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ALTERNATIVE TRAINING AGENTS PHASE III--MEDIUM-SCALE TESTS SORTIE GENERATION

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13. ABSTRACT (Maximum 200 words)

This effort evaluated medium-scale candidate halon alternatives for use instead of Halon 1211 in firefighter training scenarios. Candidate agents tested included neat HCFC-123, neat HCFC-22, and selected blends containing two components from the set of HCFC-22, -123, -141b, -142b, and -152a. Agents were tested progressively on JP-4 fuel fires of 4, 32, and 75 ft^2. Effectiveness was evaluated by measuring quantities and times required for extinguishment. Both neat HCFC-123 and a blend of HCFC-123 and -142b (80:20 by moles) appear attractive as alternative training agents, because their extinguishing behavior simulates that of Halon 1211, and they appear to have acceptable toxicities for outside use with protective gear. On 4-ft^2 fires the critical application rates of these two alternative agents are virtually identical to that of Halon 1211; on larger fires the critical application rates are 1.7 to 3 times that of Halon 1211. Plots of fire size versus quantities of agents required for extinguishment gave smooth curves and allowed estimation of the quantities of agents required to extinguish fires of various surface areas. It is recommended that both neat HCFC-123 and a blend of HCFC-123 and -142b (80:20) be tested on 150-ft^2 pool fires and 75-ft^2 three-dimensional fires in Phase IV of this effort.

14. SUBJECT TERMS

Halon, Alternative, Blends, Fire, Training, Extinguishment, JP-4, HCFC

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EXECUTIVE SUMMARY

A. OBJECTIVE

The purpose of these medium-scale studies was to evaluate candidate halon alternatives for potential use in place of Halon 1211 in firefighter training scenarios.

B. BACKGROUND

Approximately 70 percent of Air Force usage of Halon 1211 is in firefighter training. It is believed that Halon 1211, with an Ozone Depletion Potential (ODP) of 3, contributes significantly to depletion of stratospheric ozone. Under the 1990 London Amendments to the Montreal Protocol, production of Halon 1211 will be phased out by the year 2000 for all but essential uses. In Phase I of this effort, promising near-term low-ODP candidate agents (termed Group 1 candidates) for firefighter training were identified (Reference 1). These candidates included HCFC-123 neat and in blends with HCFC-22, -141b, or -142b. In Phase II of this effort, laboratory-scale tests were conducted on neat HCFC-123 and blends using both the cup burner and laboratory-scale discharge extinguishment (LSDE) apparatuses.

Among the most important fire extinguishment characteristics of halons are knockdown, suppression effectiveness, discharge characteristics, and burnback control. Knockdown is the rapid initial control of a fire. Burnback is the ability of remaining flames to reignite fuel surfaces that have already been extinguished. When first applied to a fuel fire, Halon 1211 generally causes the leading edge to retreat rapidly if the agent is applied in the correct concentrations. Both knockdown and burnback inhibition become increasingly important for fires that are larger and, therefore, more difficult to control.

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C. SCOPE

This phase of the alternative training agent development included three stages of testing. Candidate agents were tested progressively on fires of 4, 32, and 75 ft^2. Agents were evaluated at each stage, and those with favorable properties were tested further.

D. METHODOLOGY

Several test parameters were used to study the effectiveness of each of the agent blends compared to Halon 1211. The amount of agent required to extinguish a fire indicated the general effectiveness of the candidate agent. The way the agent reacted to the fire when applied, the amount of effort and time required for extinguishment, and the agent flow rate were also important factors. The flow rate was varied by charging the extinguishers with different agent amounts and charge pressures. Both flow rate and spray pattern were varied by changing nozzles.

E. TEST DESCRIPTION

Military grade JP-4 fuel was floated on a water surface to create a layer 0.25 to 2.0 inches thick in fire pans with surface areas of 4, 32, and 75 ft^2. After preburns of 30 to 60 seconds, extinguishing agents were applied. Seven types of hand-held fire extinguishers (with capacities of 5, 9, 13, 17, 20, and 30 pounds of Halon 1211) and 50- and 150-pound wheeled units were used. Pressures of 125 to 250 $lb/in.^2$ were used, and both standard and Task Force Tip (TFT) nozzles were tested. Weights of agents applied and times to extinguishment were recorded, and flow rates were calculated.

F. RESULTS

For 4-ft^2 fires, the most promising agents were those containing HCFC-123 neat or in blends with either HCFC-22 or -142b. The most promising mixtures proved to be blends of HCFC-123 & HCFC-22 (80:20), HCFC-123 & HCFC-142b (80:20), and HCFC-123 & HCFC-22 (50:50). Here, and throughout this report, the ratios given are mole ratios. Neat HCFC-123 and the 80:20 blends of HCFC-123 with HCFC-22 or -142b exhibited many properties similar to Halon 1211 including rapid extinguishment and reignition control, nonreactivity in flames, and sufficient throw range and flow rate. The HCFC-123 and HCFC-22 (50:50) mixture exhibited remarkably rapid knockdown that allowed extinguishment of the 4-ft^2 fire with a minimal amount of agent, similar to the amount of Halon 1211 used. The other recommended agents (neat HCFC-123 and 80:20 blends of HCFC-123 and -22 or -142b) required approximately twice as much agent to extinguish the fire as did Halon 1211.

Neat HCFC-123 and mixtures of HCFC-123 with either HCFC-22 or -142b were tested at the 32 ft^2 level. The initial rapid knockdown of the fire by the blend HCFC-123 and HCFC-22 (80:20) was similar to that of Halon 1211. The firefighter could maintain control of the fire and extinguish it 50 to 60 percent of the time. It required twice as much agent to be applied as Halon 1211, even with ideal test conditions and application techniques. Similar results were obtained with the 75:25 and 70:30 blends of HCFC-123 and -22.

The HCFC-123 and HCFC-22 (50:50) mixture gave effective knockdown and initial control of 32 ft^2 fires. However, this mixture did not have the throw range to reach the length of the pan. The agent stream was dispersed and did not form a cohesive stream. Based on these results further evaluation of this blend was discontinued.

The neat HCFC-123 and HCFC-123 & HCFC-142b (80:20) candidates were also tested on 32 ft^2 fires. Neat HCFC-123 controlled the fire rapidly and, if a fast-sweeping technique was used, gave effective extinguishment. However, the agent produced a denser, more liquid stream than Halon 1211 when expelled from an extinguisher, making it difficult to maintain effective containment of the fire throughout the test. The fire could easily reignite behind the agent stream, and the firefighter often had to engage the entire pan fire again. Similar problems, though not as pronounced, were noted with the 80:20 blend of HCFC-123 and -142b. Agents containing high concentrations of HCFC-142b showed flammability.

None of the agents tested, including Halon 1211, extinguished the 75-ft^2 fires consistently when the 17- and 20-pound extinguishers were used. With these extinguishers, Halon 1211 extinguished the fires 60 percent of the time, and neat HCFC-123 was 20 percent effective. The other agent mixtures, HCFC-123 and HCFC-22 (80:20) and HCFC-123 and HCFC-142b (80:20), were not effective with 17- and 20-pound extinguishers because the flow rates were too low. A larger 30-pound extinguisher, was also tried and produced similar unsatisfactory results. Tests were then conducted with the next larger extinguisher, a 50-pound unit. An adjustable spray nozzle manufactured by TFT Corporation was tested with this extinguisher along with the standard nozzle. It was found that, although some fires were extinguished by the neat HCFC-123 agent, the agent blends could not completely extinguish a 75-ft^2 fire with a 50-pound extinguisher. The extinguishment was unsatisfactory because the agent flow rates were too low. Finally, a 150-pound extinguisher fitted with the TFT nozzle was used, and the fires were extinguished consistently with all the test agents.

The results show that it takes roughly twice as much neat HCFC-123 and three times as much HCFC-123 & HCFC-142b (80:20) as Halon 1211 to extinguish 75-ft^2 fuel fires. Depending on the agent used, a minimum flow rate for alternative agents of 1.6 to 4.6 lb/s must be maintained in order to extinguish this size fire. The required flow rates and amounts of agent necessary to extinguish the fire for neat HCFC-123 were twice that required for Halon 1211. For HCFC-123 and HCFC-142b (80:20) three times the flow rates and amounts of agent as for Halon 1211 were required.

The use of the agent HCFC-123 & HCFC-22 (80:20) was discontinued early in the 75-ft^2 testing. Although this mixture could extinguish the test fires, the other candidates appeared to have better toxicity/effectiveness properties. Since the mixture HCFC-123 & HCFC-142b (80:20) has a lower toxicity than neat HCFC-123, testing with the HCFC-123 & HCFC-142b blend was increased.

The HCFC-123 and HCFC-142b (80:20) intensified the fire slightly as it was applied. This effect is believed to be caused by the flammability of the HCFC-142b. The blend of HCFC-123 and HCFC-142b (80:20) was also not quite as effective in extinguishing the fires in this series of tests as neat HCFC-123.

G. CONCLUSIONS

Quantities of agents required for extinguishment depend on pressure, nozzle type, and application technique, as well as fire size. However, plots of fire size versus quantities of agents required for extinguishment gave smooth curves. These plots allow estimation of the quantities of agents required to extinguish fires of various surface areas. Both neat HCFC-123 and an 80:20 blend of HCFC-123 and -142b appear attractive as alternative training agents, because their extinguishing behavior simulates that of Halon 1211, and they have a toxicity acceptable for outside use with protective gear. Of these two agents, neat HCFC-123 is slightly more effective, but the blend with HCFC-142b has an approximately 20 percent lower toxicity. On small (4 ft^2) fires the critical application rates (lb/s needed for extinguishment) of neat HCFC-123 and 80:20 blends of HCFC-123 and -142b are virtually identical (within 20 percent) to that of Halon 1211. On 32-ft^2 fires, the critical application rates of the two alternative agents are approximately 1.7 to 1.9 times that of Halon 1211, and on 75-ft^2 fires the critical application rates are 2 to 3 times that of Halon 1211. As fire size increased, a greater flow rate of the blend was required. This may be a result of the high volatility of HCFC-142b (boiling point -10 °C), which may make it difficult to deliver agent to the back edge of a large fire.

H. RECOMMENDATIONS

It is recommended that both neat HCFC-123 and an 80:20 (mole percent) blend of HCFC-123 & -142b be tested on 150-ft^2 pool fires and 75-ft^2 three-dimensional fires in Phase IV of this effort.

PREFACE

This report was prepared by the New Mexico Engineering Research Institute (NMERI), University of New Mexico, Albuquerque, New Mexico 87131-1376, under contract F08635-85-C-0129, for the Engineering and Services Laboratory, Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403-6001.

This report summarizes medium-scale fire extinguishment test methodologies, compounds tested, and test results for Halon 1211 alternatives accomplished at NMERI between February and September 1990. The HQ AFESC/RDCF Project Officer was Capt. John Floden. Robert E. Tapscott was the principal investigator. The project technicians were Jimmy D. Watson and Jesse M. Parra.

This report has been reviewed by the Public Affairs Officer (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

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LIST OF ABBREVIATIONS

AFB	Air Force Base
APT	Advanced Protection Technologies
CAS	Chemical Abstracts Service
CERF	Civil Engineering Research Facility
CFC	chlorofluorocarbon
FC	fluorocarbon
FRMC	Factory Mutual Research Corporation
GWP	global warming potential
HCC	hydrochlorocarbon
HCFC	hydrochlorofluorocarbon
HFC	hydrofluorocarbon
ICI	Imperial Chemical Industries
ID	inside diameter
IUPAC	International Union of Pure and Applied Chemistry
KAFB	Kirtland Air Force Base
LLNL	Lawrence Livermore National Laboratory
LSDE	laboratory-scale discharge extinguishment
MSA	Mine Safety Appliances
MSDS	Material Safety Data Sheet
NIST	National Institute of Standards and Technology
NMERI	New Mexico Engineering Research Institute
ODP	ozone depletion potential
SCBA	self-contained breathing apparatus
UL	Underwriters' Laboratories
UNM	University of New Mexico
USAF	United States Air Force

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SECTION I
INTRODUCTION

A. OBJECTIVE

The purpose of these studies was to evaluate candidate halon alternatives at medium-scale for use in place of Halon 1211 in firefighter training.

B. BACKGROUND

Approximately 70 percent of Air Force usage of Halon 1211 is in firefighter training. It is believed that Halon 1211, with an Ozone Depletion Potential (ODP) of 3, contributes significantly to depletion of stratospheric ozone. Under the 1990 London Amendments to the Montreal Protocol, production of Halon 1211 will be phased out by 2000 for all but essential uses. In Phase I of this effort, promising near-term low-ODP candidate agents (termed Group 1 candidates) for firefighter training were identified. These candidates included HCFC-123 neat and in blends with HCFC -22, -141b, or -142b. In Phase II of this effort, laboratory-scale tests were conducted on neat HCFC-123 and blends using both the cup burner and laboratory-scale discharge extinguishment (LSDE) apparatuses.

The most important characteristics of halons related to extinguishment are knockdown, suppression effectiveness, discharge characteristics, and burnback control. Knockdown is the rapid initial control of a fire. When first applied to the fire, Halon 1211 generally causes the leading edge of a fuel fire to retreat rapidly if the agent is applied in the correct concentrations. Burnback control is the ability of the agent to prevent remaining flames from reigniting fuel surfaces that have already been extinguished. Both knockdown and burnback inhibition become increasingly important for fires that are larger and therefore more difficult to control.

C. SCOPE

This phase of the alternative training agent development included three stages of testing. Candidate agents were tested progressively on 4-, 32-, and 75-ft^2 fires. Agents were evaluated at each stage of testing, and those with favorable properties were tested further.

D. TECHNICAL APPROACH

Several test parameters were used to study the effectiveness of each of the agent blends compared to Halon 1211. The amount of agent required to extinguish a fire indicated the general effectiveness of the candidate agent. The way the agent reacted to the fire when applied, the amount of effort and time required for extinguishment, and the agent flow rate were also important factors. The flow rate was varied by charging the extinguishers with different agent amounts and charge pressures. Both flow rate and spray pattern were varied by changing nozzles.

SECTION II
TEST EQUIPMENT AND DESCRIPTIONS

A. FACILITIES

The medium-scale testing facilities were located on Kirtland Air Force Base at the Civil Engineering Research Facility (CERF). The tests were conducted in sheltered and fenced wind enclosures constructed largely of TENAX Riparella mono-oriented net wind fencing. This material is designed to reduce wind velocity by 80 to 85 percent without restricting the passage of air. It has 85 percent porosity. The wind enclosures were built as pairs of concentric circles to maximize wind abatement. Two enclosures, one large and one small, were used for this testing.

The smaller enclosure surrounded a 4-ft^2 metal fire pan. The outer ring of the smaller enclosure was 10 feet high and 30 feet in diameter, constructed of TENAX wind fencing. The inner ring, 7 feet high and 14 feet in diameter, was constructed of steel panels connected to form a three-fourths circle with the open side facing north. The 4-ft^2 pan was placed in the center of this double enclosure, as shown in Figures 1 and 2.

The larger enclosure totally surrounded the second test area and had an outer fence diameter of 140 feet, an inner fence diameter of 85 feet, and a height of 20 feet. A 32-ft^2 pan, a 75-ft^2 pan, and a 150-ft^2 pit were located within this structure (Figures 3 and 4). The 32-ft^2 pan fire was chosen as the next step after the 4-ft^2 fire in this testing because it was approximately half the size of the next larger fire (75 ft^2).

The square 4-ft^2 pan was constructed of 0.25-inch steel with a depth of 4 inches. The pan position producing the most realistic and reproducible fires was established by placing the pan on the ground and building an earthen berm to the pan sides to reduce turbulence effects from the vertical edges of the pan.

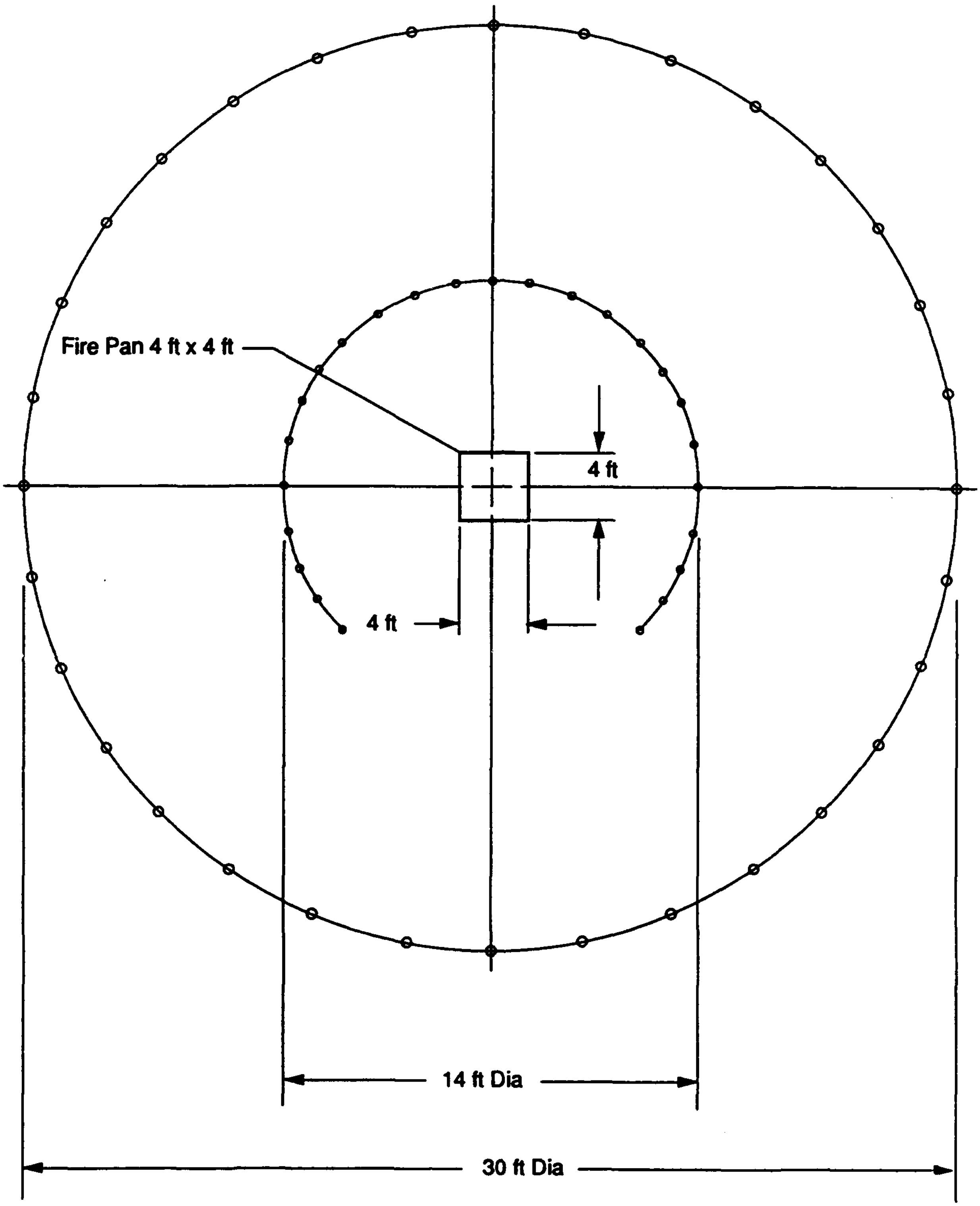

Figure 1. Schematic Overview of 4-ft^2 Enclosure.

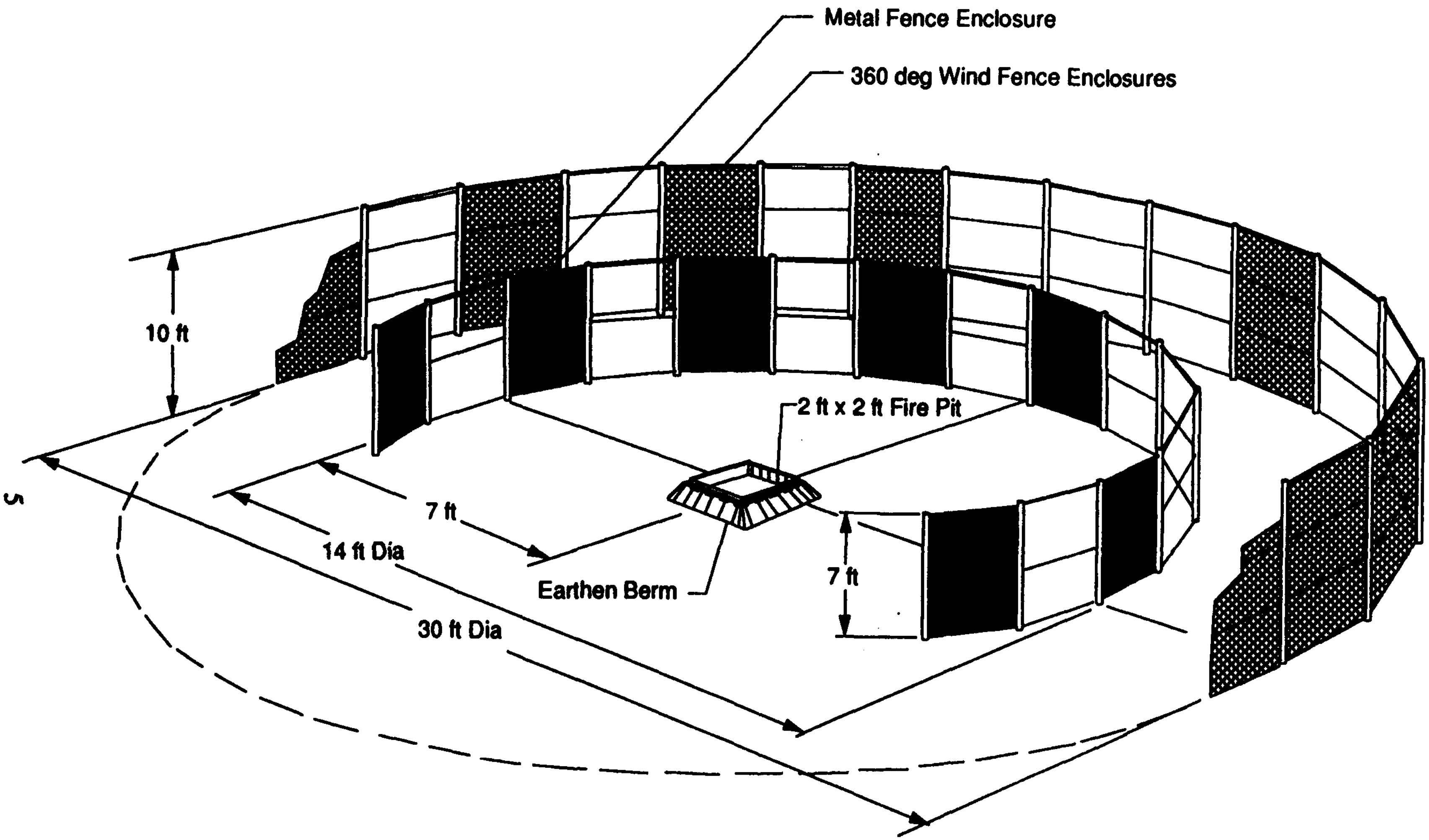

Figure 2. General Layout of 4-ft^2 Enclosure. (All fencing panels are in place in the actual metal and wind fence enclosures.)

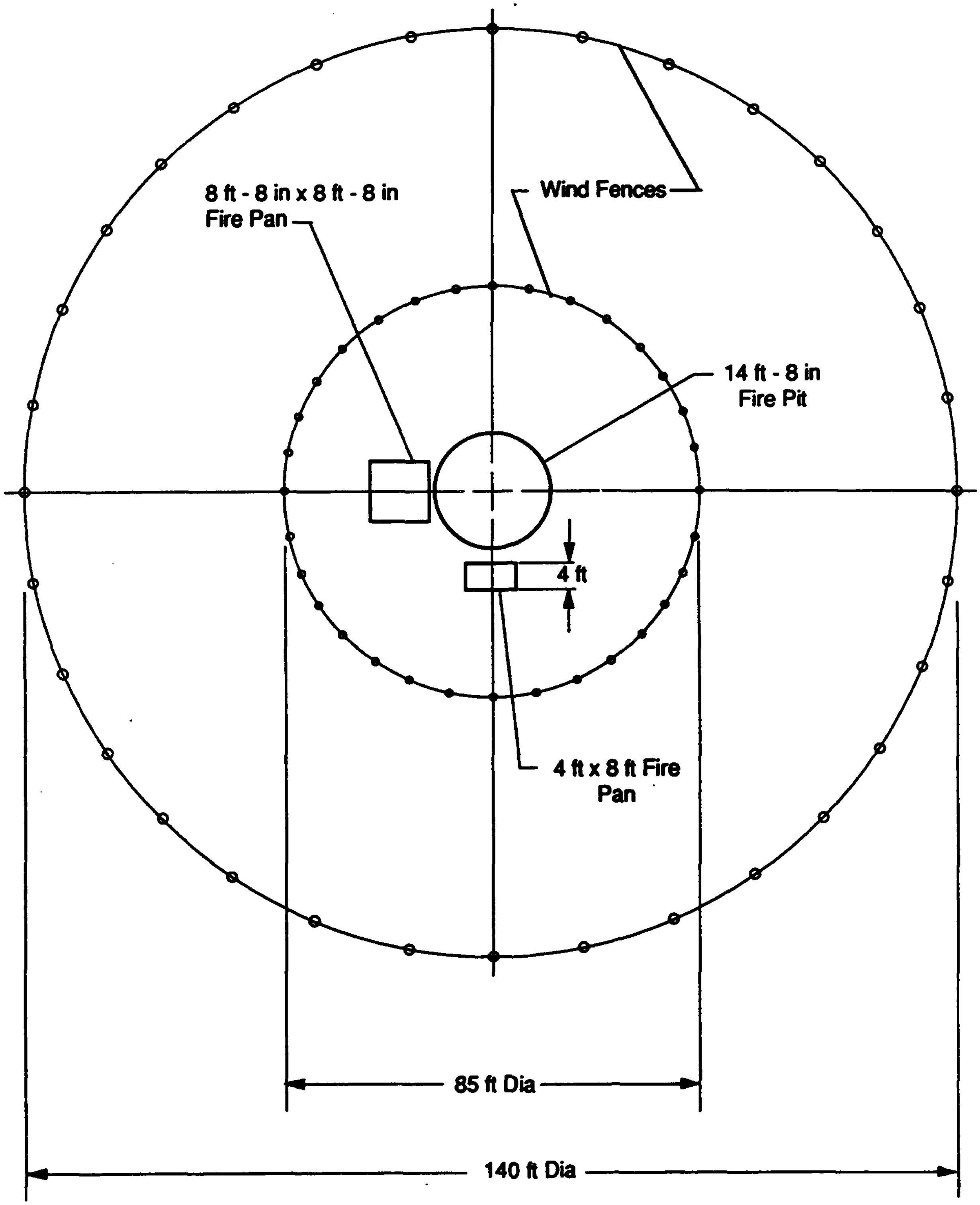

Figure 3. Schematic Overview of Large Test Enclosure.

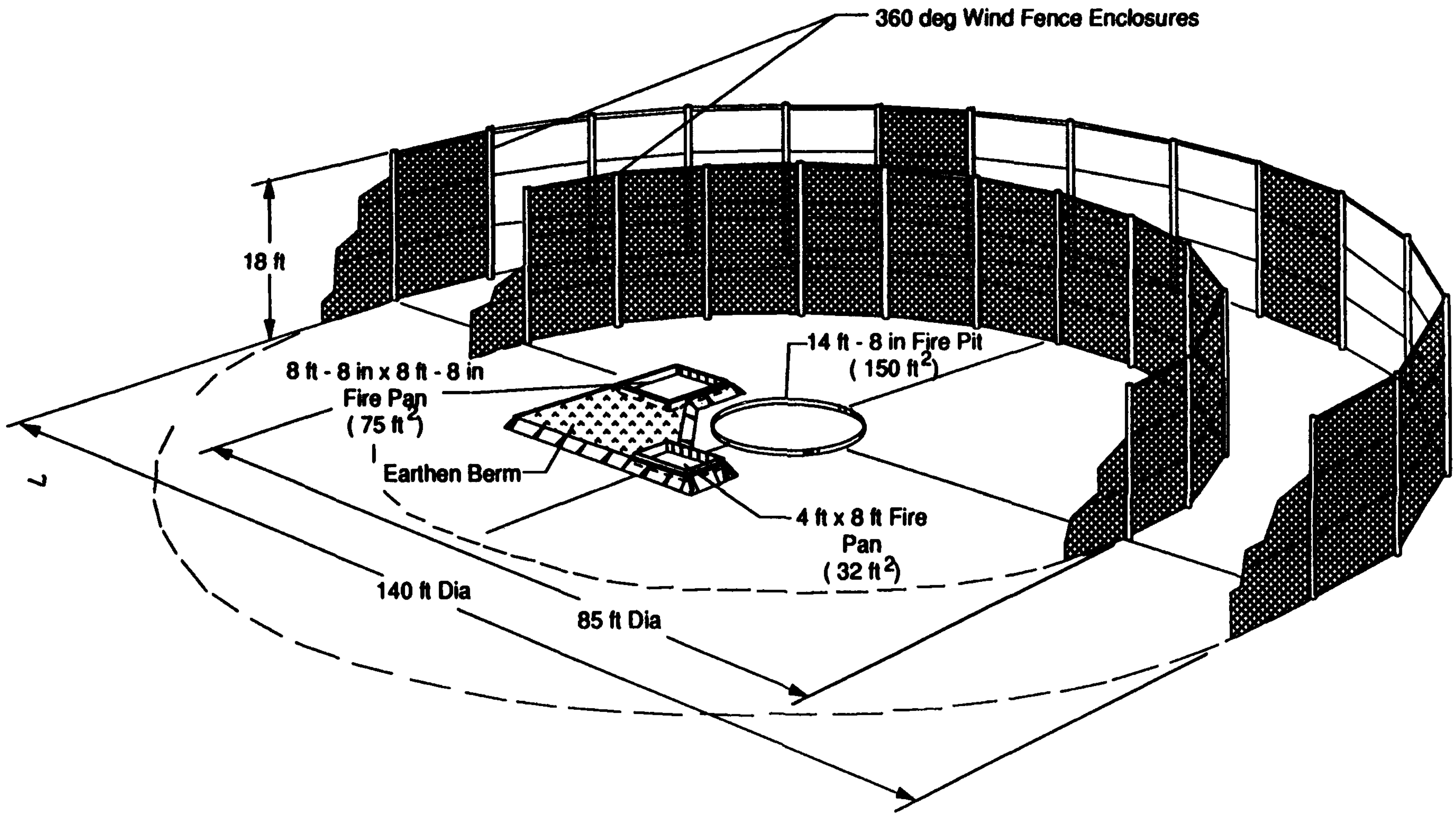

Figure 4. General Layout of Large Test Enclosure with 32-, 75-, and 150-ft^2 Pans and Pit. (All fencing panels are in place in the actual wind fence enclosures.)

The rectangular 32-ft^2 pan was constructed of 0.25-inch thick steel with a 1.25 by 1.25-inch angle welded along the lip of the pan to give added support and minimize the effects of turbulence caused by air entrainment during testing. The pan was 4 by 8 by 0.5 feet deep and was positioned with the long dimension aligned north to south. The firefighter approached from the narrow side of the pan to confront a more difficult fire. Approaching from this direction made it necessary to throw the agent at least 8 feet past the leading edge of the fire. Since the winds were predominantly from the south, the firefighter approached from the south in order to keep the wind, if any was present, to his back. The edges of the pan were bermed with earth to minimize the uncontrolled swirling of fuel fumes caused by air entrainment along outside vertical pan surfaces during a fire.

The square 75-ft^2 pan was constructed of 0.25-inch thick steel with a by 1.25 by 1.25-inch steel angle welded along the top outside edges of the pan. The pan was 8 feet 8 inches (square) and 8 inches deep. The edges of the pan were initially bermed with earth to minimize turbulence caused by air entrainment during fire testing. In later tests, the pan was placed in a 150-ft^2 pit, and the pit was filled with water until the vertical edges of the pan were covered. In the final tests, a circular metal ring, 16 inches high (allowing a freeboard of 2 inches) and giving a surface area of 75-ft^2, was used in the 150-ft^2 pit. This arrangement allowed greater flexibility for the firefighter to approach the fire from any direction.

B. FUEL

The fuel used for this testing was military grade JP-4. The fuel was floated on a water surface in the fire pan. In order to produce a reasonably difficult fire for the test, 5 to 280 gallons of water were used, depending on the size of the containment pan, to fill the pan partially and maintain a 2-inch freeboard (pan wall height) above the fuel surface. The required amount of fuel was determined as the amount necessary to produce a fully involved fire in 60 seconds after ignition and to maintain full intensity throughout the entire test. This amount was determined by conducting standard 4-ft^2 and 32-ft^2 burns with known quantities of fuel and measuring the fire intensity and duration.

The approximate volume of fuel required for each pan size was determined by placing calibrated Type-K thermocouples both in the water beneath the fuel surface and directly in the flame. The thermocouple in the flame was positioned 1 inch above the fuel surface for the 4-ft^2 fire and 10 inches above the fuel for the 32-ft^2 fire. Fifty-six to sixty ounces of fuel in the 4-ft^2 pan allowed an average flame temperature of 700 °C to be maintained for approximately 2 minutes after a 60-second preburn. This fuel-to-water ratio (60 ounces of fuel to 5 gallons of water, or 12 ounces of fuel per gallon of water, resulting in a fuel depth of approximately 0.375 inches floating on water) produced a representative and reproducible fire. Even though fuel depths of up to 2 inches were tested, this fuel-to-water ratio was used as the standard throughout the fire testing at the levels of 4 ft^2 through 75 ft^2, except for the final tests that used the 75-ft^2 ring. For the 75-ft^2 ring tests the amount of fuel was decreased by half (12.5 rather than 25 gallons) to provide an approximate fuel depth of 0.25 inches on top of the water. The fuel was decreased for these tests because it was found to continue to give a reproducible fire that was sufficiently long-lived for testing and saved fuel. Moreover, these conditions matched those being used in other Air Force testing at Tyndall Air Force Base.

C. EXTINGUISHERS

Seven types of hand-held fire extinguishers, all manufactured by Amerex Corporation, were used for these tests. The various sizes of extinguishers allowed quantitative testing of different extinguishing agent amounts, agent flow rates, spray patterns, and throw ranges, and permitted development of optimal extinguishing techniques. Since a replacement agent for Halon 1211 was being sought, standard Halon 1211 extinguishers were used in the testing. All extinguisher valve head assemblies, hoses, discharge nozzles, containment cylinders, and sealing materials (such as O-rings) were of the types normally used for Halon 1211.

Three types of hand-held extinguishers were used in the 4-ft^2 fire tests. A Model 355, 5-pound Halon 1211 extinguisher was first tested with Halon 1211, then with a variety of candidate agent blends. This extinguisher expelled the agent at a sufficient rate to compare the agent blends; however, an extinguisher with a faster flow rate and a larger fill capacity was tested to determine the effect of agent flow rate on the fire. The extinguisher used in this testing was a Model 369, 9-pound Halon 1211 unit. Finally, an extinguisher that combined the characteristics of a higher flow rate with optimum fill capacity and ratio was found: a Model 357, 5-pound Halon 1211 unit. This extinguisher could deliver a relatively high flow rate while maintaining a satisfactory fill capacity.

Several extinguisher sizes, each containing various amounts of agent, were tested in the 32-ft^2 fire scenarios. These extinguishers were Amerex Model 369 (9-pound Halon 1211), Model 371 (13-pound Halon 1211), Model 361 (17-pound Halon 1211), and Model 372 (20-pound Halon 1211) units. The valve/head assemblies of these units were identical to each other and to that of the Model 357, the 5-pound Halon 1211 unit used in the earlier tests. These assemblies are designed to produce minimal flow obstruction and pressure loss during operation. Various standard, molded nozzles were used to vary the agent flow rates to study the effects of nozzles on agent application. It was determined that a 13-pound extinguisher could effectively extinguish the fire for certain agents and agent mixes. All of the 32-ft^2 fires could be extinguished with the 17-pound extinguisher.

Five different sizes and types of extinguishers, various agents (including blends), and a variety of nozzles were evaluated in the 75-ft^2 fire tests. Hand-held extinguishers with 17-, 20-, and 30-pound Halon 1211 fill capacities were tested, and it was found that the 20-pound unit held just sufficient Halon 1211 to extinguish this size fire. The

30-pound extinguisher (Model 570) provided improved test repeatability and better data. As expected, the amount of agent needed to extinguish a fire depended on the application technique, agent flow rate, and the cohesiveness of the agent stream as it reached the farthest edge of the fire. Since the 30-pound unit held insufficient agent to test certain candidate blends on the 75-ft^2 fires, a 50-pound capacity extinguisher (Model 695) was used. To better simulate the effects of Halon 1211 with the agent blends, an adjustable nozzle manufactured by the Task Force Tip (TFT) Corporation, with a capacity of 10 to 165 gallons/minute, was used. The nozzle was adjusted to simulate the spray pattern and throw range of Halon 1211. This adjustment improved the effectiveness of the agent and produced more repeatable test results. The capacity and delivery rates of the 50-pound extinguisher were still too low for effective extinguishment of 75-ft^2 fires, so a 150-pound (Model 600) extinguisher with a TFT nozzle was used. The higher agent flow rates from this extinguisher, combined with the improved spray patterns from the TFT nozzle, produced the best results.

SECTION III
PROCEDURES

Extinguishers were inspected, and worn parts were replaced. The chemicals used in the agent mixtures rapidly degraded the Buna rubber O-rings and valve stem seats and necessitated replacement of these items once or twice during a series of 10 to 12 tests. The mixtures were then measured into the extinguishers. The required amounts were measured by volume for liquid agents and by weight for gaseous agents. The extinguishers were each filled to the capacity used by the manufacturer when filling the unit with Halon 1211. These fill ratios ranged from 38 to 66 percent full, depending on the size of extinguisher. The extinguishers were then weighed and pressurized to their charge pressure. The charge pressure was varied during testing to study the effect of varying the agent flow rate.

All agents under consideration were tested first at 4 ft^2. For these fires, two types of 5-pound Halon 1211 extinguisher and one 9-pound extinguisher were used. The extinguishers were filled to 55 to 65 percent of their full capacities and were pressurized from 100 to 195 $lb/in.^2$ The effectiveness of each agent was compared to Halon 1211 using the same test conditions. After testing at several charging pressures, the most repeatable results were obtained at 125, 150, and 175 $lb/in.^2$

For 32-ft^2 fire tests, extinguishers with 9-, 13-, 17-, and 20-pound Halon 1211 capacities were used. The 5-pound capacity extinguishers used in initial tests contained enough agent for extinguishment only in the case of Halon 1211. All extinguishers were filled to 38 to 66 percent of full capacities and pressurized to 195 $lb/in.^2$

For 75-ft^2 fire tests, extinguishers with 17-, 20-, 30-, 50-, and 150-pound Halon 1211 capacities were used. The smaller (17- to 30-pound) extinguishers were pressurized to 195 $lb/in.^2$ The 50- and 150-pound units were overpressurized to 250 to 300 $lb/in.^2$ so that the nozzle could be operated at its optimum flow capacity.

Fresh fuel was added to the water for each test to ensure reproducible conditions. The fuel was ignited and allowed to burn for 30 to 60 seconds to achieve full development. After the 30- to 60-second preburn, the firefighter used a sweeping side-to-side technique to extinguish the fires. When using this technique, the firefighter started the agent flowing toward the fire, sweeping in front of the fire to create a high concentration of agent. This concentrated agent cloud was then pushed into the fire with the agent stream, sweeping side-to-side and overlapping the edges of the fire pan to maintain a sufficient agent concentration throughout the fire area and to finish extinguishing the flames at the back of the pan. The fuel was relighted and burned off after each test to maintain test repeatability.

Several test parameters were recorded during the testing. Weather conditions, such as wind speed and direction, ambient temperature, and barometric pressure were recorded for each test. The amount of agent used, agent flow duration, and agent flow rate were also recorded.

The knockdown and inertion abilities and agent throw range were observed and recorded. Firefighter techniques were also studied and improved throughout the testing effort.

SECTION IV
RESULTS

A. GENERAL

Several characteristics of Halon 1211 facilitate rapid extinction of fuel fires: high vapor pressure combined with deliverability and chemical and physical extinguishment mechanisms. Halon 1211 neither reacts violently nor intensifies the fire when applied. However, several of the alternative agents tested were slightly flammable and intensified the fire when first applied, making control difficult. These flammable agents included HCFC-141b and -142b and HFC-152a when used in high concentrations (40 percent or greater) in blends.[1]

After the initial control (knockdown) of the fire has been established, the Halon 1211 vapor hinders fire reignition during the extinguishing process. A fuel fire can be very unpredictable and can reignite quickly (flashback). When larger fuel fires are to be extinguished, the agent must be able to control and extinguish a fire over a large area. The agent must be sufficiently cohesive (low enough in volatility) so that the agent stream can be lofted to reach the far end of the fire. Adequate throw range is critical in extinguishing large fires. Halon 1211 also affords rapid knockdown, allowing the firefighter to gain initial control of the fire quickly.

Weather factors including wind intensity and direction, barometric pressure, and temperature affected test results to some degree, and these variations were considered in evaluating the data.

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[1]Throughout this report all blend concentrations are expressed in mole percent or mole ratio. These give the volume percent or volume ratio upon evaporation.

To interpret the results shown in Tables 1-3, both amounts of agents and times to extinguishment should be compared. Percent extinguishment means the percentages of that size fire extinguished by that agent.

B. 4-FT^2 FIRES

For 4-ft^2 fires, the most promising agents were those containing HCFC-123 either in neat form or in blends with HCFC-22 or -142b. Blends of HCFC-141b or -152a with HCFC-123 were also tested at 4 ft^2 but were not as effective and were not recommended for further testing. The most promising mixtures proved to be neat HCFC-123, HCFC-123 & HCFC-22 (80:20), HCFC-123 & HCFC-142b (80:20), and HCFC-123 & HCFC-22 (50:50). The first three agents exhibited many properties similar to Halon 1211 including rapid extinguishment and reignition control, nonreactivity in flames, and satisfactory throw range and flow rate. The HCFC-123 & HCFC-22 (50:50) mixture exhibited remarkably rapid knockdown that allowed extinguishment of the 4-ft^2 fire with a minimal amount of agent, similar to the amount of Halon 1211 used. The other recommended agents (neat HCFC-123 and 80:20 mole percent blends of HCFC-123 and -22 or HCFC-123 and -142b) required approximately twice as much agent to extinguish the fire compared to Halon 1211.

The results of tests on 4-ft^2 fires are shown in Table 1.

The square 4-ft^2 pan was constructed of 0.25 inch steel with the dimensions of 2 feet by 2 feet by 4 inches. The pan position producing the most realistic and reproducible fire was established by placing the pan on the ground and building an earthen berm to the sides of pan to reduce turbulence effects from the vertical edges of the pan.

TABLE 1. DATA FOR 4-FT^2 FIRES.

Agent	Conc., Mole%	Pressure lb/in.^{2}	Extinguishment Tests			Average For All Runs			Extinguishment			Nonextinguishment		
			%Ext.	No.Pos.	No.Neg.	WtAgent, lbs	Time, s	FlowRate, lb/s	WtAgent, lbs	Time, s	FlowRate, lb/s	WtAgent, lbs	Time, s	FlowRate, lb/s
HALON 1211	100	125	100	12	0	1.6	2.5	0.7	1.6	2.5	0.69	--	--	--
		150	100	3	0	1.9	2.6	0.7	1.9	2.6	0.71	--	--	--
		175	100	3	0	1.5	2.6	0.6	1.5	2.6	0.57	--	--	--
HCFC-123	100	125	100	2	0	2.9	5.7	0.5	2.9	5.7	0.51	--	--	--
		150	63	5	3	2.5	6.1	0.5	2.6	6.1	0.45	2.7	8.3	0.32
		175	100	5	0	2.3	4.7	0.5	2.3	4.7	0.54	--	--	--
HCFC-22	100	125	50	1	1	1.9	7.0	0.3	2.2	7.4	0.31	1.6	6.7	0.24
		150	0	0	1	2.2	7.9	0.3	--	--	--	2.2	7.9	0.28
		175	0	0	1	2.6	8.2	0.3	--	--	--	2.6	8.2	0.32
HCFC-123 & -22	80:20	125	100	4	0	3.0	6.0	0.6	3.0	6.0	0.62	--	--	--
		150	100	2	0	2.0	3.6	0.6	2.0	3.6	0.56	--	--	--
		175	100	2	0	2.1	3.5	0.6	2.1	3.5	0.61	--	--	--
	70:30	125	71	5	2	2.4	6.7	0.4	2.4	6.7	0.38	3.1	12.6	0.25
		150	80	4	1	2.0	4.5	0.5	2.0	4.5	0.46	2.5	8.9	0.28
		175	50	1	1	2.5	7.8	0.3	2.6	8.9	0.29	2.4	6.7	0.36
	60:40	125	88	7	1	2.4	10.3	0.3	2.5	10.9	0.27	1.9	6.2	0.31
		150	100	2	0	1.3	4.2	0.3	1.3	4.2	0.32	--	--	--
		175	100	4	0	1.8	6.0	0.3	1.8	6.1	0.31	--	--	--
	50:50	125	75	3	1	1.4	5.8	0.3	1.4	5.8	0.26	2.0	11.7	0.17
		150	66	2	1	1.8	5.3	0.4	1.8	5.3	0.35	2.0	10.0	0.20
		175	100	2	0	1.4	2.4	0.6	1.4	2.4	0.58	--	--	--
	40:60	125	100	1	0	2.1	4.6	0.5	2.1	4.6	0.46	--	--	--
		150	86	6	1	1.7	4.7	0.4	1.8	4.7	0.39	3.6	4.6	0.24
		175	75	3	1	2.2	3.8	0.6	2.2	3.8	0.57	2.2	7.4	0.49
HCFC-123 & -141b	90:10	125	100	3	0	2.8	5.9	0.5	2.8	5.9	0.48	--	--	--
		150	66	2	1	1.9	5.0	0.4	1.9	4.8	0.41	1.8	5.4	0.33
		175	50	2	2	1.6	3.2	0.5	1.6	3.2	0.48	3.8	7.5	0.53
	80:20	125	75	3	1	3.8	9.2	0.5	3.4	8.5	0.51	4.8	11.4	0.42
		150	66	2	1	4.0	8.6	0.5	3.9	8.5	0.52	3.9	8.8	0.44
	70:30	150	50	1	1	2.6	6.6	0.4	2.7	6.3	0.43	2.6	6.8	0.37

TABLE 1. DATA FOR 4-FT^2 FIRES (CONCLUDED).

Agent	Conc., Mole%	Pressure lb/in.^{2}	Extinguishment Tests %Ext.	Extinguishment Tests NoPos.	Extinguishment Tests NoNeg.	Average For All Runs WtAgent, lbs	Average For All Runs Time, s	Average For All Runs FlowRate, lb/s	Extinguishment WtAgent, lbs	Extinguishment Time, s	Extinguishment FlowRate, lb/s	Nonextinguishment WtAgent, lbs	Nonextinguishment Time, s	Nonextinguishment FlowRate, lb/s
HCFC-123 & -142b	80:20	125	100	1	0	3.0	8.4	0.4	3.1	8.4	0.36	--	--	
		150	88	7	1	3.2	4.8	0.7	7.2	4.3	0.71	3.8	8.2	0.46
		175	100	4	0	3.0	3.7	0.9	3.1	3.7	0.85	--	--	
	70:30	125	50	1	1	2.5	7.3	0.3	2.6	7.3	0.36	2.4	7.3	0.32
	60:40	125	100	2	0	2.9	5.3	0.5	2.9	5.3	0.54	--	--	--
		150	100	3	0	4.9	6.0	0.7	4.9	6.0	0.74	--	--	--
		175	100	1	0	5.8	6.9	0.8	5.8	6.9	0.84	--	--	--
HCFC-123 & -152a	90:10	125	75	3	1	2.8	5.4	0.5	2.8	5.4	0.51	2.9	5.4	0.54
		150	100	3	0	2.7	4.7	0.6	2.7	4.7	0.57	--	--	--
	80:20	125	75	3	1	2.8	5.3	0.5	2.8	5.3	0.53	3.5	6.9	0.52
		150	100	3	0	3.2	5.9	0.6	3.2	5.9	0.56	--	--	--
HCFC-141b & -22	60:40	125	0	0	1	3.3	12.2	0.3	--	--	--	3.3	12.2	0.27
		150	100	4	0	4.2	10.2	0.4	4.2	10.2	0.43	--	--	--
		175	100	3	0	3.7	7.1	0.5	3.7	7.1	0.51	--	--	--

Some of the agents presented in Table 1 were not as effective as it might appear from these data alone. The blends of HCFC-123 & HCFC-22 (60:40 and 40:60) extinguished fires consistently; however, an experienced firefighter was required and extinguishment took longer than with the other agents. These two blends reacted with the fire and initially made it more difficult to control and extinguish. The same was true for the blends of HCFC-123 & -152a and the 60:40 blend of HCFC-123 & -142b. This last blend intensified the fire when it was applied, because of the high flammability of the HCFC-142b. The firefighter was able to maintain control and extinguish fires with this agent only because of experience, effective technique, and the small size of the test fire.

C. 32-FT^2 FIRES

Neat HCFC-123 and mixtures of HCFC-123 with either HCFC-22 or -142b were tested at this level. The 80:20 blend of HCFC-123 and -22 was tested extensively at 32 ft^2. The initial rapid knockdown of the fire by this agent was similar to that of Halon 1211. The firefighter could maintain control of the fire and extinguish it 50 to 60 percent of the time. Twice as much agent as Halon 1211 was required, even with ideal test conditions and application techniques. This was also true of the 75:25 and 70:30 blends of HCFC-123 and -22.

The mixture of HCFC-123 & HCFC-22 (50:50) gave effective knockdown and initial control of 32 ft^2 fires. However, this mixture did not have the throw range to reach the length of the pan. The agent stream was dispersed and could not be lofted sufficiently. Based on these results, further evaluation of this blend was discontinued.

The neat HCFC-123 and blend of HCFC-123 & HCFC-142b (80:20) were also tested on 32 ft^2 fires. The neat HCFC-123 agent controlled the fire rapidly and, if a fast sweeping technique was used, gave effective extinguishment. However, the agent produced a denser, more liquid stream than Halon 1211 when expelled from an extinguisher, and this dense stream made it difficult to maintain effective containment of the fire throughout the test. The fire could easily reignite behind the agent stream, and the firefighter often had to engage the entire pan fire again. Similar problems, though not as pronounced, were noted with the 80:20 blend of HCFC-123 & -142b.

Results of these tests are shown in Table 2. All tests at 32 ft^2 were carried out at a charge pressure of 195 $lb/in.^2$ using 9-, 13-, 17-, or 20-pound extinguishers. Agents containing high concentrations of HCFC-142b showed flammability.

D. 75-FT^2 FIRES

None of the agents tested, including Halon 1211, extinguished the 75-ft^2 fires consistently when the 17- and 20-pound extinguishers were used. With these extinguishers, Halon 1211 extinguished the fires 60 percent of the time, and neat HCFC-123 was 20 percent effective. The other agent mixtures, HCFC-123 & HCFC-22 (80:20) and HCFC-123 & HCFC-142b (80:20), were not effective with 17- and 20-pound extinguishers because the flow rates were too low. A larger extinguisher, a 30-pound unit, was also tried and produced similar unsatisfactory results. Tests were then conducted with the next largest extinguisher, a 50-pound unit. An adjustable spray nozzle manufactured by TFT Corporation was tested with this extinguisher along with the standard nozzle. It was found that, although some fires were extinguished by the neat HCFC-123 agent, the agent blends could not completely extinguish a 75-ft^2 fire with a 50-pound extinguisher. The extinguishment was unsatisfactory because the agent flow rates were too low. Finally, a 150-pound extinguisher fitted with the TFT nozzle was used, and the fires were extinguished consistently with all the test agents. The results are shown in Tables 3 and 4.

TABLE 2. DATA FOR 32-FT^2 FIRES.

Agent	Conc., Mole %	Extinguishment Tests			Average For All Runs			Extinguishment			Nonextinguishment		
		% Ext.	No. Pos.	No. Neg.	Wt. Agent, lbs	Time, s	Flow Rate, lb/s	Wt. Agent, lbs	Time, s	Flow Rate, lb/s	Wt. Agent, lbs	Time, s	Flow Rate, lb/s
Halon 1211	100	100	7	0	5.5	5.9	1.0	5.5	5.9	1.0	--	--	--
HCFC-123	100	100	2	0	9.7	6.4	1.5	9.7	6.4	1.5	--	--	--
HCFC-123 & -22	90:10	0	0	4	9.9	11.1	0.9	--	--	--	9.9	11.1	0.9
	80:20	54	7	6	10.0	9.5	1.1	8.7	7.5	1.2	11.5	11.8	1.0
	75:25	100	1	0	11.2	8.1	1.4	11.2	8.1	1.4	--	--	--
	70:30	50	3	3	7.0	9.8	0.8	5.4	5.6	1.0	8.0	15.5	0.5
	50:50	0	0	3	8.5	14.4	0.6	--	--	--	8.5	14.4	0.6
HCFC-123 & -142b	80:20	67	2	1	9.7	7.3	1.4	8.0	5.7	1.4	13.1	10.6	1.2

TABLE 3. DATA FOR-75 FT^2 FIRES.

Agent	Conc., Mole%	Extinguisher Size, lb	Extinguishment Tests %Ext.	NoPos.	NoNeg.	Average For All Runs WtAgent, lbs	Time, s	FlowRate, lb/s	Extinguishment WtAgent, lbs	Time, s	FlowRate, lb/s	Nonextinguishment WtAgent, lbs	Time, s	FlowRate, lb/s
Halon 1211	100	17	57	8	6	17	14.7	1.2	16.0	13.0	1.3	18.9	16.9	1.2
		50	100	2	0	16.5	10.5	1.6	16.5	10.5	1.6	--	--	--
HCFC-123	100	17	17	1	5	21.6	18.7	1.2	14.9	10.7	1.4	21.9	19.0	1.2
		30	0	0	2	23.0	21.5	1.5	--	--	--	23.0	21.5	1.5
		50	50	1	1	41.5	25.2	1.7	40.0	21.1	1.9	43.0	29.4	1.5
		150	100	3	0	37.0	9.8	3.8	37.0	9.8	3.8	--	--	--
HCFC-123 & -22	80:20	17	0	0	2	22.4	21.8	1.1	--	--	--	22.4	21.8	1.1
HCFC-123 & -142b	80:20	30	0	0	2	21.8	23.5	0.9	--	--	--	21.8	23.5	0.9
		50	0	0	3	47.3	40.7	1.2	--	--	--	47.3	40.7	1.2
		150	100	2	0	41.0	8.9	4.7	41.0	8.9	4.7	--	--	--

TABLE 4. AMOUNTS AND FlOW RATES OF AGENTS REQUIRED FOR EXTINGUISHMENT.

Agent	Conc., Mole %	Average Wt. to Extinguish, lbs			Avg., lb/ft^2	Min. Flow Rate to Extinguish, lb/s			Avg., $lb/s\text{-}ft^2$
		$4\ ft^2$	$32\ ft^2$	$75\ ft^2$		$4\ ft^2$	$32\ ft^2$	$75\ ft^2$	
HALON 1211	100	1.6	5.5	16	0.26	0.6	1.0	1.3	0.066
HCFC-123	100	2.5	9.7	33	0.46	0.4	1.5	1.4	0.055
HCFC-22	100	1.9	--	--		0.3	--	--	
HCFC-123 & -22	80:20	2.5	8.7	--		0.6	1.2	--	
	70:30	2.3	7.0	--		0.3	0.8	--	
	60:40	2.1	--	--		0.3	--	--	
	50:50	1.5	8.5	--		0.2	0.6	--	
	40:60	1.9	--	--		0.4	--	--	
HCFC-123 & -141b	90:10	2.2	--	--		0.5	--	--	
	80:20	3.6	--	--		0.5	--	--	
	70:30	2.6	--	--		0.4	--	--	
HCFC-123 & -142b	80:20	3.1	9.7	41	0.54	0.4	1.4	4.7	0.069
	70:30	2.5	--	--		0.3	--	--	
	60:40	4.4	--	--		0.5	--	--	
HCFC-123 & -152a	90:10	2.8	--	--		0.5	--	--	
	80:20	3.0	--	--		0.5	--	--	
HCFC-141b & -22	60:40	4.0	--	--		0.5	--	--	

The results show that it takes roughly twice as much neat HCFC-123 and three times as much HCFC-123 & HCFC-142b (80:20) as Halon 1211 to extinguish 75-ft^2 fuel fires. Depending on the agent used, a minimum flow rate for alternative agents of 1.6 to 4.6 lb/s must be maintained in order to extinguish this size fire. The required flow rates and amounts of agent necessary to extinguish the fire for neat HCFC-123 and HCFC-123 & HCFC-142b (80:20) were twice and three times that required for Halon 1211, respectively.

The use of the agent HCFC-123 & HCFC-22 (80:20) was discontinued early in this phase of testing. Though this mixture could effectively extinguish some of the test fires, the other candidates appeared to have better toxicity/effectiveness properties. The mixture of HCFC-123 & HCFC-142b (80:20) has a somewhat lower toxicity than neat HCFC-123, and testing with the blend of HCFC-123 & -142b was increased.

The blend of HCFC-123 & HCFC-142b (80:20) intensified the fire slightly as it was applied. This effect is believed to be caused by the flammability of the HCFC-142b. The HCFC-123 & HCFC-142b (80:20) blend was also not as effective in extinguishing fires as neat HCFC-123.

Quantities of agents required for extinguishment depend on pressure, nozzle type, and application technique, as well as fire size. However, plots of fire size versus quantities of agents required for extinguishment give the plots shown in Figures 5 through 8. These plots also allow estimation of quantities of agents used for other fire sizes. For example, interpolation indicates that 50-ft^2 fires will require approximately 11 pounds of Halon 1211, 21 pounds of HCFC-123, or 23 pounds of HCFC-123 & HCFC-142b (80:20) for extinguishment. By extrapolation, 150-ft^2 fires are expected to require approximately 34 pounds of Halon 1211, 75 pounds of HCFC-123, or 85 pounds of the blend of HCFC-123 & HCFC-142b (80:20) for extinguishment. Limited actual testing in Phase IV of this project indicates that the performance of the candidates is, however, closer to that of Halon 1211 than predicted here.

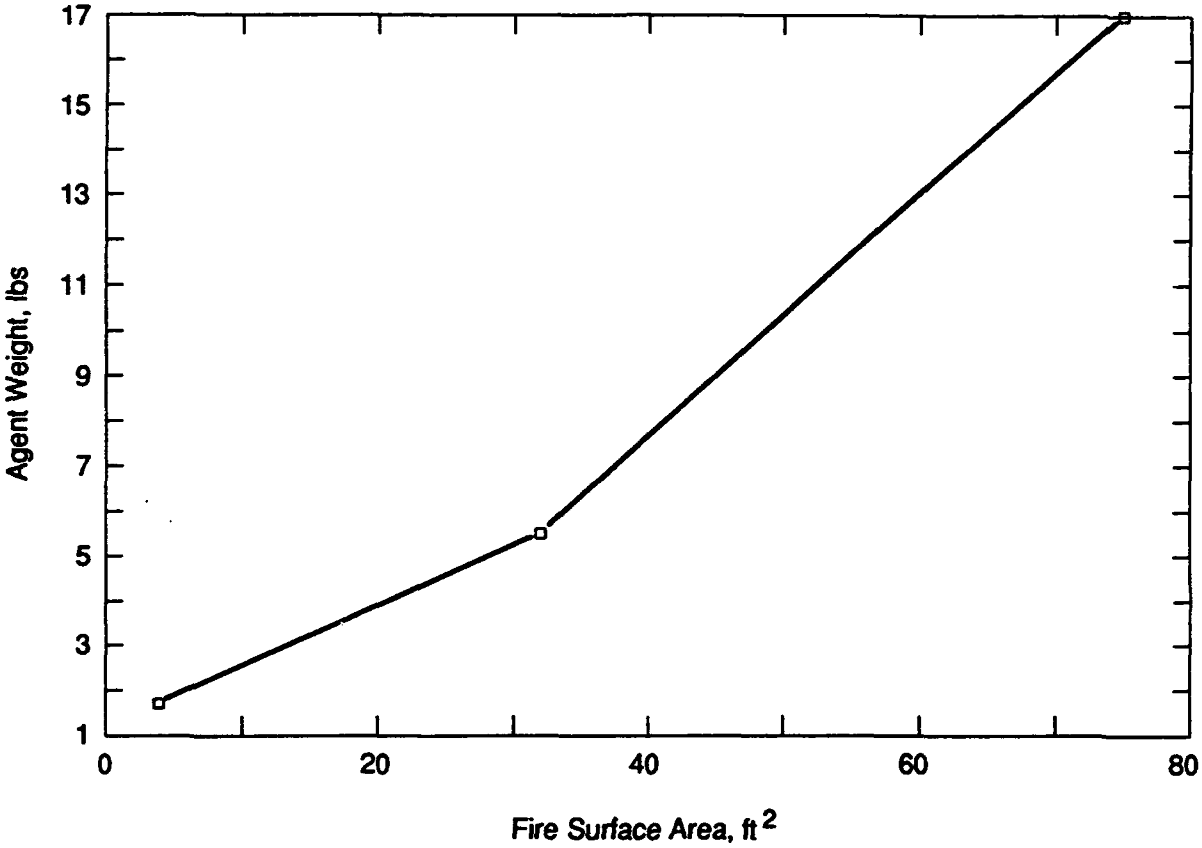

Figure 5. Pounds of Halon 1211 Required Versus Fire Size.

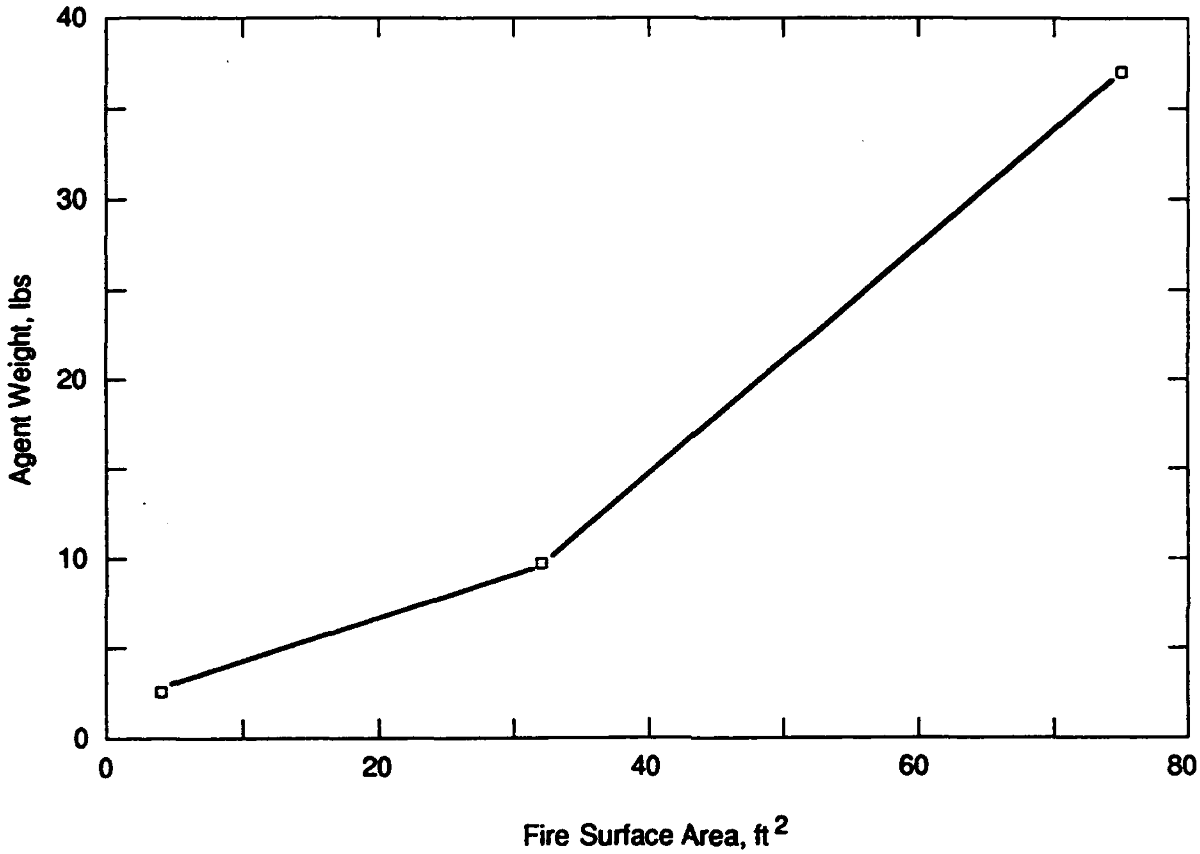

Figure 6. Pounds of HCFC-123 Required Versus Fire Size.

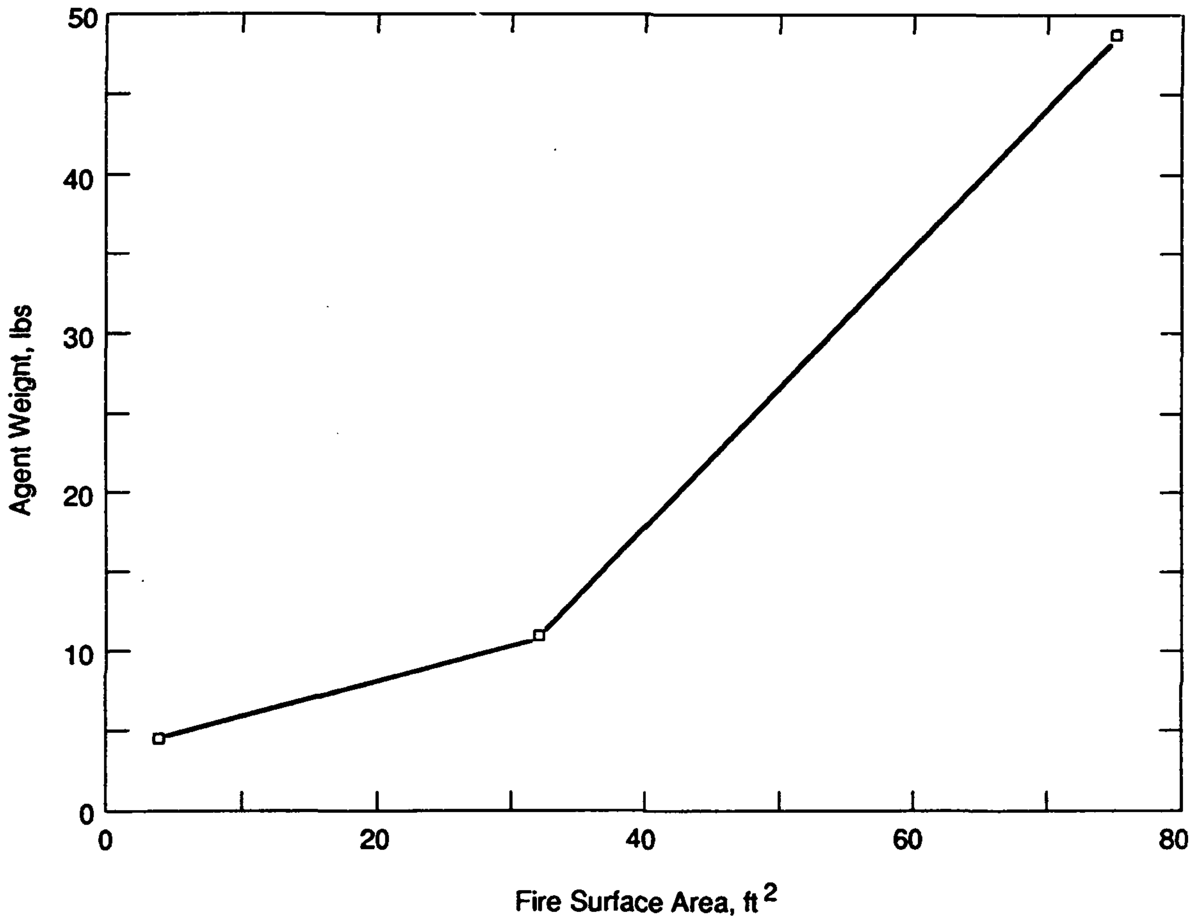

Figure 7. Pounds of HCFC-123 & HCFC-142b Blend (80:20) Required Versus Fire Size.

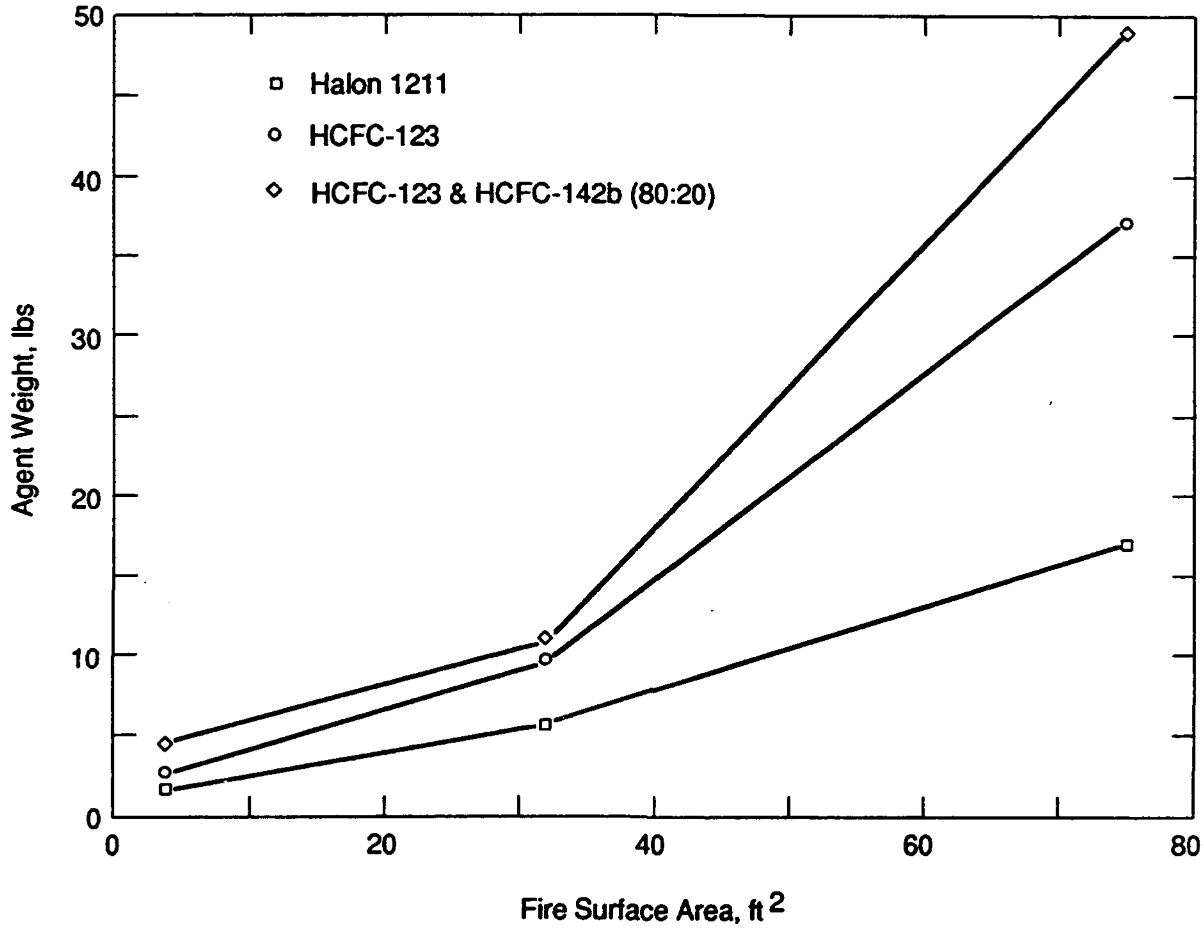

Figure 8. Summary of Agent Quantities Versus Fire Size.

Figure 9 shows a plot of critical application rate versus fire size for each of the three agents tested to 75 ft^2. From this plot it can be seen that the order of effectiveness on all fire sizes is Halon 1211 > HCFC-123 > HCFC-123 & HCFC-142b (80:20). Plots for all three agents show some upward curvature, especially noticeable for small fires. This curvature indicates that the amount of agent required per square foot of fire surface area decreases as fire size increases. It may be that more agent than the minimum necessary was applied to the 4-ft^2 fires since it is difficult to limit application to very small amounts. The nonlinearity was more pronounced with the alternative agents than with Halon 1211.

Table 5 shows average flow rates and flow rates per square foot required for extinguishment.

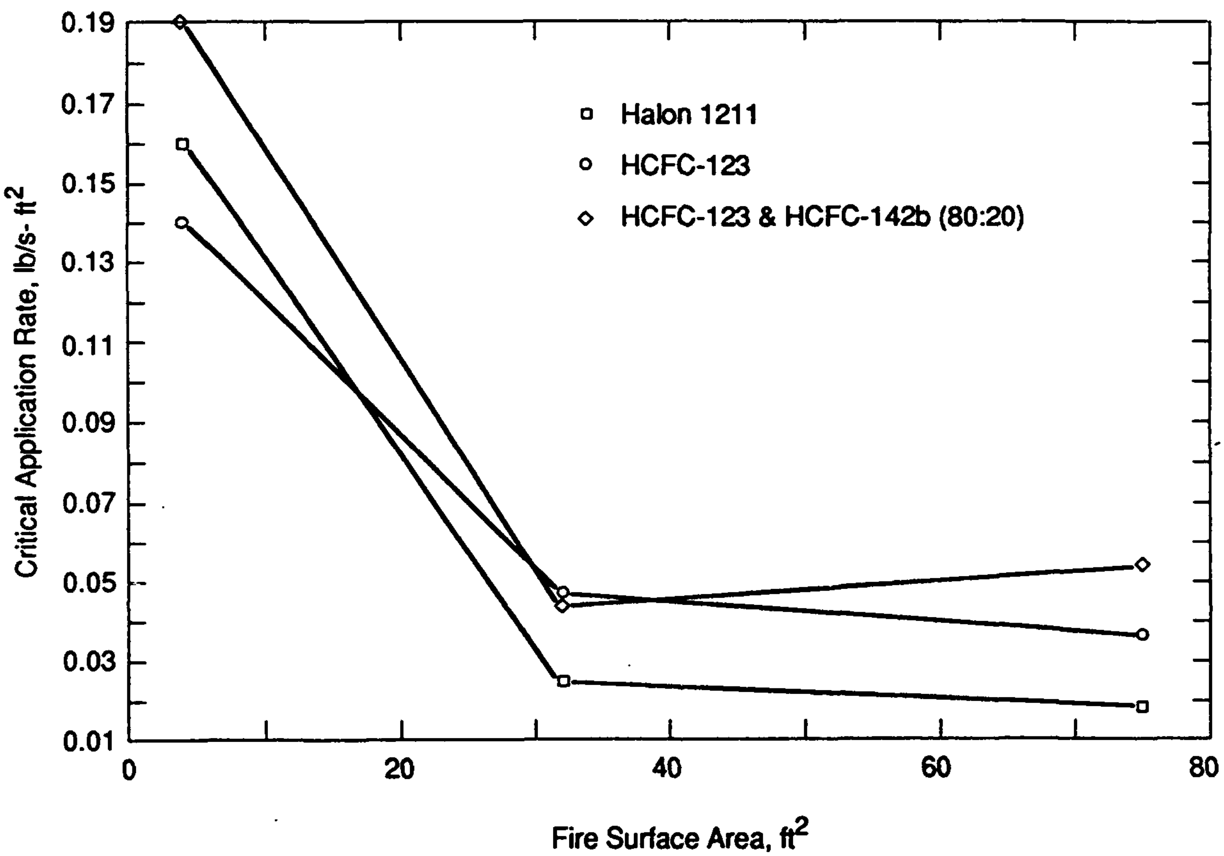

Figure 9. Summary of Critical Application Rates Versus Fire Size.

TABLE 5. AVERAGE FLOW RATES AND CRITICAL APPLICATION RATES.

Fire Surface Area, Ft^2	Agent	Mole Percent	All Runs		Extinguishment Only	
			Flow Rate, lb/s	Flow Rate, lb/s-ft^2	Flow Rate, lb/s	Flow Rate, lb/s-ft^2
4	Halon 1211	100	0.65	0.16	0.65	0.16
	HCFC-123	100	0.54	0.14	0.54	0.14
	HCFC-123 & -142b	80:20	0.77	0.19	0.77	0.19
32	Halon 1211	100	0.80	0.025	0.80	0.025
	HCFC-123	100	1.50	0.047	1.50	0.047
	HCFC-123 & -142b	80:20	1.25	0.042	1.4	0.044
75	Halon 1211	100	1.27	0.017	1.34	0.018
	HCFC-123	100	1.89	0.025	2.7	0.036
	HCFC-123 & -142b	80:20	2.19	0.029	4.1	0.054

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

Several agent blends were tested at various stages of this test series. The following agent effectiveness criteria were applied: rapid knockdown and initial containment, maintenence of control without flashback or reignition, adequate throw range, effective extinguishment of large fires, and extinguishment without intensification. The candidate agent blends were tested with fires having surface areas of 4 ft^2, 32 ft^2, and 75 ft^2 in which 0.25 to 2 inches of JP-4 aviation fuel were floated on top of water and ignited. As the testing progressed, ineffective agent mixtures were dropped from further consideration.

The first agents to be discontinued were the mixtures containing HCFC-152a or -141b. These agents were mixed with various amounts of HCFC-123 or HCFC-22 and were not effective in extinguishing 4-ft^2 fires. Blends of HCFC-123 and -141b did not disperse well and gave poor knockdown; both drawbacks can be attributed to the low volatility of these blends. HCFC-141b is flammable and appears to be a poor extinguishing agent in blends. The HCFC-152a blends were relatively successful during the 4-ft^2 tests; however, blends containing HFC-152a intensified the fire, especially with higher concentrations of HFC-152a.

Mixtures of HCFC-123 with HCFC-22 or -142b proved effective throughout the testing when mixed in the correct proportions (30 percent or less HCFC-22 or -142b). Mixtures containing 40, 50, and 60 percent of HCFC-22 and -142b were discontinued at various test levels for several reasons. The HCFC-123 and HCFC-22 (50:50) mixture provided excellent knockdown but had a poor flow rate and throw range. Similar results were obtained with the mixtures containing 40 percent HCFC-22. The 70:30 and 80:20 blends of HCFC-123 and -22 proved effective through the 75-ft^2 fire tests. Testing of these mixtures was discontinued because other agents appeared more promising.

Mixtures that contained 40 percent or more HCFC-142b could not be tested effectively due to agent flammability. The HCFC-123 & HCFC-142b (70:30) mixture also proved ineffective. The mixture of HCFC-123 & HCFC-142b (80:20) was effective and was tested up to 75 ft^2; however, the agent mixture did intensify the fire to some degree, decreasing its extinguishing ability.

Neat HCFC-123 extinguished fires consistently if twice the weight of agent as the average required weight of Halon 1211 was used. To achieve this effectiveness, an adjustable spray nozzle and a large capacity extinguisher that delivered the agent at a higher flow rate were required for the larger fires.

For all tests, it was shown that a higher candidate agent flow rate than that of Halon 1211, coupled with a smooth, overlapping agent application method controlled and extinguished the fires most effectively. When these methods were used, roughly twice as much neat HCFC-123 and three times as much HCFC-123 & HCFC-142b (80:20) as Halon 1211 were required for extinguishment. This relationship also applies to the agent flow rate. Depending on the agent used, flow rates of 1.6 to 4.6 lb/s must be maintained in order to extinguish 75-ft^2 fires. The required flow rates for neat HCFC-123 and HCFC-123 & HCFC-142b (80:20) were two to three times that required of Halon 1211.

Neat HCFC-123 and HCFC-123 & HCFC-142b (80:20) are effective as alternative training agents and simulate the use of Halon 1211, providing proper equipment is used to give the required agent flow rates and dispersion. However, further work will be needed to develop more practical nozzles, a standard test/training scenario, and agent-compatible materials.

The nozzle used in this testing was not designed for this type of use and could prove expensive to purchase for training purposes. Simple nozzles could be designed that are suited for use with the agents without adjustment; these could be produced and procured at much lower cost than the adjustable nozzles used here.

During the testing, it was discovered that neither standard test procedures nor standard test apparatuses exist for firefighter training. The lack of standard scenarios made it difficult to choose the most appropriate test conditions and equipment. A study should be conducted to standardize firefighter training so that agent testing can be carried out under realistic conditions.

The materials used in O-ring seals, valve seats, and other critical extinguisher parts degraded quickly when exposed to the candidate agents. A materials compatibility study is needed to find materials that are compatible with the agents.

The HCFC-142b mixtures were effective and had lower toxicities than neat HCFC-123. Blends of HCFC-123 and -141b did not disperse well and gave poor knockdown. Both of these drawbacks can be attributed to the low volatility of this blend and possibly the flammability of HCFC-141b.

SECTION VI
EXPERIMENTATION PLAN FOR PHASE IV

A. INTRODUCTION

Phase IV is a continuation of the field-scale testing conducted in Phase III of this project in which candidate extinguishing agents were tested on 4-, 32-, and 75-ft^2 fires. In Phase IV, the most promising agents will be tested further with three-dimensional (3-D) running fuel fires of 75 ft^2 and standard pool fires of 150 ft^2. The following is a proposed extension of an existing test plan in which the 75-ft^2 3-D and 150-ft^2 test procedures are outlined (Reference 2).

B. TEST SITE DESCRIPTION

The testing facilities will be located on Kirtland Air Force Base at the CERF facility. The tests will be conducted in a fenced wind enclosure constructed of TENAX Riparella mono-oriented net wind fencing. The wind enclosure is constructed as a pair of concentric circles to maximize the wind abatement effect.

This enclosure totally surrounds the test area and has an outer fence diameter of 140 feet, and inner fence diameter of 85 feet, and a height of 20 feet. The 75-ft^2 pan and 150-ft^2 pit are located within this structure.

C. TEST SCHEDULE

This testing was scheduled for 15 June to 30 September 1990.

D. TEST EQUIPMENT

The first series of 75-ft^2 3-D running fuel fires will be conducted in the existing square 75-ft^2 fire pan. The pan was constructed of 0.25 inches thick steel with a 1.25 by 1.25-inch steel angle welded along the top outside edges of the pan. The pan had dimensions of 8 feet, 8 inches (square) by 8 inches deep. The edges of the pan were bermed with earth to minimize turbulence caused by air entrainment during fire testing. The first 3-D fire apparatus will be placed in this pan.

This apparatus will serve as a prototype in the conduct of preliminary testing of this type of device. It will be contructed of steel pipe and a steel support structure to elevate the pipe above the fire pit lengthways so that one open end of the pipe is 15 degrees lower than the other. Fuel will be pumped to a spray bar located at the back end of the pipe, to allow fuel to be sprayed evenly into the pipe at a constant rate. The fuel will then flow through the pipe and into the 75-ft^2 pan located 4 feet below the raised pipe apparatus.

The second 3-D apparatus will be constructed to simulate an aircraft engine suspended under the wing of the aircraft. Two barrels of different sizes will be nested, and an intake cowling from an actual aircraft will be fitted over them. A pumped fuel line will be run into the middle of this apparatus and will spray fuel toward the front end of the apparatus at a given rate. The apparatus will be suspended from a boom over a containment fire pit and tilted 15 degrees forward.

The 150-ft^2 tests will resemble the 75-ft^2 tests except for use of a larger fire area. For each test, sufficient fuel will be pumped into the fire pit to float 0.25 inches of fuel over the entire surface of the water.

Standard 150-pound Halon 1211 extinguishers will be used for all tests. Smoothbore flightline nozzles and adjustable spray nozzles will be tested to determine the most appropriate agent streaming pattern.

E. TEST PROCEDURES

In both of the 75-ft^2 3-D running fuel fires, the fuel will be allowed to flow through the apparatus into the pan or pit to cover the water surface before the fuel is ignited. The bottom pan or pit will be allowed to become fully engulfed in flame before extinguishment is started. The firefighter will extinguish this fire by building up a large concentration of agent in the lower pan or pit and using a sweeping motion similar to the methods used in earlier tests. When most of the fire in the bottom pan or pit has been controlled, the agent stream will be directed into the apparatus and the running fuel fire will be extinguished. The firefighter will then finish extinguishing the bottom fire and any remaining fire in the apparatus.

The method used in extinguishing the 150-ft^2 fire will follow standard firefighting procedures. The fuel will be added to the water, ignited, and allowed to burn for 30 seconds. The firefighter will then apply the agent stream to the fire in a sweeping, side-to-side motion to extinguish the fire progressively from the front edge to the back edge.

F. ENVIRONMENTAL CONCERNS

Compliance with all environmental regulations and local, state, and federal agencies has been assured by conducting an environmental survey of potential problems with this testing. All aspects of this survey are documented in the previous test plan (Reference 2) for the previous phase of testing.

REFERENCES

1. Nimitz, J. S., Tapscott, R. E., Skaggs, S. R., and Beeson, H. D., Alternative Training Agents, Phase I -- Survey of Near-Term Candidate Fire Extinguishing Agents and Predicting Properties of Halocarbon Mixtures, Vol. 1 of 4, ESL-TR-90-39, Air Force Engineering and Services Laboratory, Tyndall Air Force Base, Florida, April 1990.

2. Moore, T. A., Moore, J. P., Nimitz, J. S., Lee, M. E., and Tapscott, R. E., Alternative Training Agents, Phase II -- Laboratory Scale Experimental Work, Vol. 2 of 4, ESL-TR-90-39, Air Force Engineering and Services Laboratory, Tyndall Air Force Base, Florida, August 1990. (Draft)

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