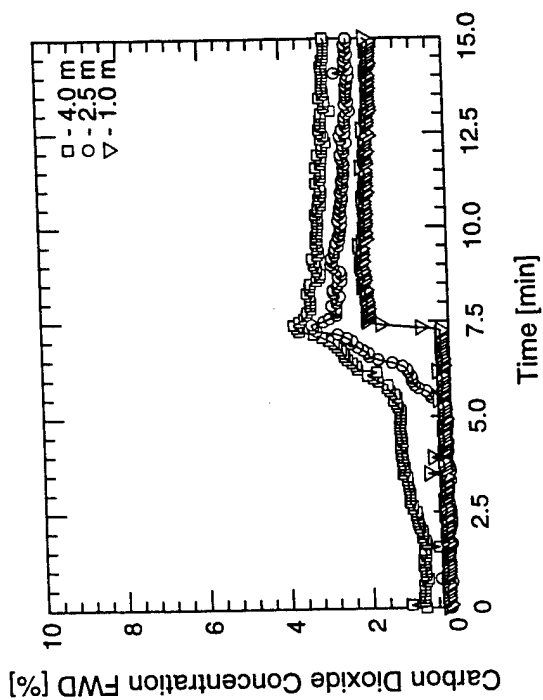
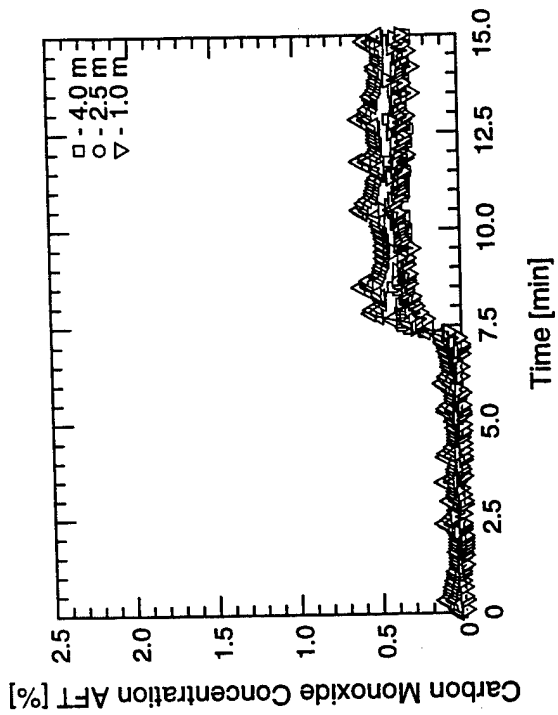
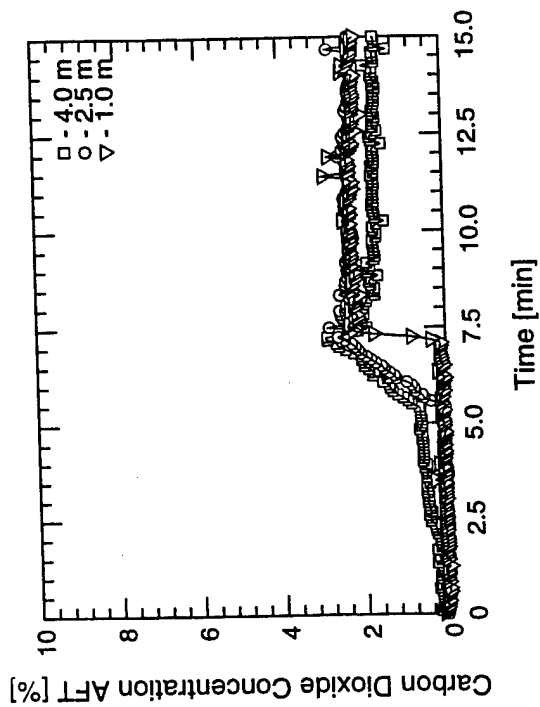
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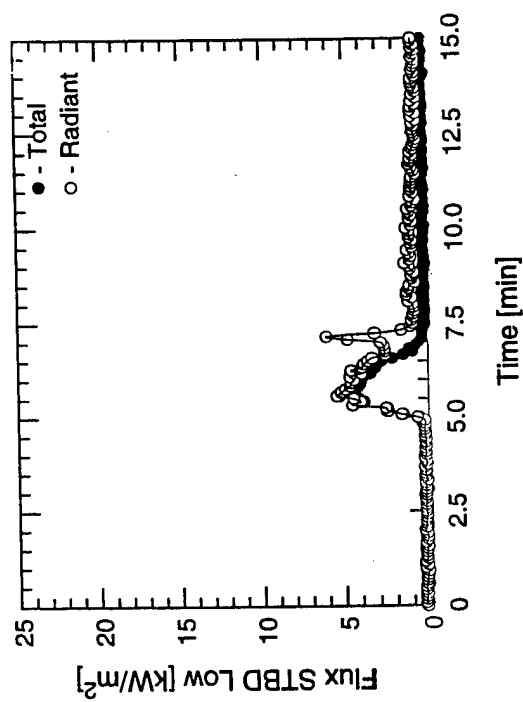
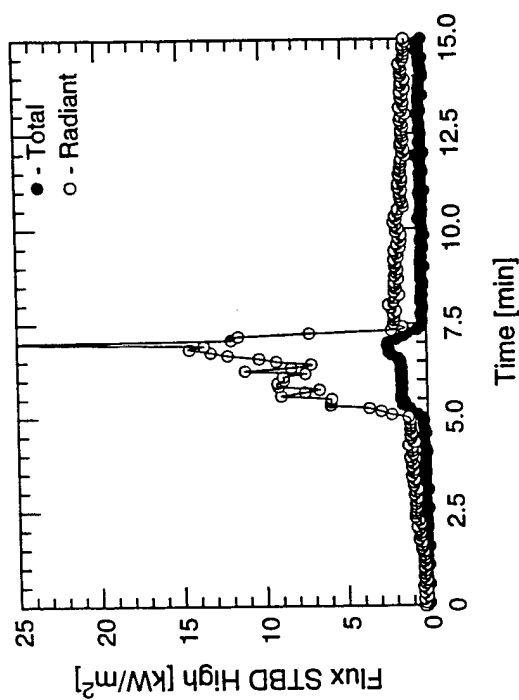
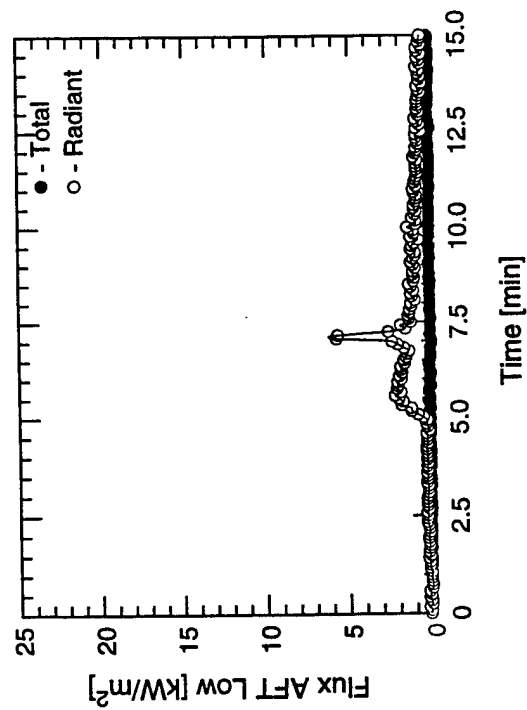
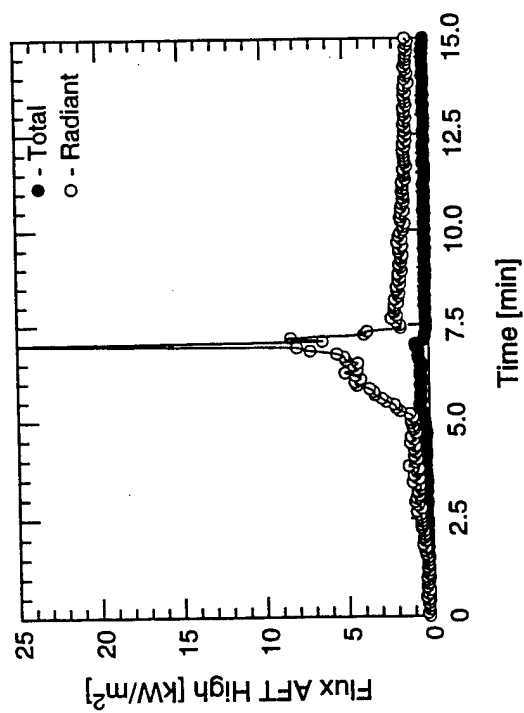




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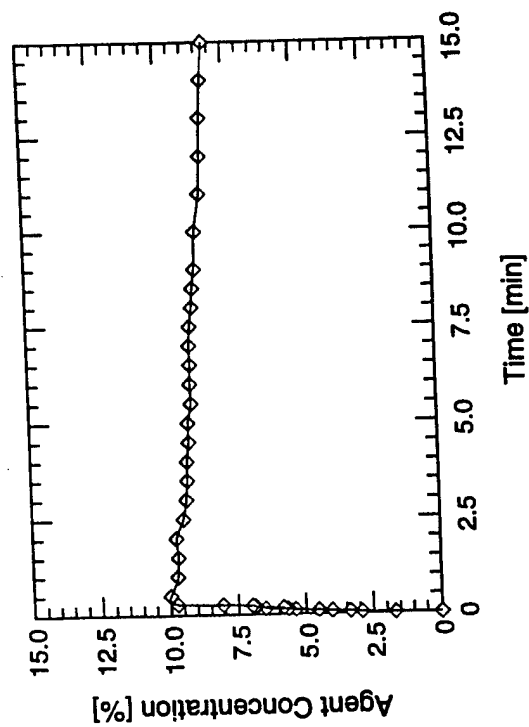
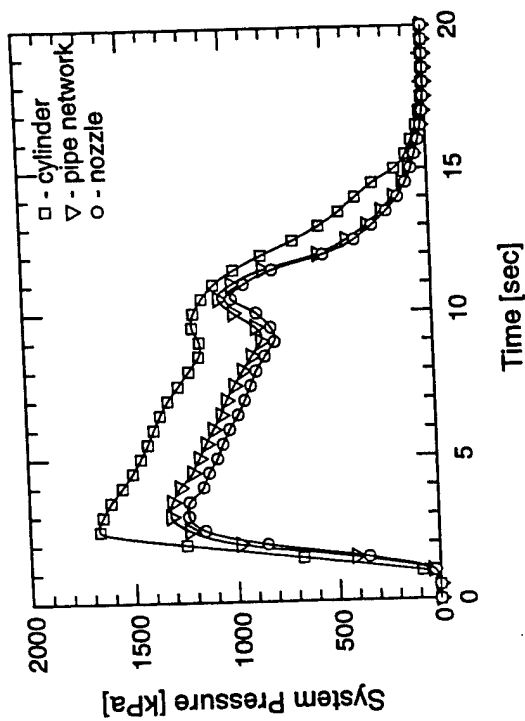
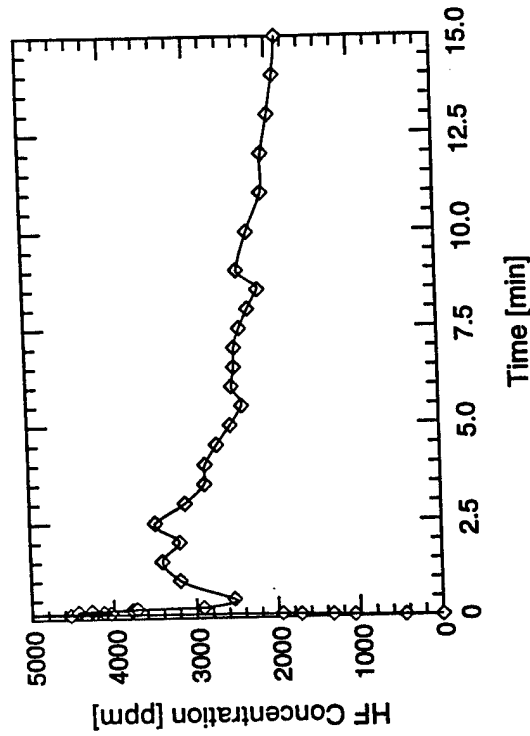
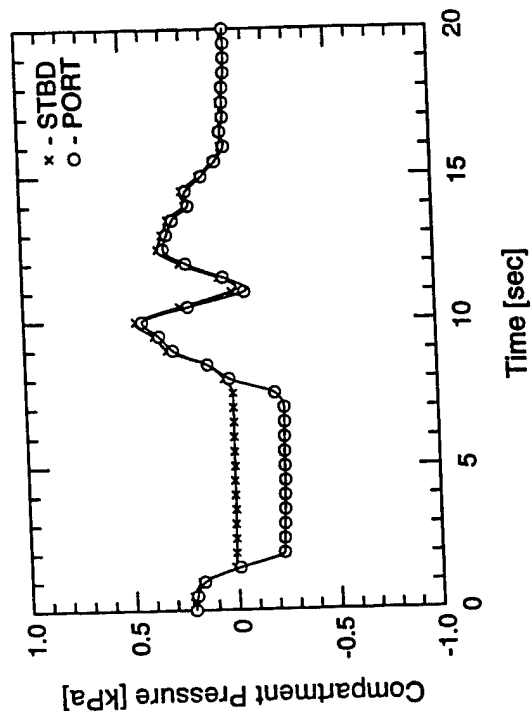


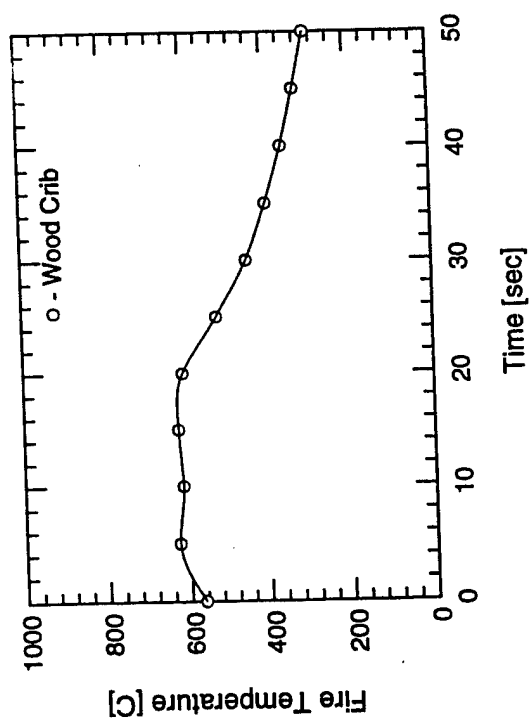
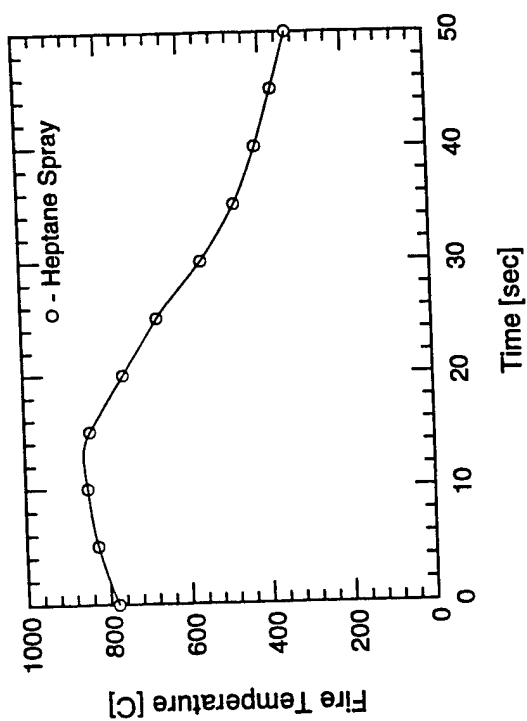
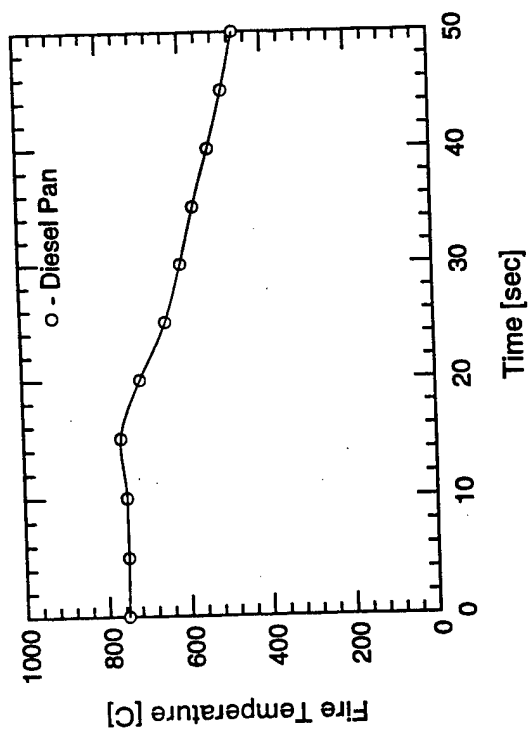
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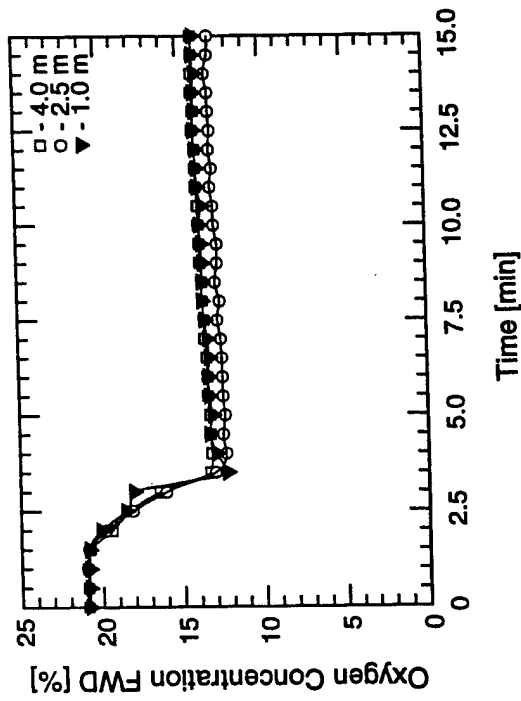
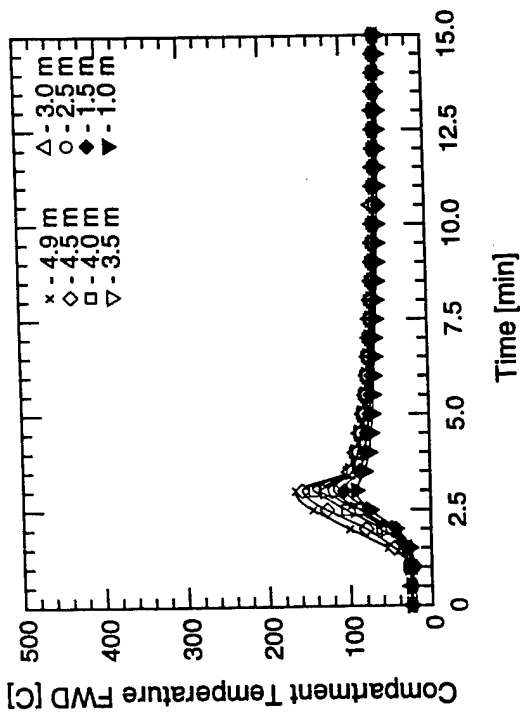
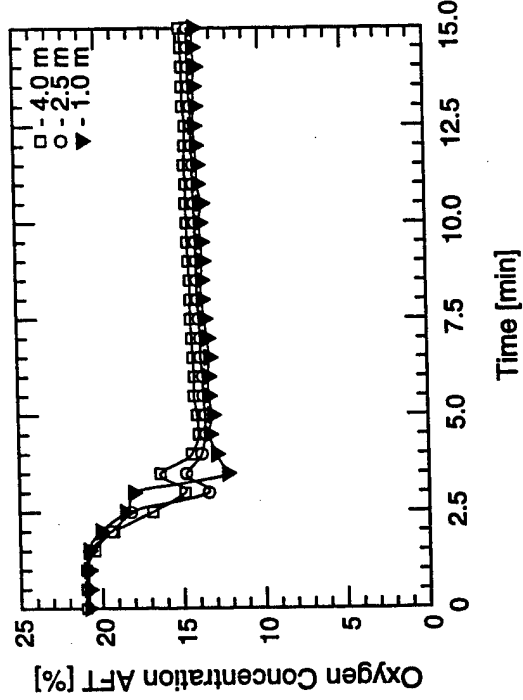
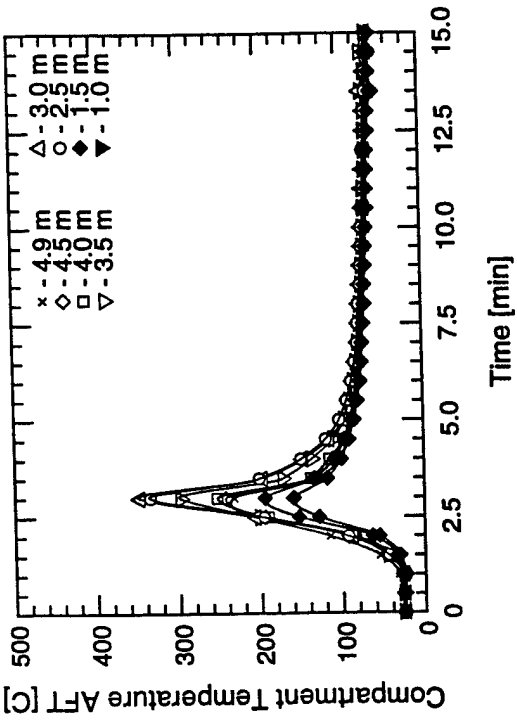
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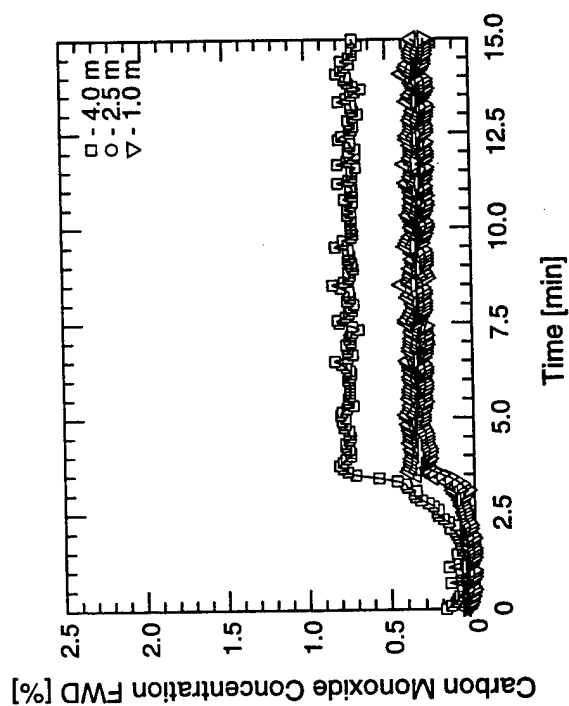
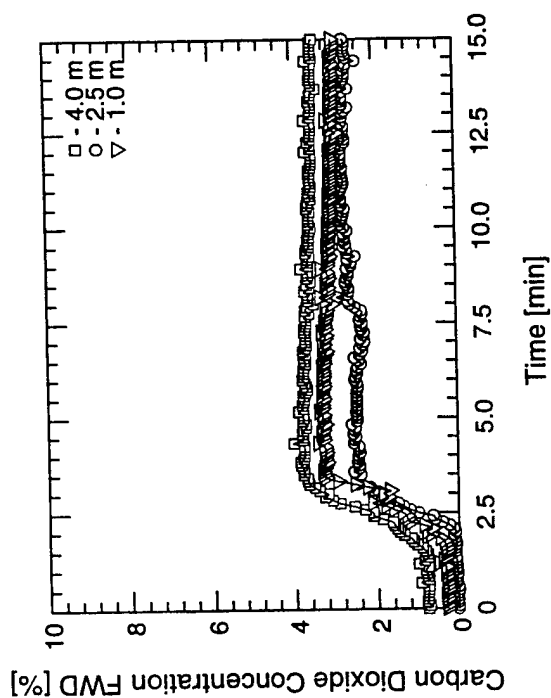
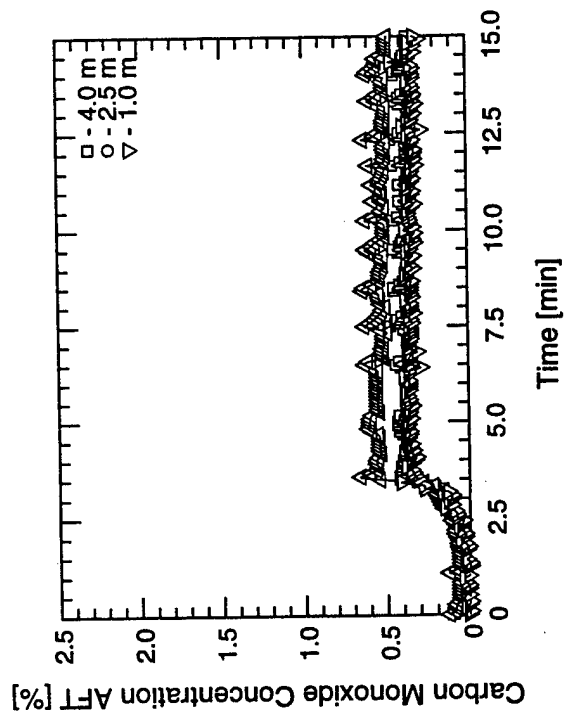
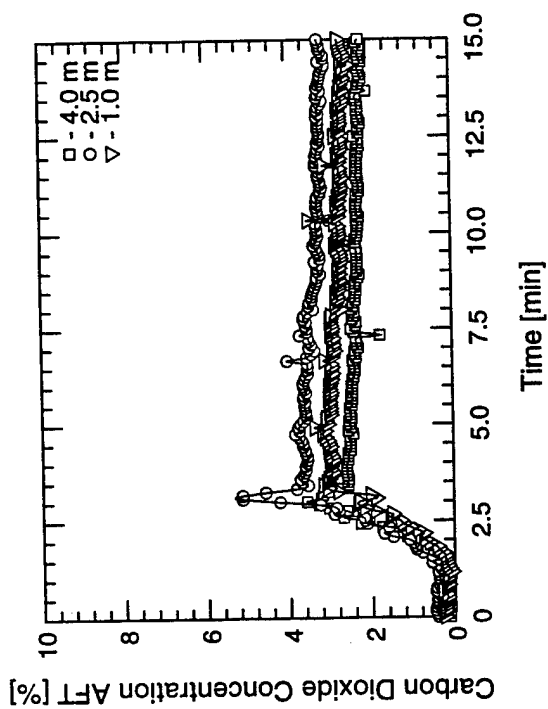




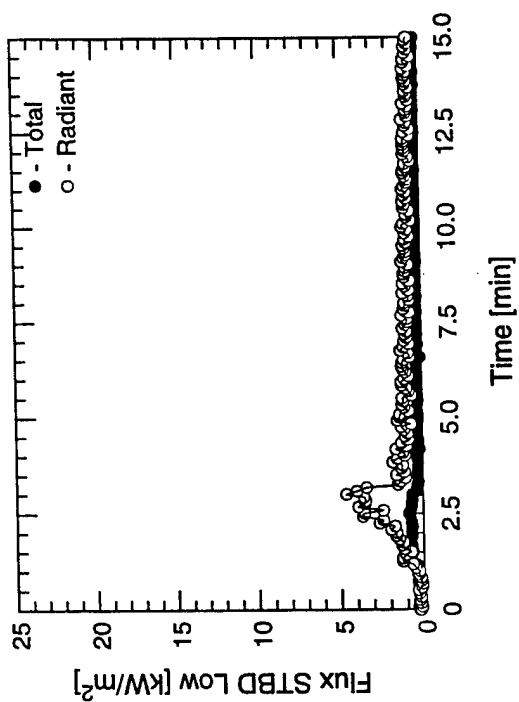
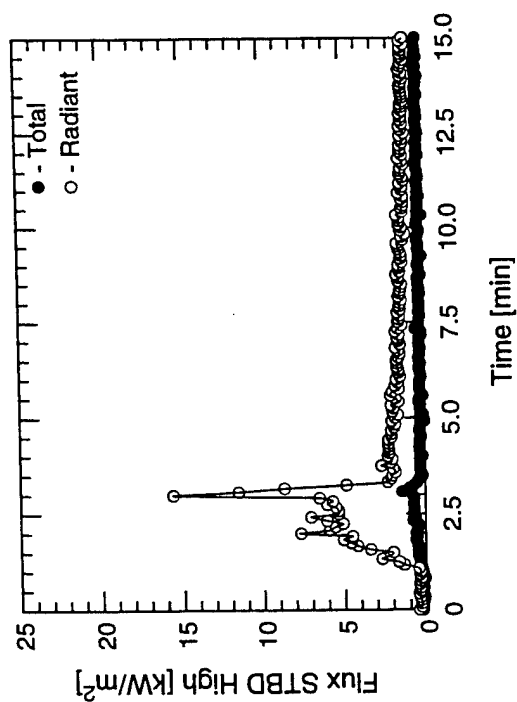
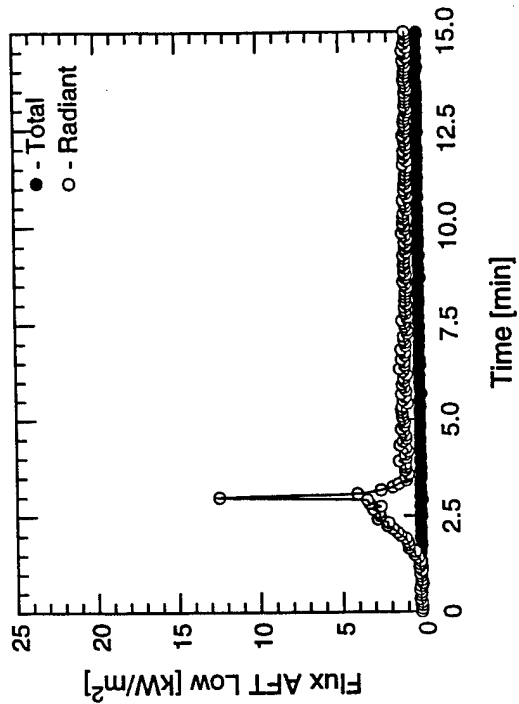
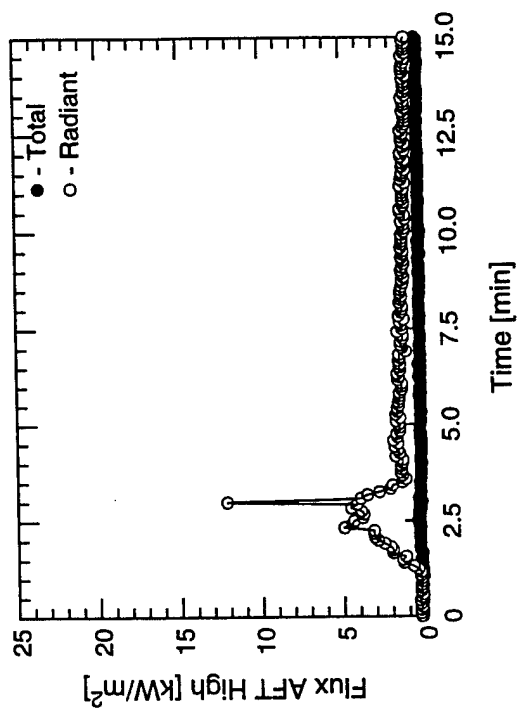
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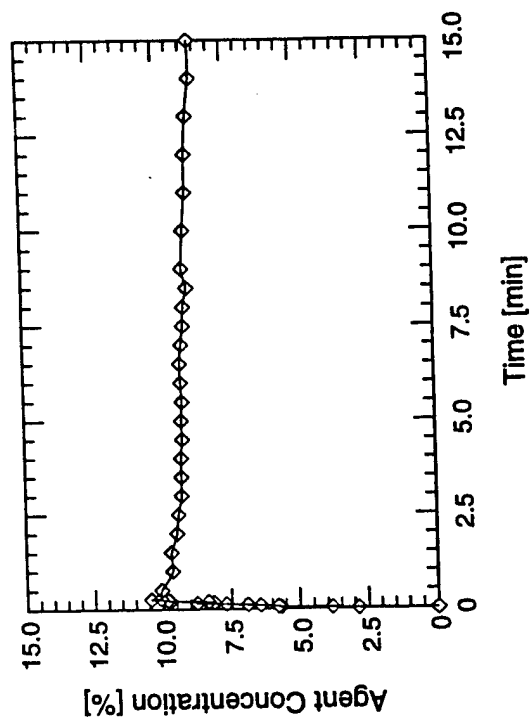
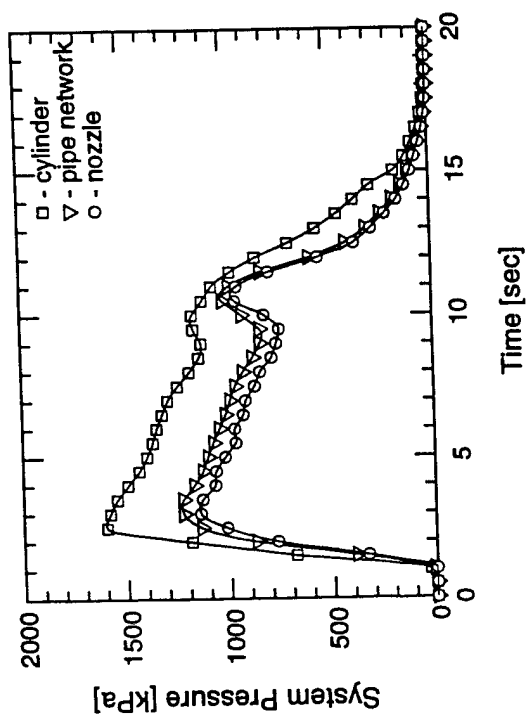
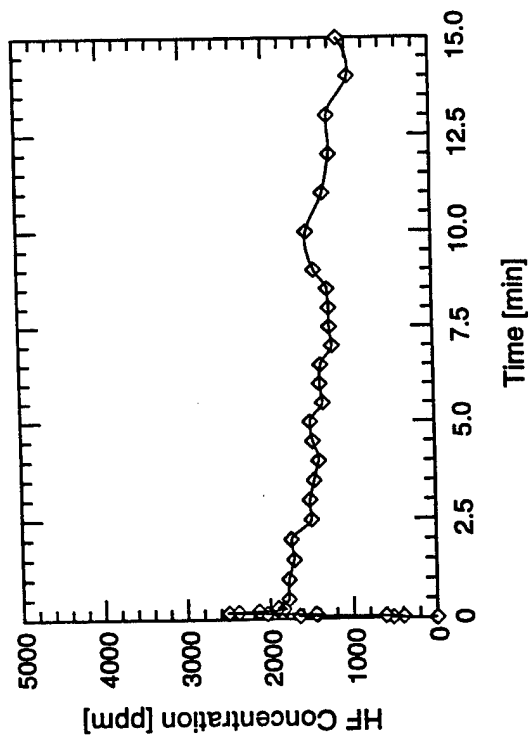
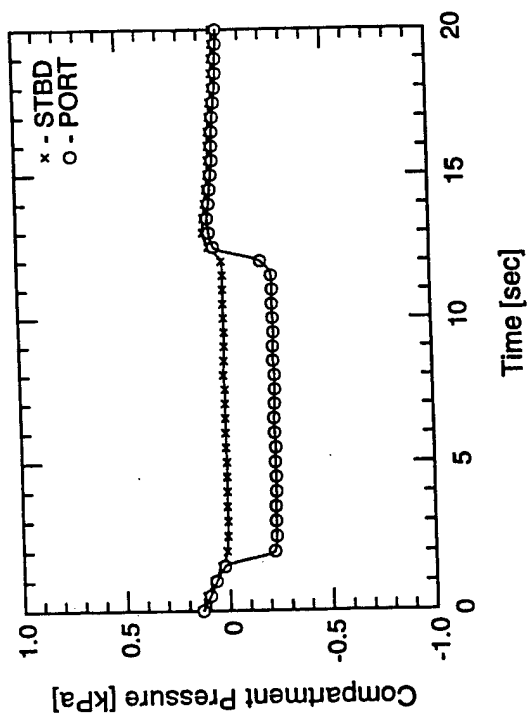
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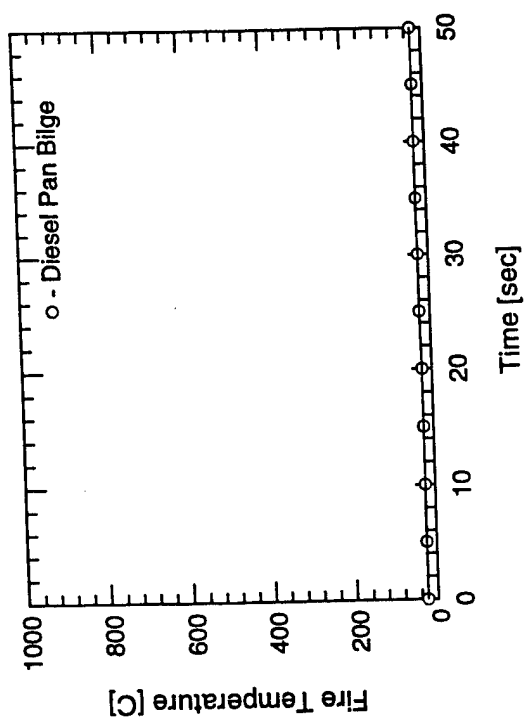
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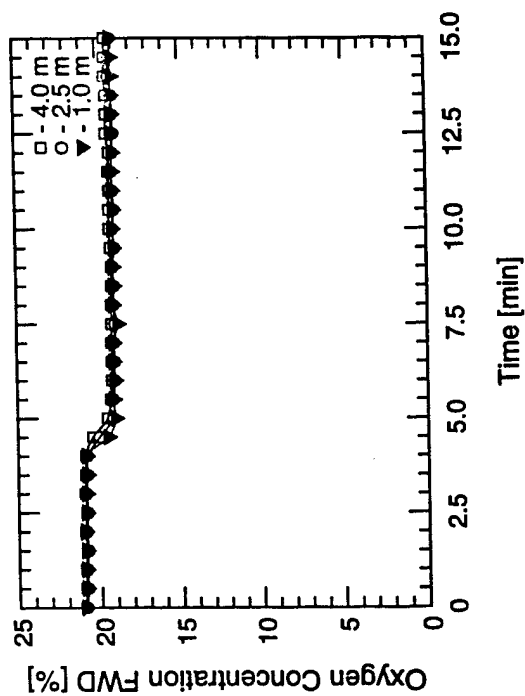
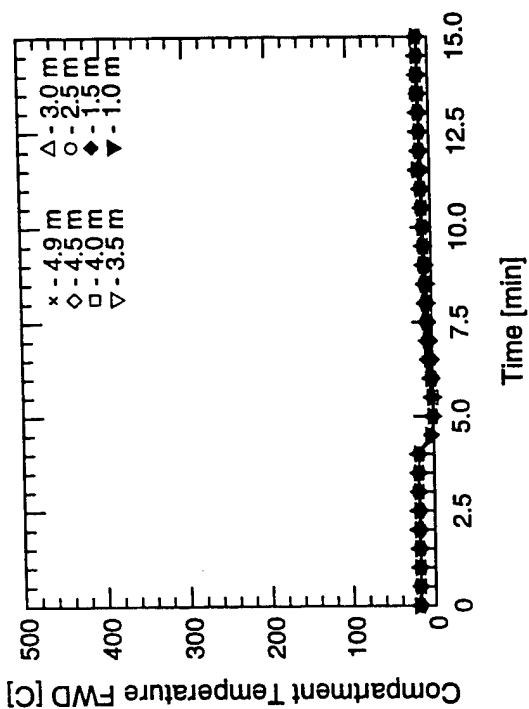
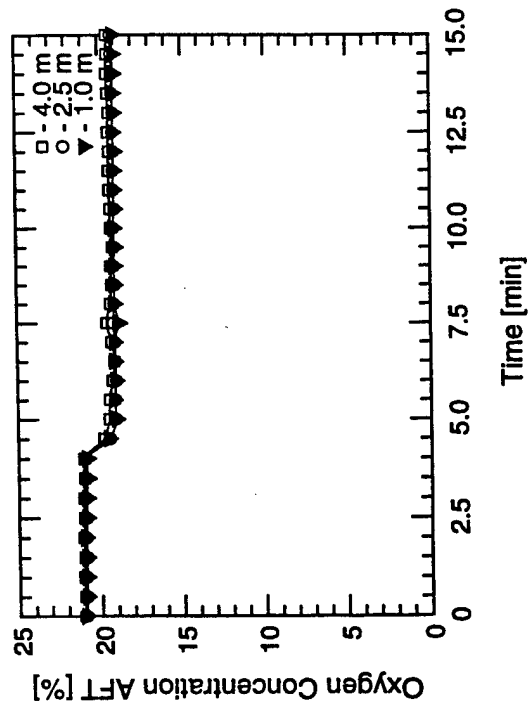
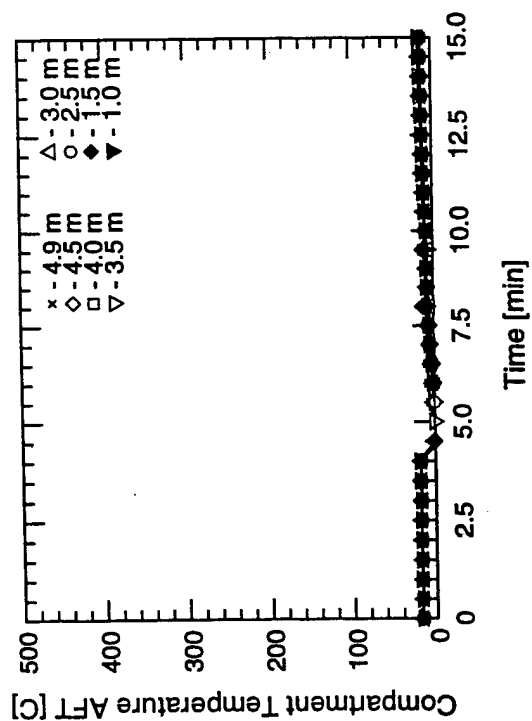


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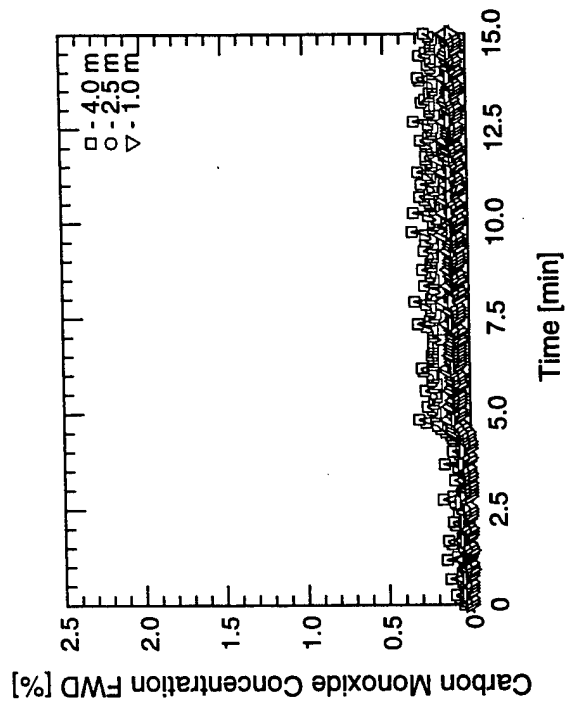
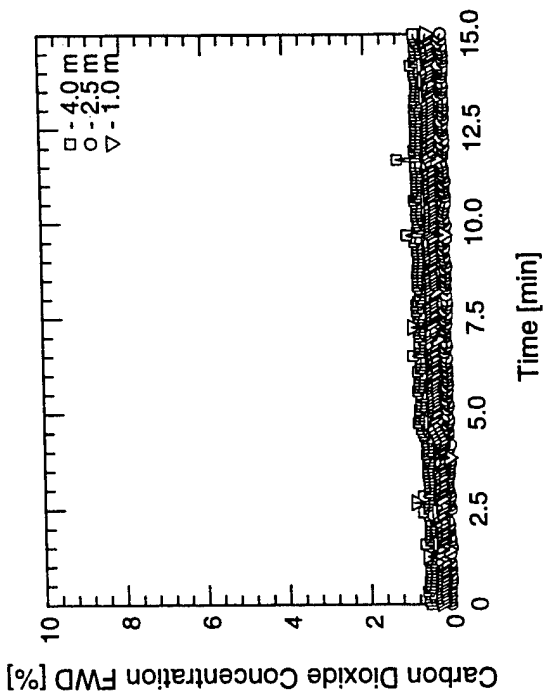
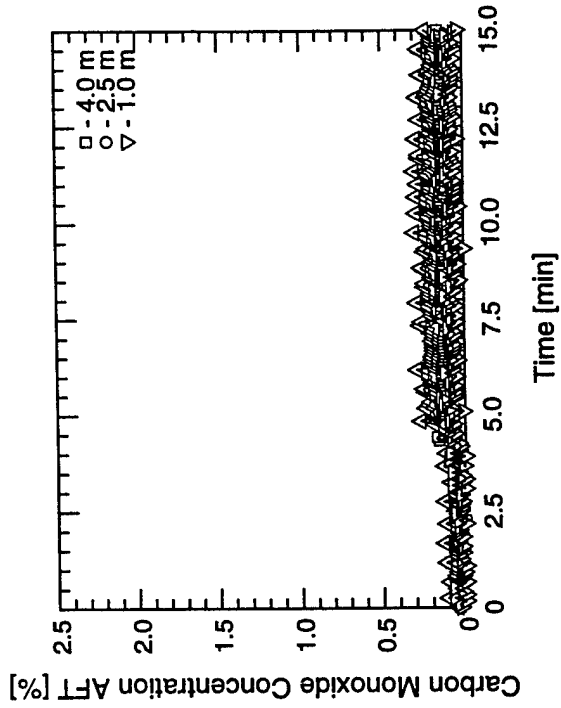
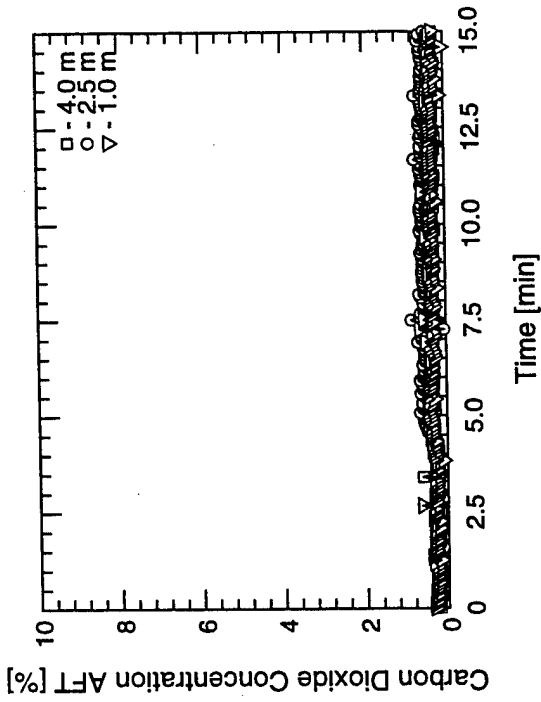
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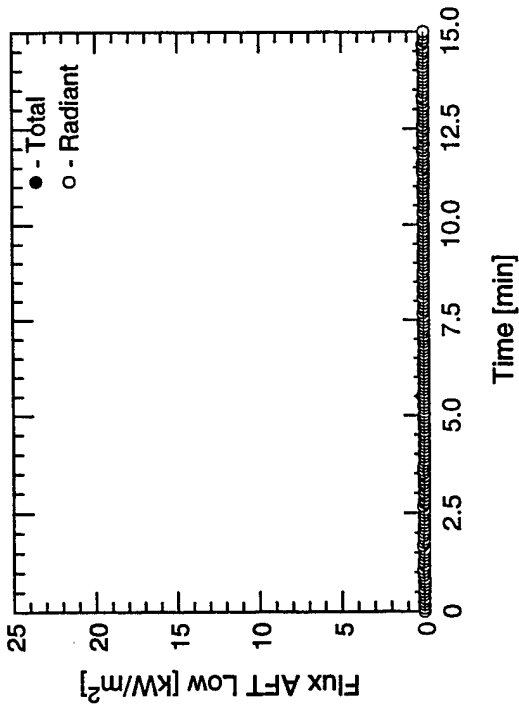
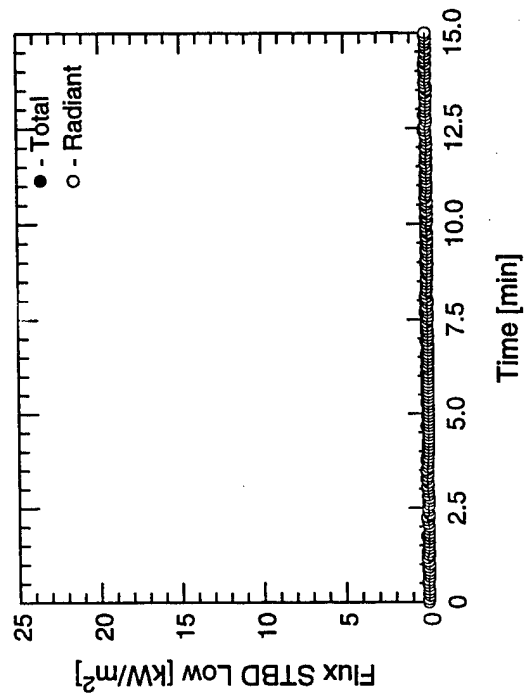
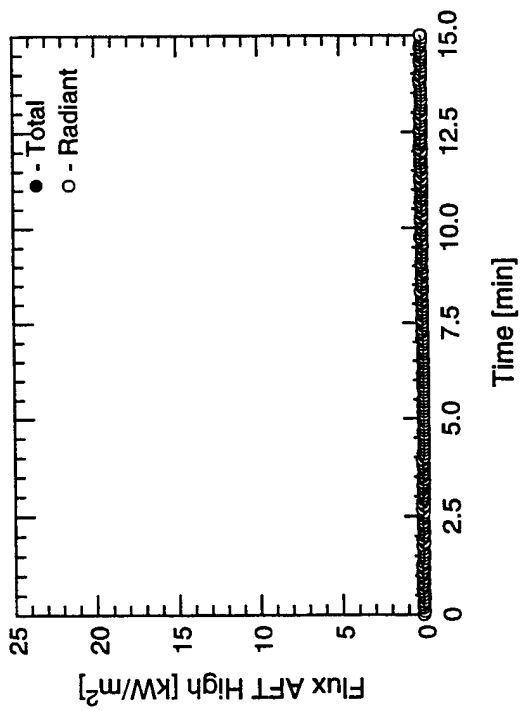
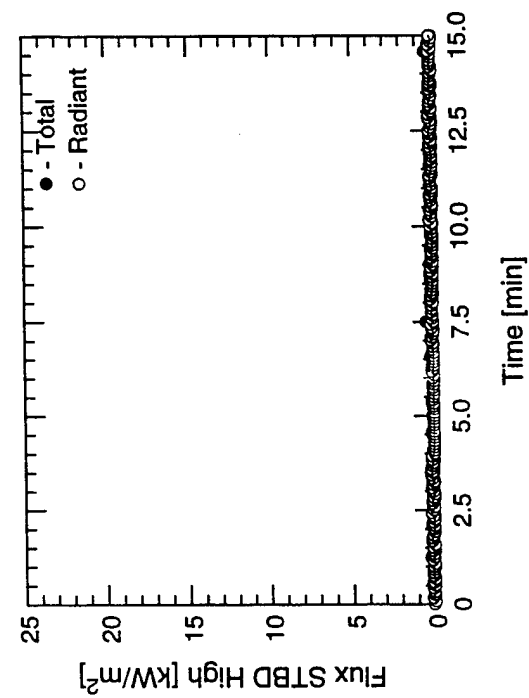
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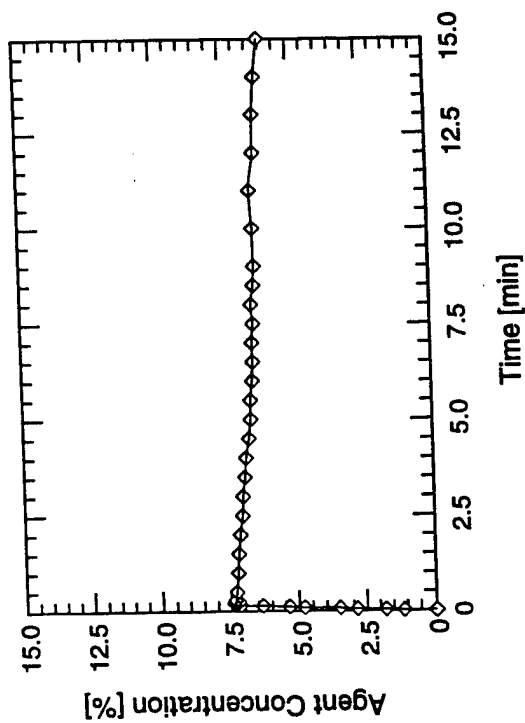
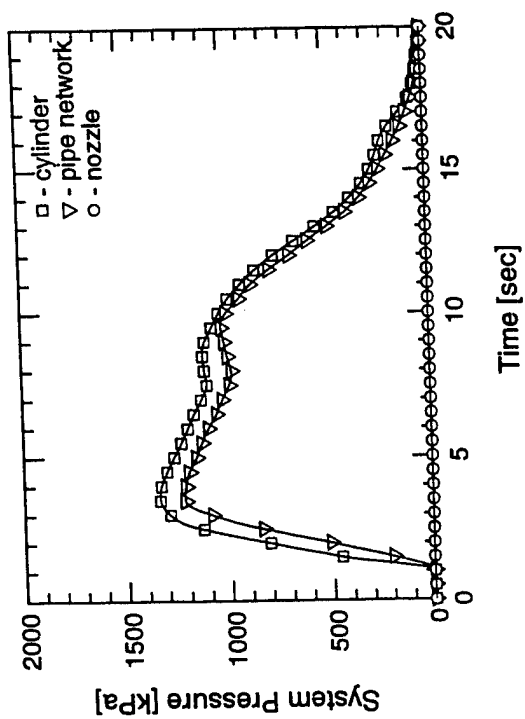
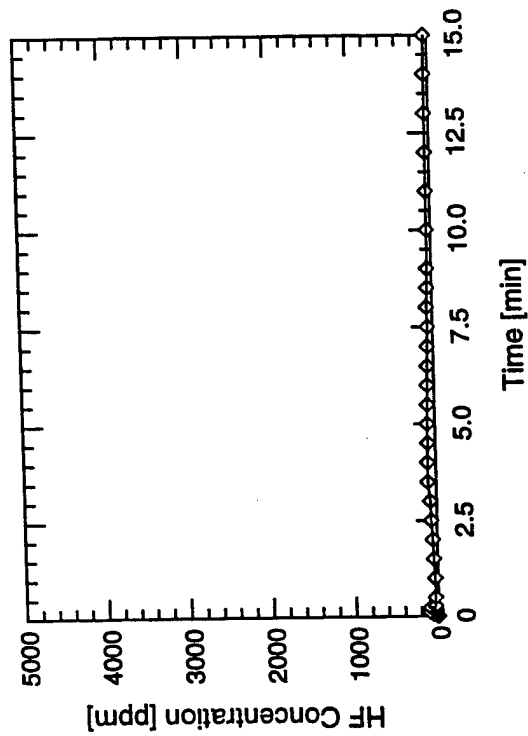
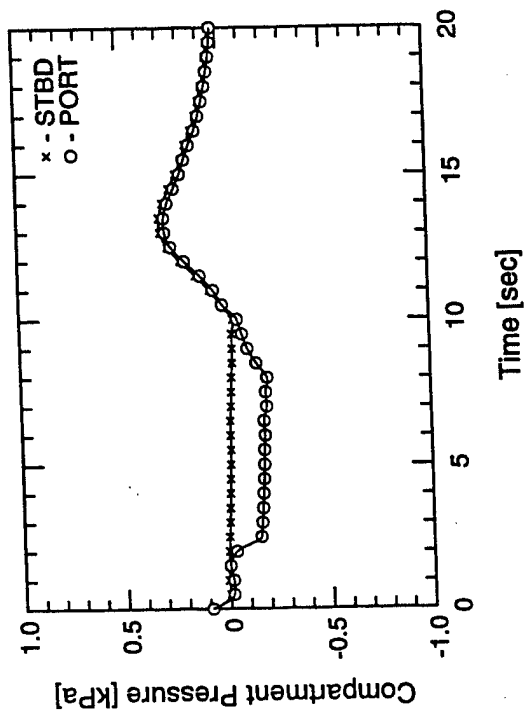
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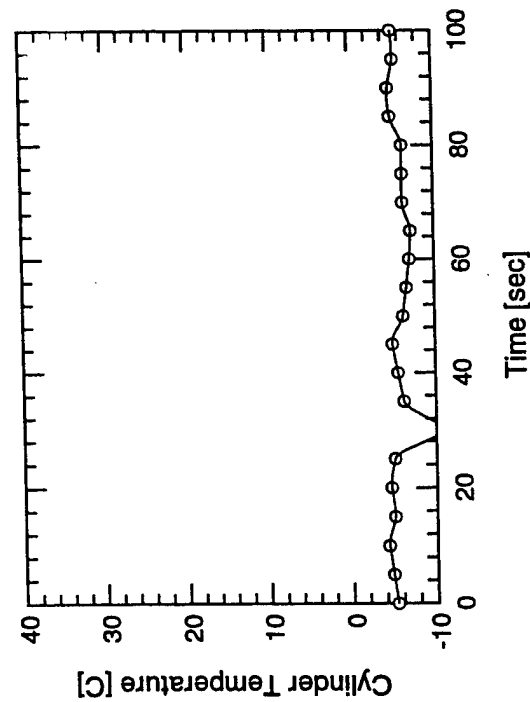
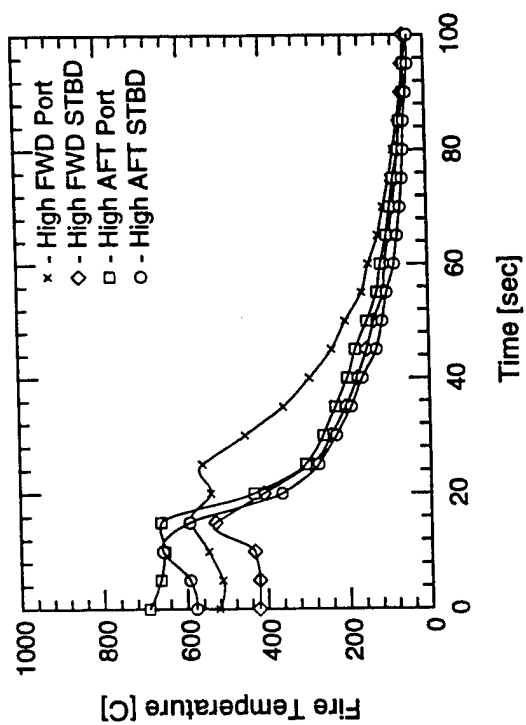
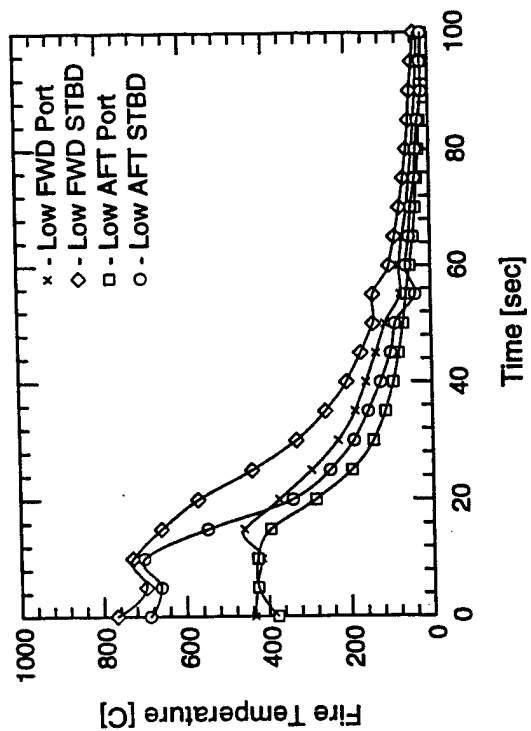
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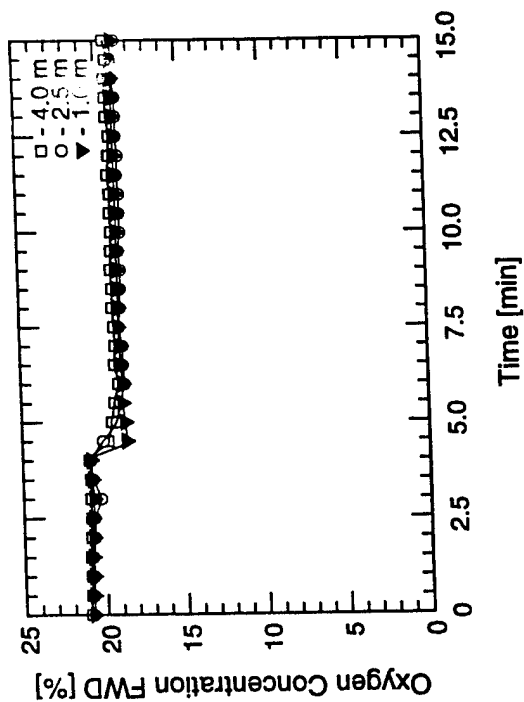
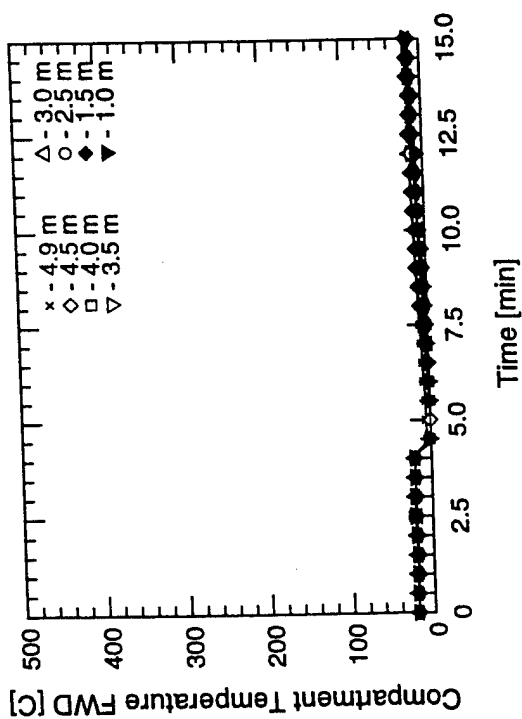
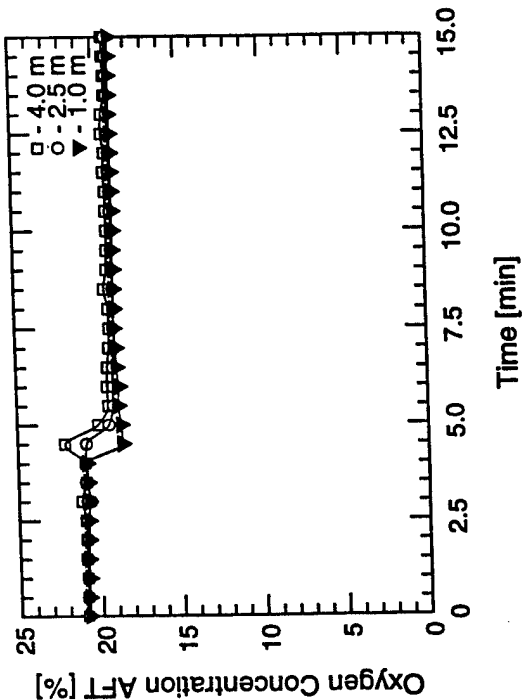
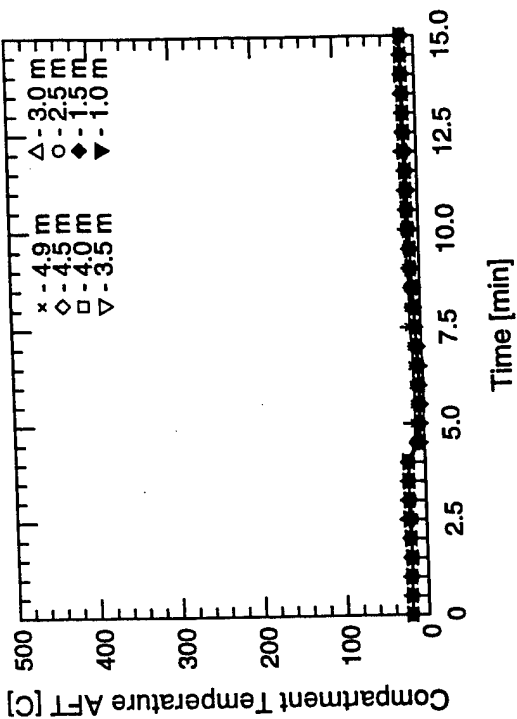


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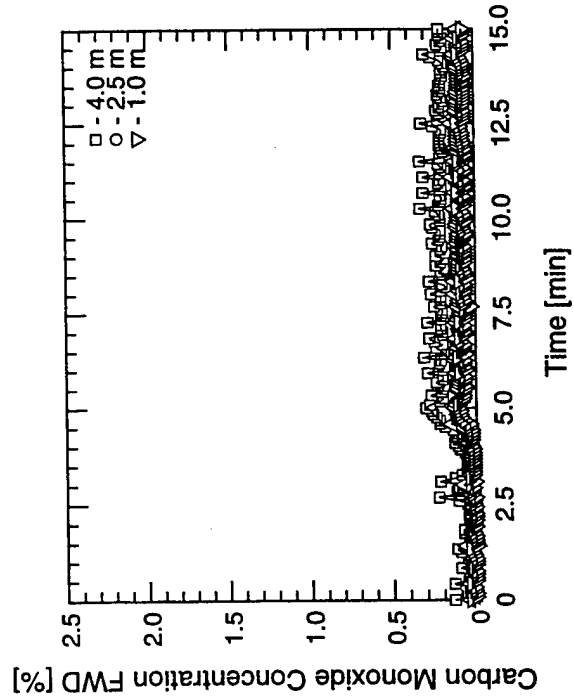
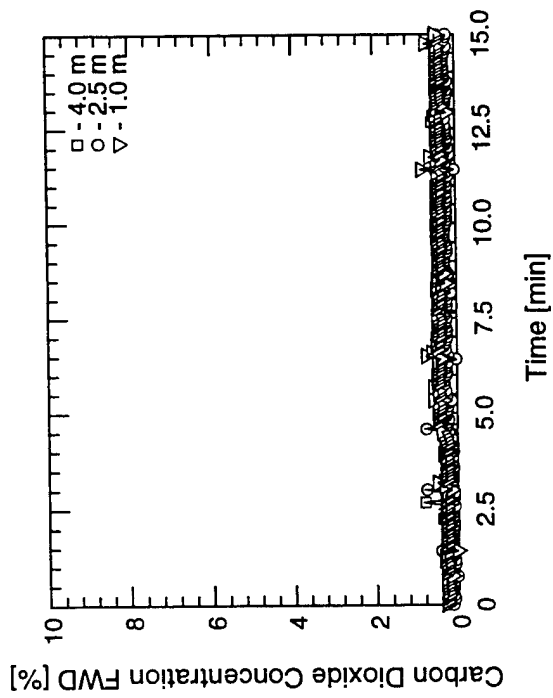
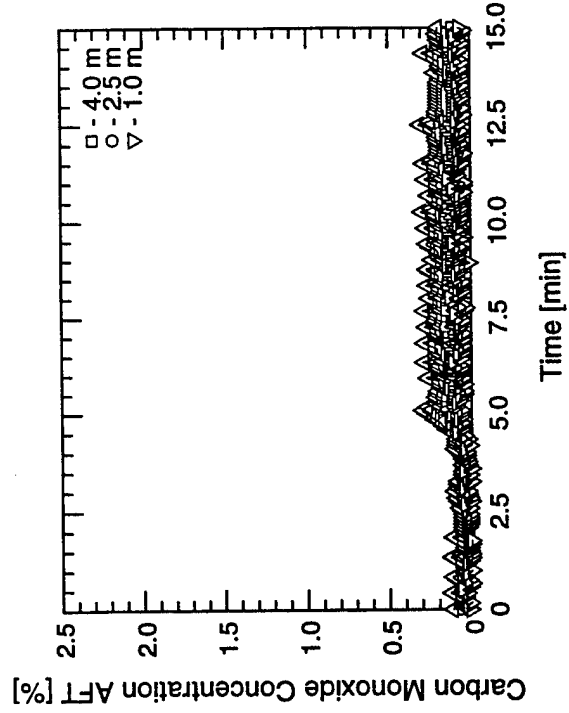
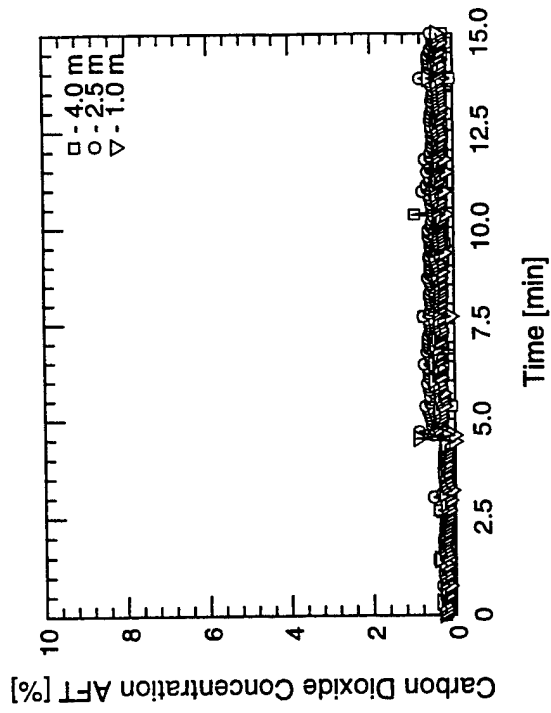




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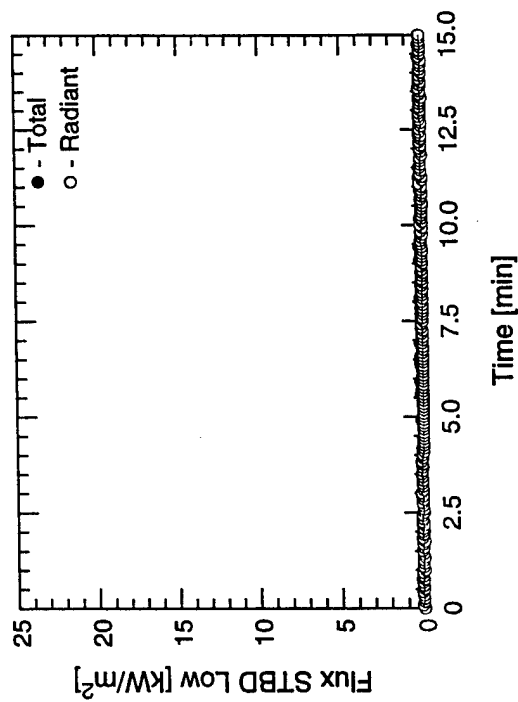
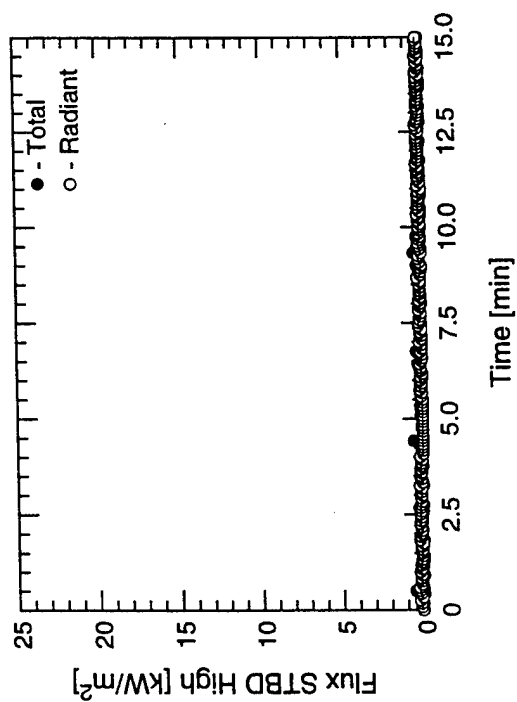
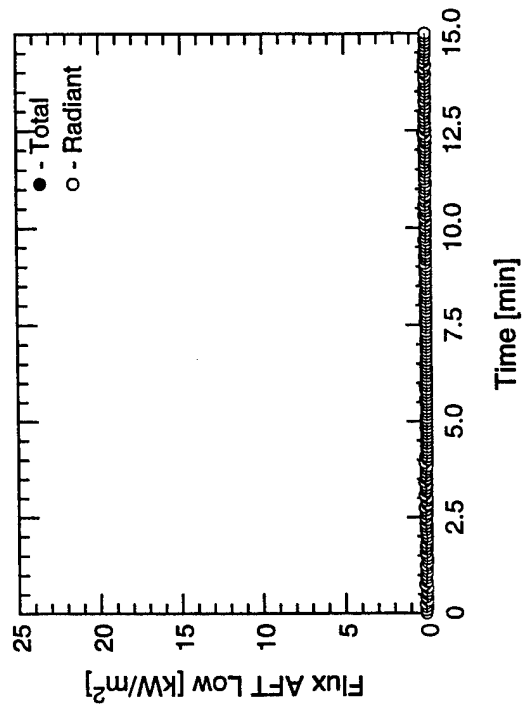
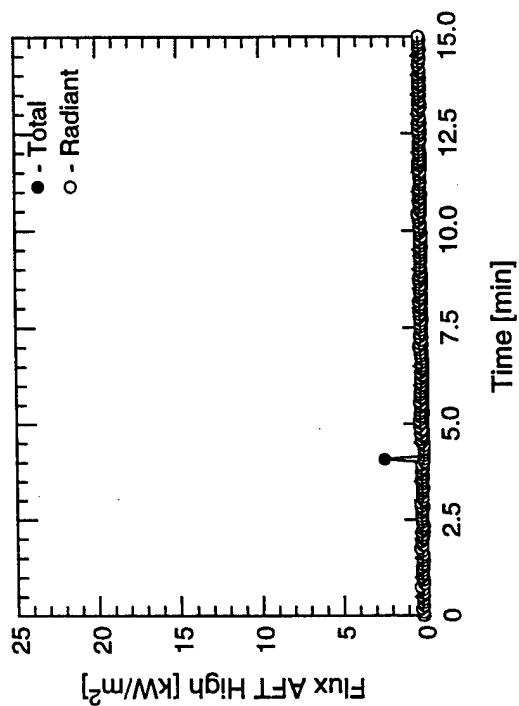


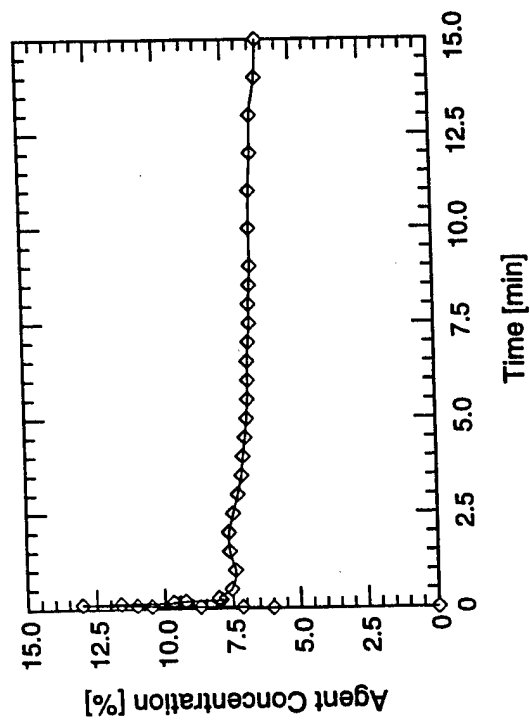
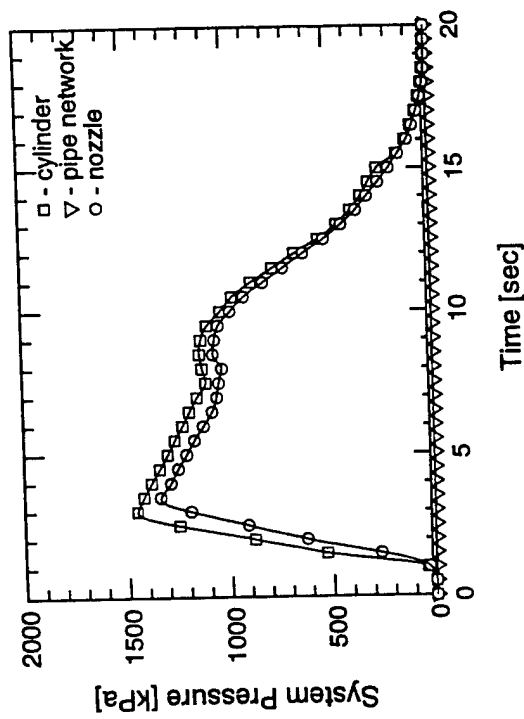
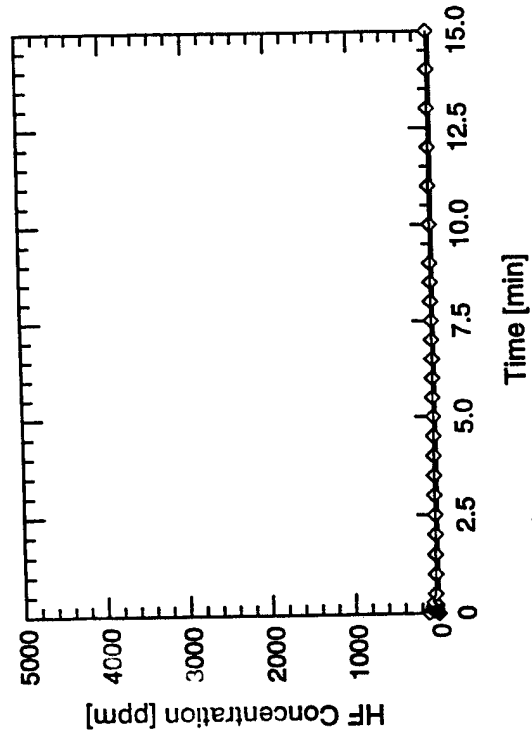
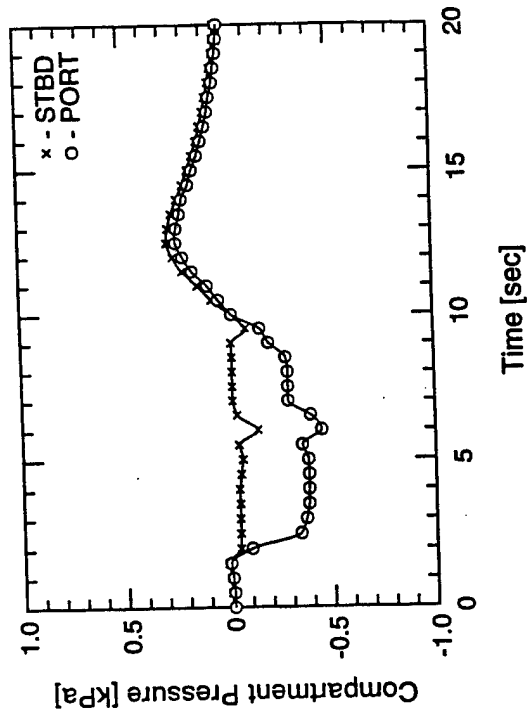
Test #39



Test #39

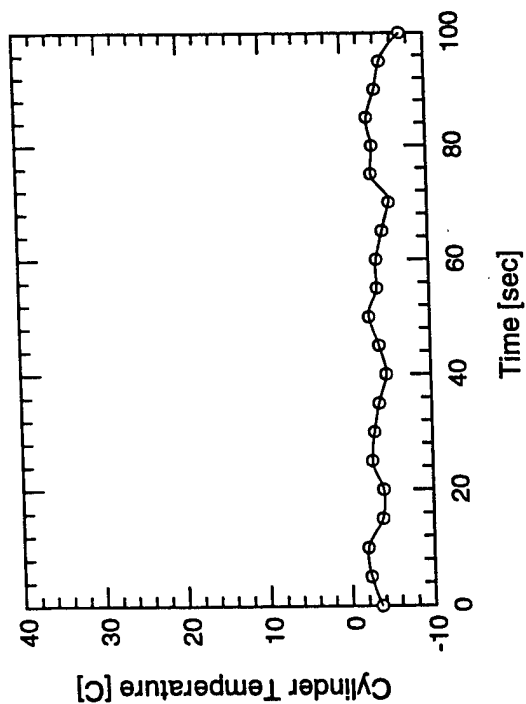
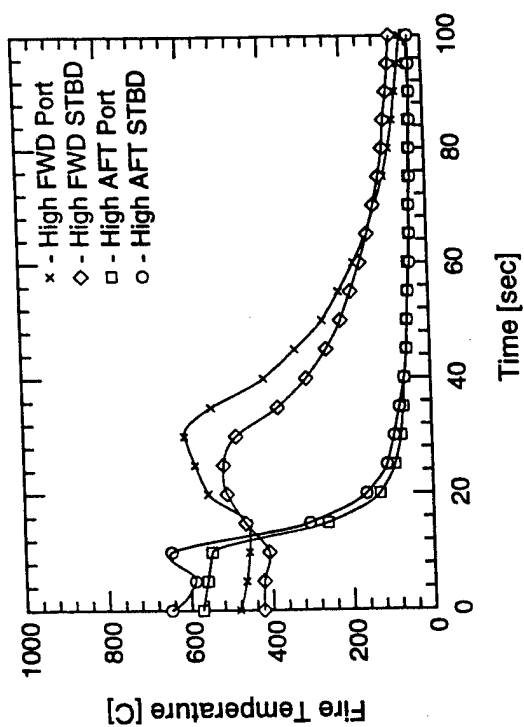
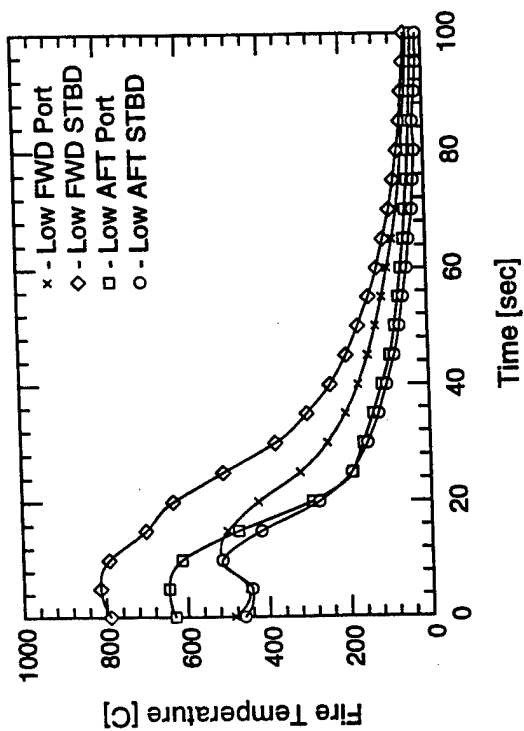
Test #39





Test #39

Test #39



APPENDIX E
U.S. COAST GUARD'S INTERPRETATION
OF THE IMO REQUIREMENTS



16714/ 162.162Ansul

Mr. John P Goudreau
Director, Marine/Government Division
Ansul Incorporated
One Stanton Street
Marinette, Wisconsin 54143-2542

JUN - 4 1998

RESPONSE TO ANSUL LETTER OF 27 APRIL 98

Dear Mr. Goudreau:

This letter is in response to your inquiry of April 27, 1998 regarding design requirements and fire tests for inert gas halon alternative fire extinguishing systems. Specifically, your letter asked for our interpretation of certain requirements of the International Maritime Organization's (IMO) Maritime Safety Committee Circular number 776 (MSC/Circ. 776).

We require all gaseous halon alternative fire extinguishing systems to be tested in accordance with IMO MSC/Circ. 776. One of the provisions of the circular is that inert gas fire extinguishing systems must comply with the requirement of Paragraph 4 of the circular's Guidelines. This requires the system to be arranged such that 85% of the agent design concentration will be achieved in 120 seconds or less. This 120 second time limit corresponds to the time when 85% of the required quantity of agent must be expelled from the nozzles in the protected space. Additionally, the required agent quantity must be determined from the concentration described in the manufacturer's approved marine system design manual. We infer that extinguishment of large fires is expected to occur soon after 85% of the required agent quantity is discharged and that all fires will be extinguished as soon as an extinguishing concentration of the agent is thoroughly mixed in the space. Paragraph 4 of the IMO Guidelines is a clear system design requirement for systems being installed. There is little room for interpretation of Paragraph 4.

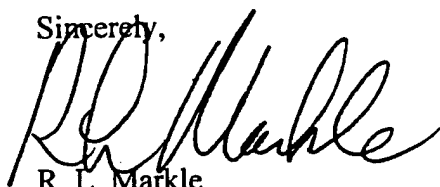
For the fire tests described in the Appendix of MSC/Circ.776, we require compliance with paragraph 4.1 of the appendix which requires all of the test fires to be extinguished within 30 seconds of the end of the agent discharge. We interpret the end of agent discharge to be the time when there is no substantial flow from the nozzles. If flow is uneven, it is the time when the first nozzle stops discharging. For Test Number 1 of Table 3 we require complete extinguishment of all of the tell-tale fires within 30 seconds after 100% of the agent used during the test stops substantially discharging from the nozzles. While this allows an unspecified time from the beginning of agent discharge until complete fire extinguishment, the scenario may be the most challenging case for agent mixing because this scenario may have the least nozzle turbulence.

RESPONSE TO ANSUL LETTER OF 27 APRIL 98

We believe that our requirements and interpretations reflect the intent of the IMO committee that developed the halon alternative gaseous agent design guidelines and test protocols. In fact, we considered the deliberation that occurred at IMO when we developed our interpretations. We reserve the right to reject test results or impose additional requirements if we believe that test fires are not being extinguished by the principle extinguishing mechanism of the inert agent. This could include cases where fires are being extinguished by their own oxygen depletion, separation of the flame from the fuel by agent velocity or by some other unanticipated mechanism.

If you have additional questions please contact Mr. Matthew Gustafson at 202-267-0170.

Sincerely,

A handwritten signature in black ink, appearing to read "R. L. Markle". The signature is fluid and cursive, with the first name "R" being particularly large and stylized.

R. L. Markle

Chief, Lifesaving and
Fire Safety Standards

By direction of the Commandant

cc: USCG R&D Center - Marine Fire & Safety