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Aircraft Hangar Fire Suppression System Evaluation—Intermediate-Scale Studies

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Tests were conducted at the Chesapeake Beach Detachment (CBD) of the Naval Research Laboratory (NRL) to evaluate the effect of water sprays on AFFF foam blankets. The tests show that application rates of AFFF above 4.1 Lpm/m^2 resulted in little improvement in extinguishing times. For the AFFF application rate cited above, the extinguishment times were decreased by an overhead water sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2). The burnback times were affected by the overhead water sprinklers. The burnback time for JP-8 was less than for JP-5 with the overhead sprinkler activated.

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AIRCRAFT HANGAR FIRE SUPPRESSION SYSTEM EVALUATION - INTERMEDIATE-SCALE STUDIES

1.0 BACKGROUND

Current Navy design standards for protecting large aircraft hangars include both overhead and low level aqueous film forming foam (AFFF) extinguishing systems [1]. The overhead AFFF system typically consists of standard closed head sprinklers that are zoned within areas defined by draft curtains. In some existing installations, the overhead systems are open head deluge systems. The low level system typically consists of multiple high flow foam monitors (e.g., 1893 Lpm (500 gpm)). The low level AFFF and overhead deluge sprinkler systems are activated by separate detection systems (heat detectors or UV/IR).

Due to high costs incurred from damage to aircraft and electronics resulting from accidental discharges of the overhead AFFF system, the Navy is exploring alternate suppression techniques. The proposed approach would replace the overhead foam suppression system with a closed-head water sprinkler system. The low level AFFF delivery system would become the primary means of fire suppression with the overhead sprinklers used to cool adjacent aircraft and protect the structural integrity of the hangar. The actuation time delay of the overhead system would be minimized through the use of quick response sprinklers. This time delay has already been quantified in previous studies [2].

The rationale for replacing the overhead AFFF system with a water sprinkler system is twofold. First, AFFF has a greater potential than water for damaging the aircraft electronics if the cockpit is open, and secondly, the higher costs associated with installing, maintaining, and restoring the overhead AFFF system after an accidental discharge can be prohibitive. After discharge, the entire suppression system must be flushed, cleaned, and reset before the system can be put back in service. Additionally, there are environmental concerns associated with the discharge of AFFF [3].

The Navy has also recognized a problem with the monitor nozzles currently used in low level AFFF systems. The typical monitor nozzles used in hangars today were originally designed to protect fuel tank farms. The spray characteristics (high trajectory) of these nozzles may result in AFFF entering an aircraft hatch or open cockpit. This can result in damaged electronics, as well as the loss of mission capability and fight time of the affected aircraft.

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The concern with combining overhead "water-only" sprinklers with a low level AFFF extinguishing system is the potential negative effects the water spray may have on the foam blanket. Overhead water sprinklers operating on the foam blanket might impact both the extinguishing capability of the foam and the ability of the blanket to resist burnback. When AFFF is applied over a flammable liquid spill or fire, the foam blanket forms a vapor barrier, suppressing the release of flammable vapors. This is shown in Figure 1. If the integrity of the foam blanket is damaged, the vapors may escape and ignite. The water droplets from the overhead water sprinkler system may have sufficient momentum and density to degrade the stability of the blanket. If the foam blanket stability is compromised, the vapor barrier may be lost and the potential for burnback and re-ignition is increased. The water may also dilute the solution (concentration of AFFF), resulting in a faster break down.

In 1970, National Foam, Inc. evaluated the effects of water sprays on protein foams [4]. The tests focused on evaluating the use of water sprinklers in conjunction with protein and fluroprotein foams to extinguish gasoline fires. AFFF was not available at that time and therefore was not tested. The tests concluded that fire knock down and control times were not dramatically affected by the water sprays from sprinkler heads. The investigation provided little data on the effect of water sprays on burnback resistance.

The tests also concluded that the size of the water spray droplets had a greater effect on the performance of the foam than water application rate. Coarse water sprays (large droplets) tended to penetrate the foam, splashing fuel back up through the blanket, making the fire harder to extinguish. The fine water sprays (small droplets) resulted in quicker knockdown, control and extinguishment of the fire. It was also noted that for a given water spray, increasing the foam application rate reduced the fire knockdown, control and extinguishment times.

Naval Facilities Engineering Command (NAVFAC) initiated the current investigation to study the effect of water sprays on AFFF foam blankets. The investigation consists of two phases. The first phase was a series of intermediate-scale tests to bound the problem and to identify the variables to be included in the second phase of the investigation. The second phase will reevaluate the problem on a larger scale. The large-scale tests will be conducted to evaluate the proposed protection scheme in real-scale.

This report addresses the intermediate-scale test series (Phase I). The tests were conducted at the Chesapeake Beach Detachment (CBD) of the Naval Research Laboratory (NRL).

2.0 OBJECTIVE

The primary objective of the intermediate-scale test series was to study the interaction between overhead water sprinklers and AFFF foam blankets. The evaluation focused on the ability of the foam to extinguish liquid pool and spill fires produced using standard Navy fuels

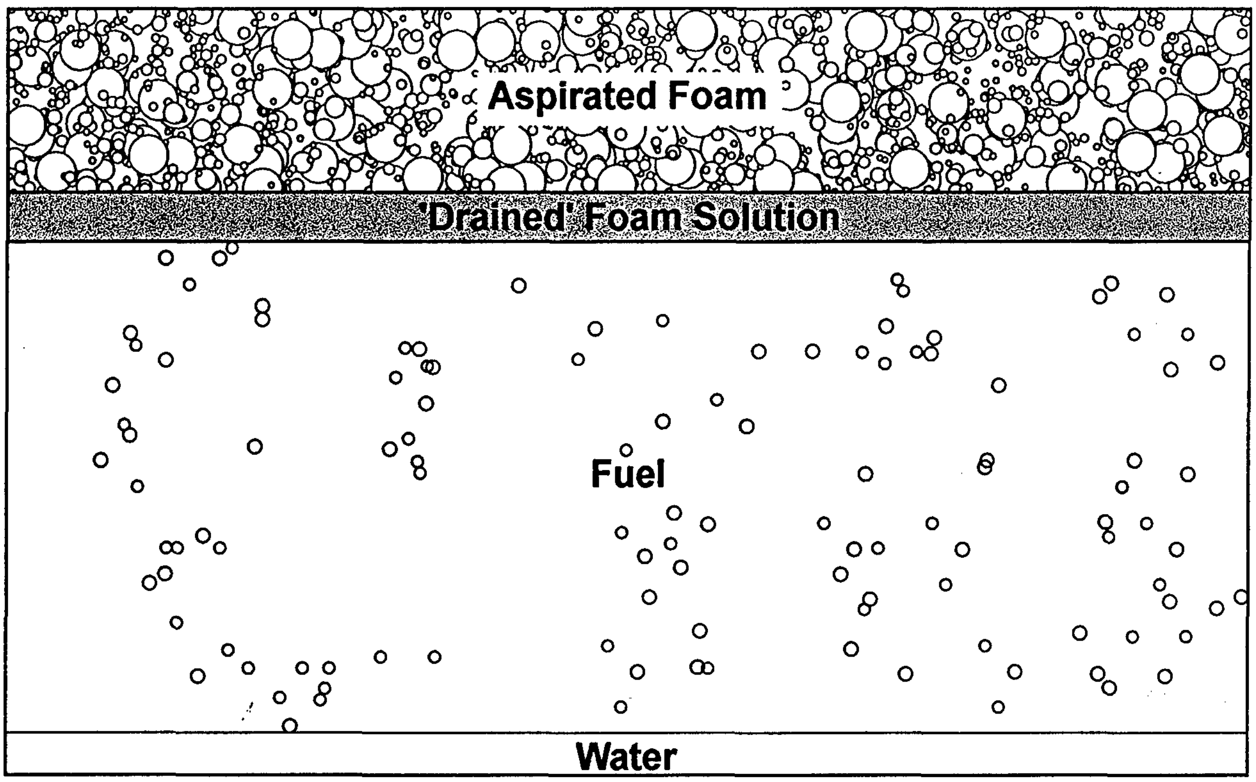


Fig. 1. AFFF blanket layers

(JP-5 and JP-8), and to prevent the fire from reigniting and spreading back across the fuel surface (burnback). Burnback was quantified in terms of the time for an ignition source to reignite the fuel and burn away 25 percent of the foam blanket. The results of these tests were applied to the development of the large-scale test series.

3.0 SCENARIO DEVELOPMENT

A primary fire hazard associated with an aircraft hangar is the ignition of a fuel spill resulting from a broken fuel line or a ruptured fuel tank. The resulting fire could consist of both a running fuel fire shielded by the wing of the aircraft and/or a large spill fire produced by the spilling fuel. Upon detection of the fire, the hangar suppression systems would be activated. For this fire scenario, the suppression system would be required to extinguish the spill fire resulting from the fuel spill and prevent the fire from spreading to areas other than under the wing of the incident aircraft. The ability of the suppression system to prevent the reignition of the fuel spill, and to control the fire once the fuel has reignited is referred to as burnback resistance. The fire suppression system is required to prevent the fire from burning back for a period of ten minutes. Ten minutes was selected based on a reasonable time required to begin manual intervention and also corresponds to the duration of the supply of AFFF.

The proposed fire suppression system consists of both a low level AFFF extinguishing system and an overhead quick response water sprinkler system. Upon the onset of a fire, at a minimum, the low level AFFF extinguishing system would be activated. If the fire spreads quickly, producing a large fire before the fire is detected and AFFF is discharged, both the overhead water and low level AFFF system may be activated simultaneously or in sequence. The possibility also exists that sprinkler activation may be delayed until after the low level AFFF system has begun discharging due to the thermal lag of the sprinkler. These fire and system variables were evaluated during this fire investigation.

3.1 Scoping Tests

A series of meetings was held with NAVFAC personnel to identify key variables associated with hangar fire suppression systems, layouts, and designs. This information formed the foundation for the initial fire test scenario and identified the test variables which were evaluated and refined during the scoping tests. A total of 121 scoping tests were conducted. A summary of the scoping tests is presented in the following paragraphs.

The initial fire scenario evaluated during the scoping tests was a pan fire (confined scenario). The pan fire was used to represent a pool fire. The term pool fire refers to a fire scenario where the fuel is restrained within definite boundaries. In this report, this fire scenario was referred to as the confined scenario.

A limited number of spill fire tests were also conducted. A spill fire scenario is one where the fuel is not confined by any boundaries. The fuel will therefore spread out to a minimum thickness that is determined by factors such as the surface tension of the fuel, porosity of the floor, and the slope of the floor. Hangar design has traditionally included drains to help limit the size of the fuel spill. In this report, the spill fire test is referred to as the unconfined scenario.

The fires were produced using typical Navy fuels (JP-5 which is the carrier based fuel and JP-8 which is the land based fuel and also used as the primary fuel by the Air Force). Tests were conducted using a range of fuels (heptane, gasoline, JP-5, and JP-8) to provide comparative data. The results of the scoping tests identified a difference in system capabilities for the various fuels requiring that both JP-5 and JP-8 be included in the intermediate-scale test series. The unconfined fire scenario was also identified as the most challenging and representative of typical hangar conditions.

The scoping tests also identified the need for a reproducible exposure fire to degrade the foam blanket and result in burnback across the fuel surface. Several burnback apparatus were evaluated during the scoping tests. One of the burnback methods evaluated during the scoping tests was the method described in the Military's Specification for AFFF, MIL-F-24385F [5]. This method proved difficult to adapt to the changing parameters of this test series. The selected burnback apparatus (one for the confined and one for the unconfined scenario) are described in Section 4 of this report.

The test fires were extinguished using either AFFF from the low level system or with the combination of AFFF and overhead water sprinklers. The AFFF system consisted of a non-air-aspirated nozzle and was evaluated at a fixed application density of 4.2 L/m^2 (0.1 gal/ft^2). This density is representative of that found in typical Navy hangars. Although the application density was held constant, the application rate and duration was varied. The results of the scoping tests identified variations in system performance due to changes in application rate requiring that application rate be re-evaluated during the intermediate-scale test series.

Two sprinkler application rates were included in the scoping tests to evaluate their effect on the extinguishment and burnback capabilities of the system. The first application rate, 6.5 Lpm/m^2 (0.16 gpm/ft^2), is required by NFPA 409 for overhead foam water sprinklers [6]. The second application rate, 10.2 Lpm/m^2 (0.25 gpm/ft^2), is required by NFPA 13 [7] for hangars that are not covered in NFPA 409. The results of the scoping tests identified variations in system performance for the two application rates requiring that both be included in the intermediate-scale test series.

In typical aircraft hangar installations (ceiling heights from 15 m (50 ft) to 61 m (200 ft)), the sprinkler drops would reach their terminal velocity well before hitting the fuel surface. The motion of the sprinkler drop as it falls to the ground can be described using first principles. C. Yao and A.S. Kalelkar have shown, the largest stable water drop that will not easily break up is 6 mm (0.24 in.) in diameter [8]. The terminal velocity for droplets of this size was found to be almost 9.4 m/s (30.9 ft/sec). The height required for a falling droplet to travel before it reaches this speed is roughly 4.5 m (14.9 ft). Based on this data, the sprinkler system used during the intermediate-scale tests was installed 5.0 m (16.4 ft) above the fire apparatus.

The scoping tests evaluated the impact of relatively short sprinkler discharge times on the burnback performance of the foam blankets. During these tests, the sprinklers were operated for a short period of time, then secured. It was decided that this procedure was not representative of conditions typically found in an aircraft hangar. Once the sprinkler system is activated in the hangar, the responding fire department will not shut off system until well after the situation is under control. To be more representative of hangar conditions, the remaining scoping tests were conducted with the sprinklers activated until the end of the test.

It was also concluded that the sprinklers should be evaluated using two activation times (simultaneous with the AFFF system or delayed to simulate the thermal lag of the system). Variations in system performance between the two activation times required that both times be included in the intermediate-scale test series.

In summary, the scoping tests were used to quantify the effects of several key variables. The scoping tests also developed several new methods of testing foam performance. The development of an unconfined fuel spill test apparatus also required many days of scoping tests to ensure that the test fire was challenging and repeatable. During the scoping tests, the following test variables were identified to be included in the intermediate-scale tests.

- Both a confined and an unconfined fire scenario should be included in the intermediate-scale studies,
- System capabilities should be determined for both JP-5 and JP-8 fuels,
- The two burnback apparatus developed during the scoping tests should be used in the intermediate-scale test series,
- The low level AFFF extinguishing system should discharge non-air aspirated foam,
- The AFFF application density should be held constant and the application rate and discharge duration should be varied,
- Two sprinkler application rates should be evaluated during the intermediate-scale test series, both 6.5 Lpm/m^2 (0.16 gpm/ft^2) and 10.2 Lpm/m^2 (0.25 gpm/ft^2).
- The impact of sprinklers should be evaluated using both a simultaneous and a delayed activation time.

4.0 INTERMEDIATE-SCALE TESTS - TEST DESCRIPTION

The intermediate-scale fire scenarios were designed to simulate fuel spill fires under controlled conditions. The confined scenario (pan fire), was used to simulate a pool fire. The unconfined scenario was designed to simulate an actual spill fire. In both scenarios, once fuel was added to the pan and ignited, AFFF, or a combination of AFFF and overhead water sprinklers were used to control and extinguish the fire. A burnback apparatus was then used to expose the fuel to a constant re-ignition source. The time required to re-ignite the fuel and involve 25 percent of the fuel surface was used to determine the relative burnback resistance of the suppression system design.

4.1 Test Facility

The tests were conducted in a burn building measuring 7.6 m (25 ft) x 7.6 m (25 ft) x 7.0 m (23 ft) high. The burn building is shown in Figure 2. The building was equipped with vents along the centerline of the roof that were kept open during tests. The height of the vents at the centerline was approximately 7.0 m (23 ft). The roof sloped away to a height of 6.1 m (20 ft) at the edge.

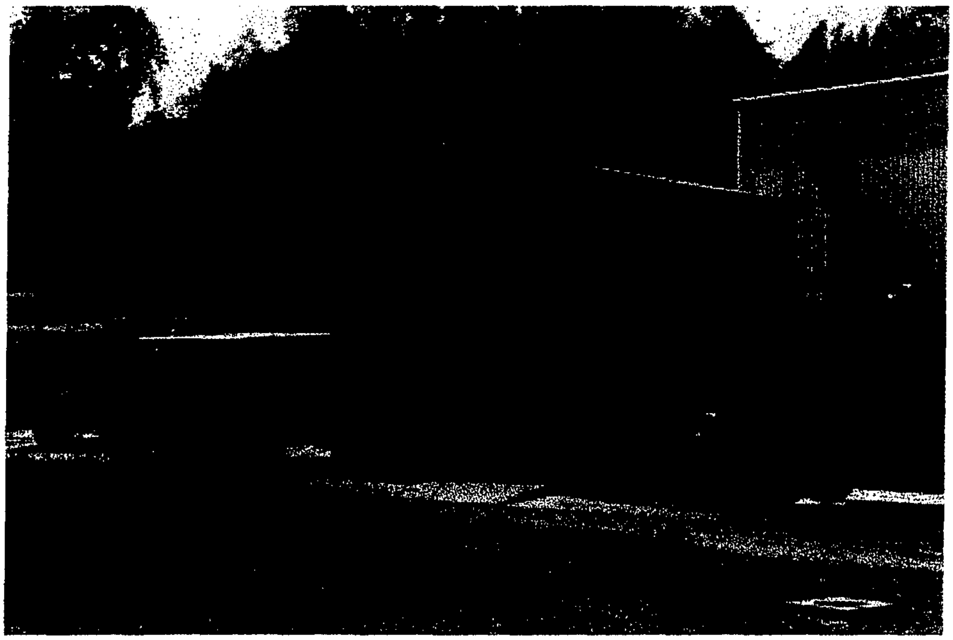
4.2 Confined Scenario

The confined fire scenario consisted of a pan fire produced using either JP-5 or JP-8 jet fuel. A water substrate was used to keep a constant fuel depth in the fire pan and to protect the pan from heat. Once the fuel was added to the pan, a small amount of heptane was used as an accelerant to make the fuel easier to ignite and to decrease the time needed to reach steady state burning. It was estimated [9] that the heptane was consumed in roughly 30 seconds, well within the pre-burn period of 45 seconds.

The fires were extinguished using AFFF or a combination of AFFF and overhead water sprinklers. The AFFF was discharged against an angled metal sheet designed to redirect the AFFF stream into the test pan. During these tests, the AFFF density was held constant (4.1 L/m^2 (0.1 gal/ft^2), but the foam application rate and duration were varied.

Two sprinkler application rates were evaluated during the confined fire tests. The first application rate, 6.5 Lpm/m^2 (0.16 gpm/ft^2), is required by NFPA 409 for overhead foam water sprinklers [6]. The second application rate, 10.2 Lpm/m^2 (0.25 gpm/ft^2), is required by NFPA 13 [7] for hangars that are not covered in NFPA 409. The sprinklers used in this evaluation are similar to ones currently used in Navy hangars.

After the fire was extinguished, a burnback apparatus (propane burner) was used to expose the pool fire to a constant re-ignition source. This simulates the heat flux that might be presented by a burning aircraft.



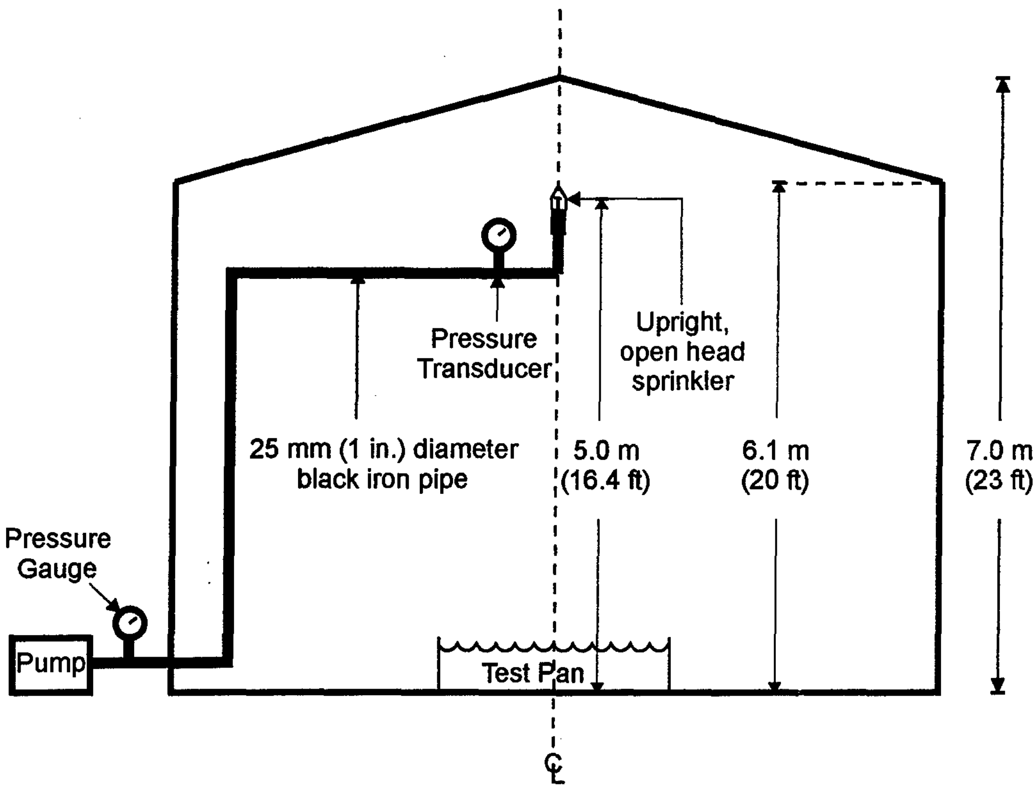


Fig. 2. CBD test facility

4.2.1 Fire Pan

The fire pan measured 1.5 m (5 ft) x 1.5 m (5 ft) x 0.30 m (1 ft) deep and was constructed of 6 mm (0.25 in.) steel plate as shown in Figure 3. The test pan was mounted 20 cm (8 in.) above the floor on four cinder blocks. A drain at the bottom of the pan was used to remove the effluent after each test was concluded.

The test fuel was floated on top of a 8 cm (3 in.) layer of water. The water temperature was maintained at 20°C (68°F) ± 5°C (9°F). In all of the tests, 37.9 L (10 gal) of fuel was poured into the test pan, creating a layer of fuel that was 1.5 cm (0.6 in.) thick. An additional 3.8 L (1.0 gal) of accelerant was added to the fuel increasing the layer thickness to 1.7 cm (0.7 in.). The fuel was ignited and allowed to pre-burn for 45 seconds before the suppression systems were activated. The accelerant burned off within 30 seconds of ignition. The estimated heat release of the pan fire was approximately 5.0 MW [9].

4.2.2 Burnback Apparatus

The burnback apparatus consisted of a pre-mixed propane burner that was located at the center of one side of the fire pan as shown in Figure 4. The burner flame was directed down onto the foam blanket at an angle of 40°. The burner itself was contained inside a section of 5 cm (2 in.) black iron pipe that served as a shield for the burner. A 0.8 m (2.7 ft) long piece of 2.5 cm (6 in.) angle iron was placed over the burner to further shield the flame from the effects of water discharged by the overhead sprinkler system.

The propane was stored in a 45.4 kg (100 lb) cylinder located outside the test building. Propane was supplied to the burner through 6 mm (0.25 in.) diameter copper tubing which ran from the cylinder to a vaporizer, through a flow gauge then into the building where it connected to the burner. The vaporizer ensured that in cold weather, the propane would be in gaseous form as it passed through the flow meter. The propane flow rate was 0.4 L/s (0.8 cfs). Based on this flow rate and assuming complete combustion of the fuel, the burner had an estimated heat release rate of 32 kW [9].

4.2.3 Low Level AFFF Extinguishing System

The AFFF extinguishing system used in the test series discharged non-air-aspirated AFFF. Three application rates were evaluated during this investigation: 1.6 Lpm/m^2 (0.04 gpm/ft^2), 4.1 Lpm/m^2 (0.1 gpm/ft^2), and 8.2 Lpm/m^2 (0.20 gpm/ft^2). The lowest rate, 1.6 Lpm/m^2 (0.04 gpm/ft^2), is the application rate used in "UL 162, Foam Equipment and Liquid Concentrates." [10] This test standard evaluates the extinguishment and burnback performance of firefighting foam at a very low (i.e., critical) application rate. The second application rate, 4.1 Lpm/m^2 (0.1 gpm/ft^2), is the application rate currently used in Navy hangars as prescribed in NFPA 409 [6]. The final rate was chosen to evaluate the effect of higher AFFF application rates.

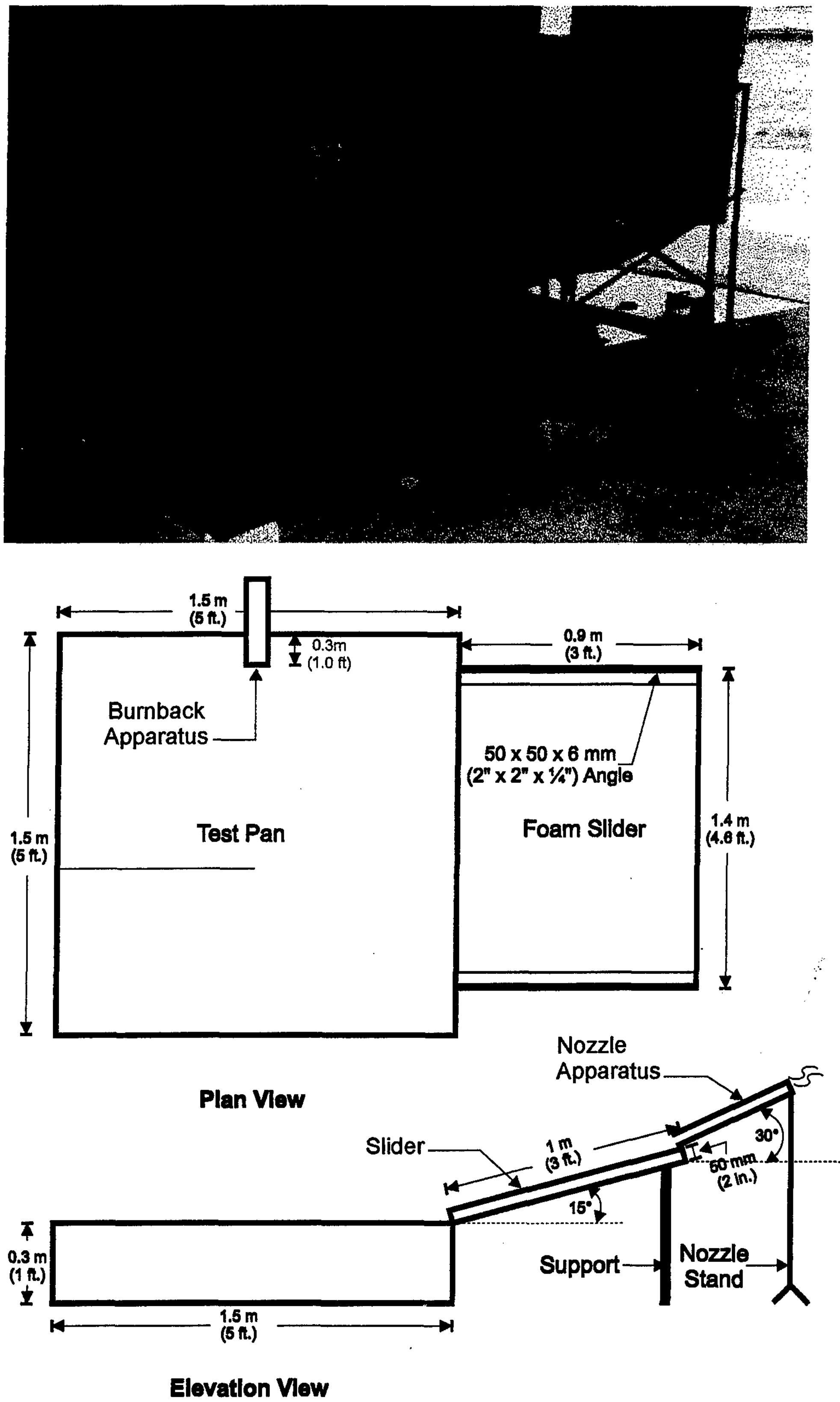


Fig. 3. Confined scenario fire pan

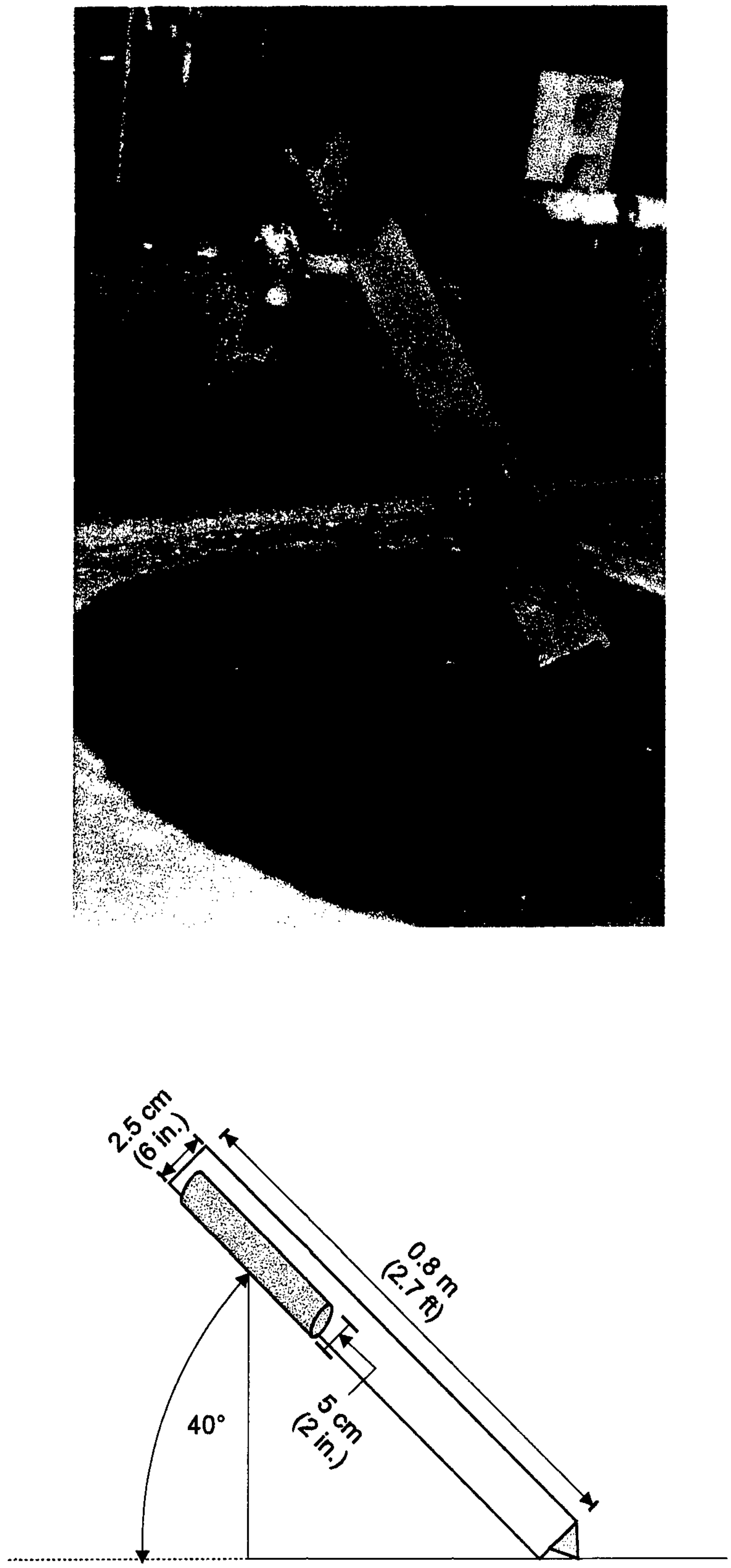


Fig. 4. Confined scenario burnback apparatus with cover removed

The AFFF extinguishing system consisted of a pressure tank, nozzle and slider as shown in Figures 5a and 5b. The pressure tank had a total capacity of 416 L (110 gal) and was initially pressurized using compressed air. Nitrogen was then used to maintain a constant pressure during discharge. AFFF was supplied to the discharge piping through a 2.5 cm (1 in.) rubber hose. The AFFF discharge piping consisted of 1.3 cm (0.5 in.) schedule 40 black iron pipe. A non-air-aspirated nozzle, fitted with removable orifice inserts, controlled the foam application rate. Nozzle pressure was monitored with the use of a pressure gauge mounted directly on the delivery system piping and was kept constant throughout the tests at 690 kPa (100 psi). The flow from the nozzle was controlled with a quarter turn valve mounted upstream of the pressure gauge.

The AFFF was discharged from a nozzle and deflected off a metal slider into the pan as shown in Figures 6a and 6b. The slider was a 1.4 m (4.6 ft) x 0.9 m (3 ft) metal ramp that extended down to the edge of the test pan at an angle of 15°. A cover was built for the slider that deflected water spray from the sprinklers away from the slider and out of the pan. This cover, or deflector, prevented the water spray from interfering with the foam delivery system and prevented excess sprinkler flow from running down the slider into the test pan.

MIL SPEC AFFF (3%) was used throughout this test series [5]. The AFFF was premixed before each test and maintained at a temperature of 21°C (70°F). Each batch was then tested for its expansion and drainage qualities before it was used in the test series. The expansion and drainage test samples were collected at the bottom of the slider apparatus where it entered the test pan. These samples were evaluated using a modified NFPA 412 method [11].

4.2.4 Overhead Sprinkler System

The overhead sprinkler system shown in Figure 7 was used during these tests. The system consisted of two Central Model A upright sprinklers. Both 1.27 cm (0.5 in.) and 1.35 cm (0.53 in.) orifice diameters were used in this test series. The smaller orifice nozzle was used to produce an application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2) at a nozzle pressure of 179 kPa (26 psi). The larger orifice nozzle was used to produce an application rate of 10.2 Lpm/m^2 (0.25 gpm/ft^2) at a nozzle pressure of 241 kPa (35 psi). The 1.27 cm (0.5 in.) orifice had a k factor of 5.6 gpm/psi$^{1/2}$ while the 1.35 cm (0.53 in.) orifice had a k factor of 8.1 gpm/psi$^{1/2}$. The fusible links were removed from the sprinkler heads at the beginning of the test series. In both cases, the sprinklers were installed with a 3.0 m (10 ft) spacing, 5 m (16.4 ft) above the floor of the compartment. A pressure tap was installed at one of the sprinklers to allow constant monitoring of the pressure at the sprinkler head. A pressure gauge at the bottom of the riser monitored the operating pressure of the system during the tests.

The sprinkler system was constructed of 2.5 cm (1 in.) schedule 40 black iron pipe with threaded fittings. The system was supplied using a fire truck connected to the CBD potable water supply as shown in Figures 8a and 8b.

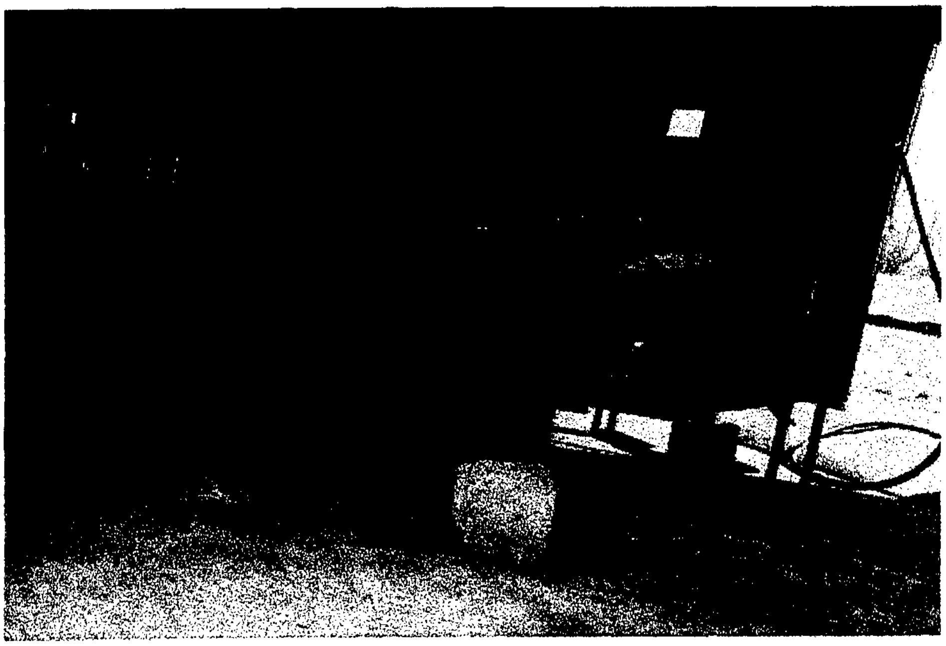


Fig. 5a. Foam nozzle and slider

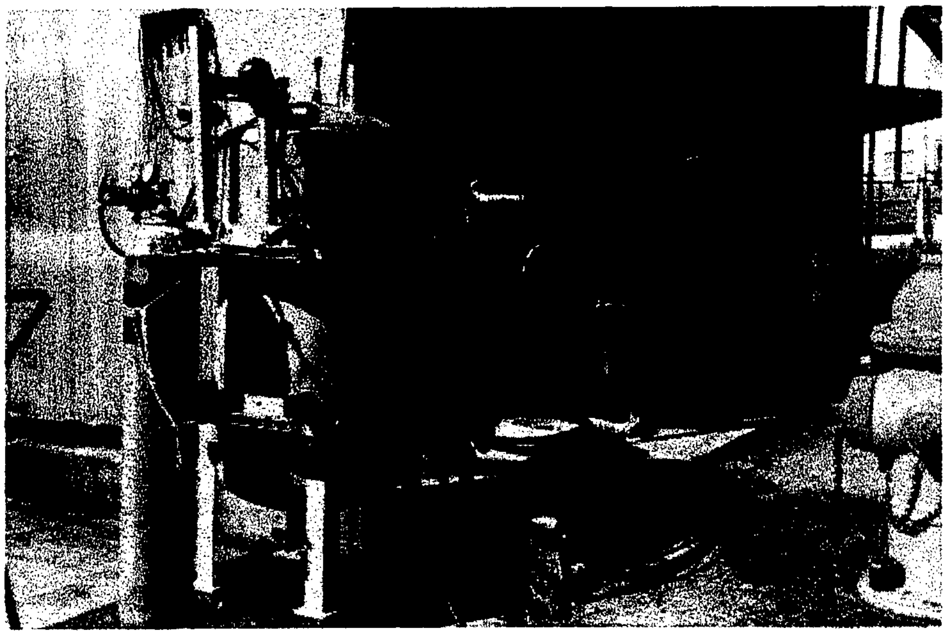


Fig. 5b. AFFF pressure tank

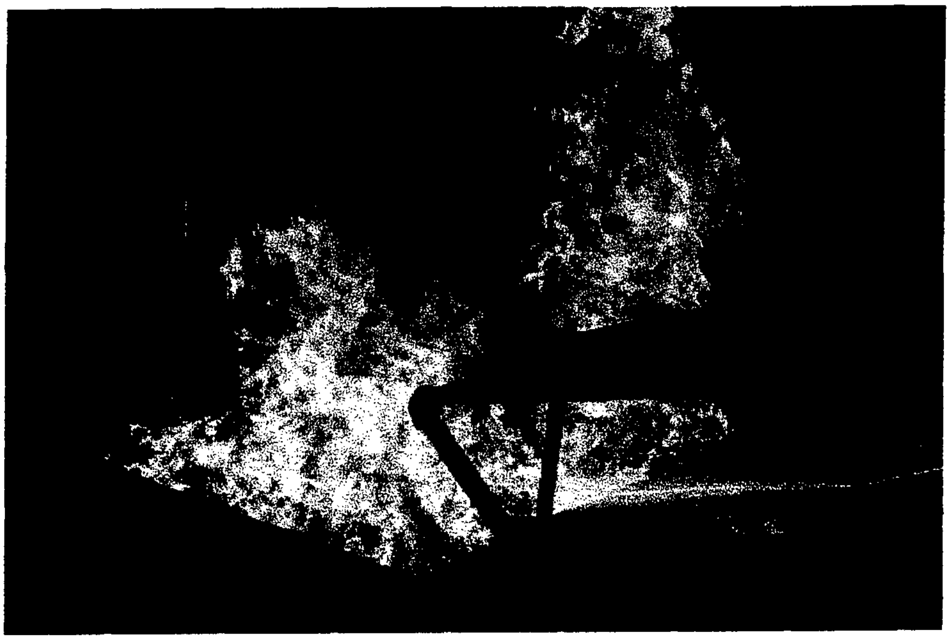


Fig. 6a. AFFF extinguishing system pan fire

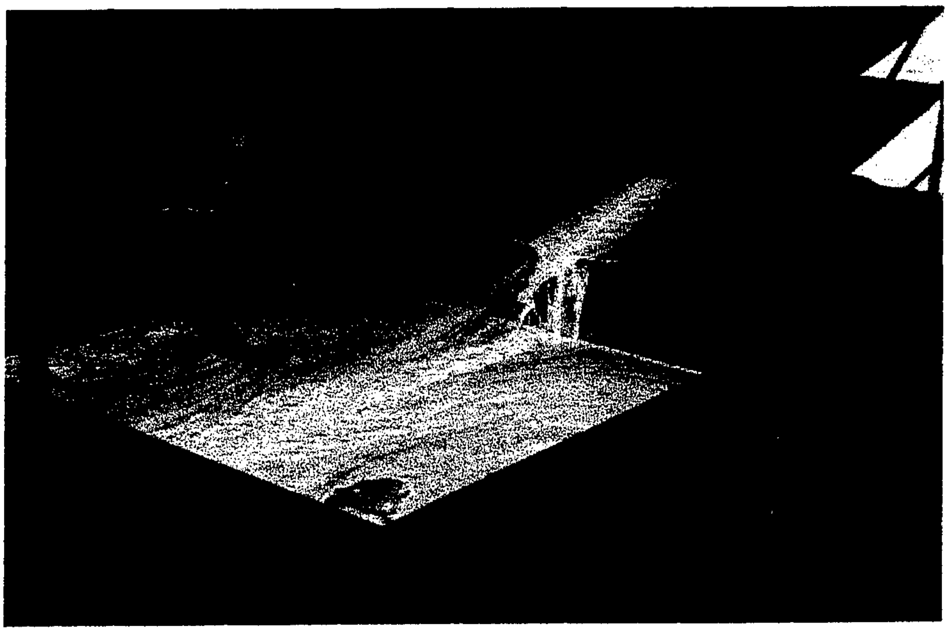
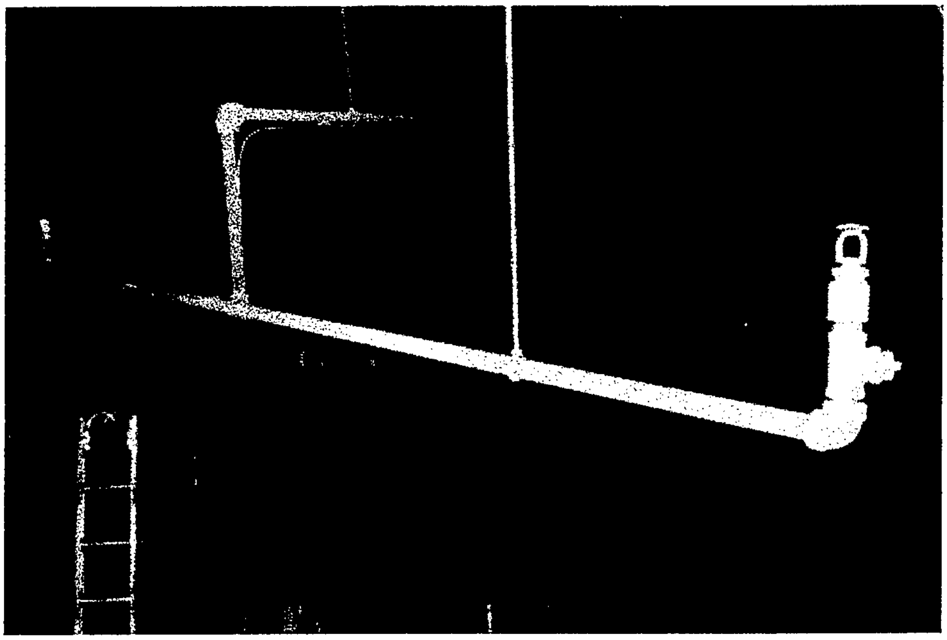


Fig. 6b. AFFF extinguishing system after fire was extinguished



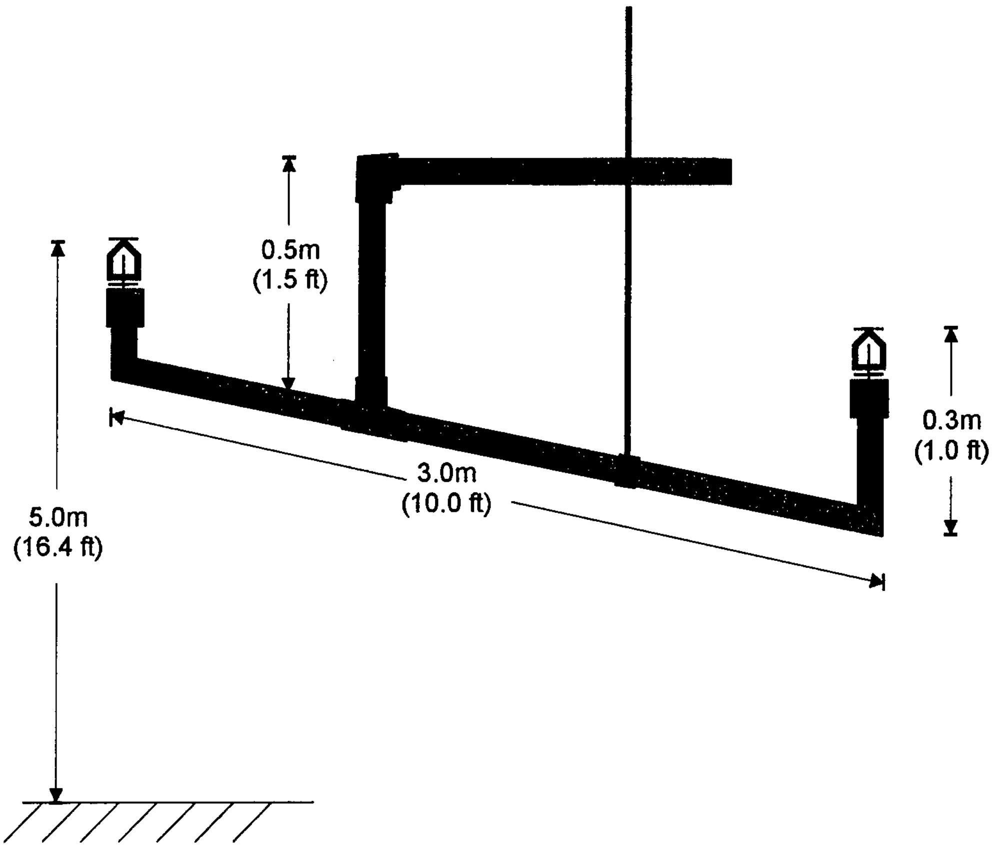


Fig. 7. Overhead sprinkler system

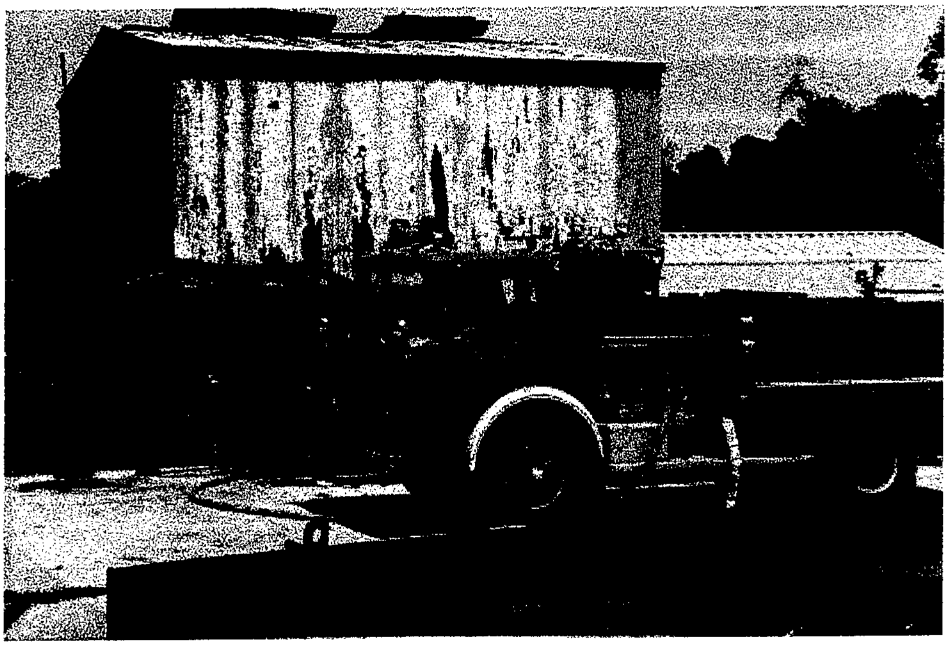


Fig. 8a. Fire truck used to supply sprinkler system

Fig. 8b. Riser detail for sprinkler system

The operating pressure of the sprinkler system was varied to produce the desired application rate to the test pan. The actual application rate for the sprinkler system was measured under a non-fire situation using twenty-five 0.1 m^2 (1 ft^2) collection pans. The actual application rate was measured by placing the pans at the location where the fire pan would be during the suppression tests. The sprinkler system was discharged for a set period of time at the desired pressure, after which, the amount of water collected in each pan was measured. This application rate data was used to determine the operating pressures of the system used during the fire tests. A more detailed explanation of the procedure is found in Appendix A.

4.2.5 Back-Up AFFF Extinguishment System

A 38 L (10 gal) portable AFFF extinguisher was used to extinguish the fire at the conclusion of each test.

4.2.6 Instrumentation

Due to the simplicity of the tests, instrumentation was limited. The majority of the test results were based on visual observations.

4.2.6.1 Video Recorder

Each test was video taped to serve as a visual record of the test. These videos were used to verify visual observations recorded during each test.

4.2.6.2 Ambient Conditions

Ambient weather (air temperature and relative humidity) was measured using a sling psychrometer. After the water substrate and the fuel was added to the test pan, the temperature of each layer was measured with a thermometer. These temperatures were then recorded.

4.2.7 Procedures

Prior to the start of the test, the AFFF solution was pre-mixed, pumped into the pressure vessel, and pressurized. The AFFF was then tested for expansion and drainage. The foam delivery device was then moved into place.

Once the AFFF apparatus was in place, the water level in the pan was brought to a depth of 2.5 cm (1 in.). The test fuel was then added and the temperatures of the fuel and water layers in the pan were measured and recorded. The video recorder was activated, and a test board indicating the date and test number was displayed to the camera. The test began with the addition of the accelerant and the ignition of the fuel. The fire was allowed to pre-burn for forty-five seconds before the suppression systems were activated. The gas burner was activated forty-two seconds into the pre-burn to ensure that it was fully operational forty-five seconds into the test. In a number of tests, the sprinkler system activation was delayed until the end of the AFFF discharge.

During the tests conducted with only AFFF, (i.e., without overhead sprinkler flow), the burner would continue to operate only until an area roughly 0.1 m^2 (1 ft^2) was burning. During the test conducted with both AFFF and overhead sprinklers (combined system) the burner was kept running throughout the entire test. Figures 9a and 9b show the burnback apparatus during operation. The test was terminated when 25 percent of the fuel surface re-ignited and sustained burning. The tests were conducted with either the two systems activated simultaneously (Simultaneous Act.) or with the water sprinkler activation at the end of the AFFF discharge (Delayed Act.). In both cases, the sprinklers continued to discharge until the end of the test.

4.2.8 Evaluation Criteria (Confined Tests)

System performance was based on three different time intervals recorded during the tests. These three times were 90 percent extinguishment, 99 percent extinguishment, and 25 percent burnback time. The 90 percent extinguishment time was the amount of time from the beginning of suppression activities until 90 percent the fire was knocked down, or controlled. The 99 percent extinguishment time was the time from the beginning of suppression activities until 99 percent of the fire was extinguished. In many cases, small flames would continue to burn around the edges of the pan prior to total extinguishment. This random burning resulted from slight gusts of wind and/or movement of the foam blanket. To eliminate this uncertainty, the measure of extinguishment was based on 99 percent extinguishment, rather than total extinguishment. The burnback time was the amount of time it took from the end of the foam discharge period until 25 percent of the fuel surface had sustained burning.

4.3 Unconfined Scenario

The second scenario was an unconfined scenario where the fuel spill was allowed to spread freely across a flat surface until it reached a drain. To provide for drainage, a false bottom (iron plate) was installed in the fire pan that was used in the confined fire scenario. A drain was then cut into the false bottom to allow fuel, water and AFFF to drain into the lower portion of the fire pan. This prevented the buildup of fuel, water and AFFF in the test area of the fire pan. These tests were conducted using only JP-5 as the test fuel.

The burnback apparatus (a steel pan with high sides) was installed in the corner of the large fire pan on top of the false bottom. Fuel was poured into the apparatus, ignited, and allowed to pre-burn for a period of time. Once the apparatus and the fuel were heated, additional fuel was pumped into the apparatus. This caused the apparatus to overflow, spilling burning fuel across the surface of the plate. The burning fuel spilling out of the apparatus presented the burnback exposure to the foam blanket. This spill apparatus was designed to simulate the hazard associated with a large fuel cell that continues to spill fuel for a long period of time.

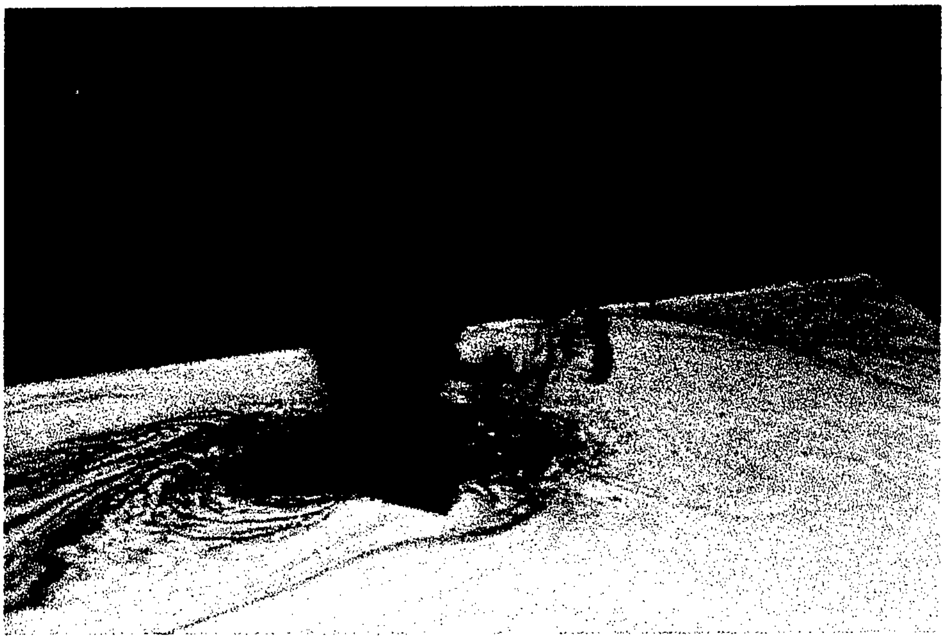


Fig. 9a. Confined series burnback apparatus during burnback – front view

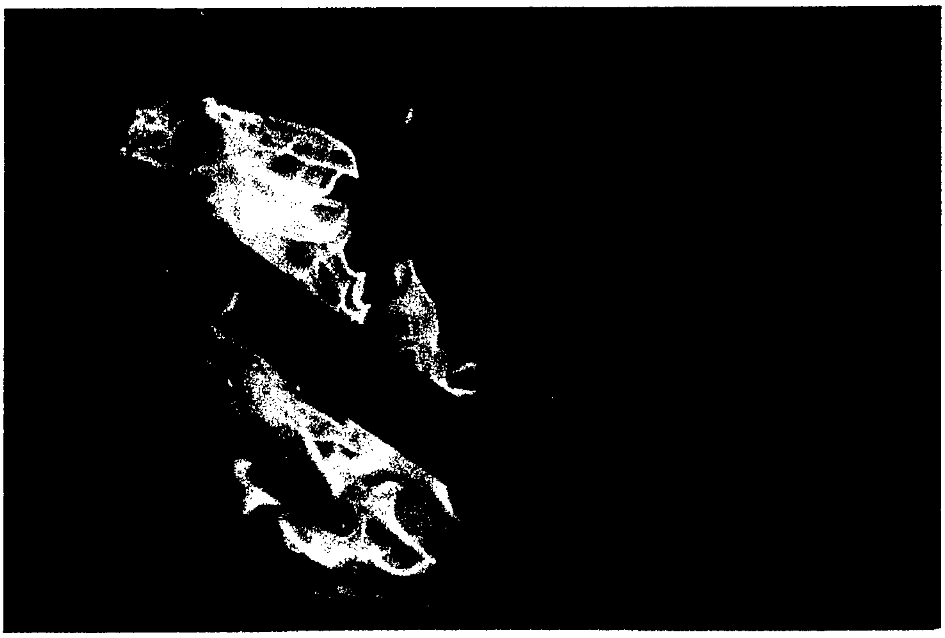


Fig. 9b. Confined series burnback apparatus during burnback – side view

AFFF or a combination of AFFF and overhead water sprinklers was used to control and extinguish the burning fuel spill. The AFFF and sprinkler systems were configured in the same manner as those used in the confined scenario.

4.3.1 Fire Pan

As shown in Figure 10, a 1.5 m (5 ft) x 1.5 m (5 ft) steel plate with 15 cm (6 in.) steel legs was installed in the fire pan used during the confined scenario tests. The plate formed a false bottom in the pan. Angle iron was installed around the perimeter of the plate to create a water tight seal. A 0.3 cm (0.1 in.) wide by 1.4 m (4.7 ft) long slit was cut in the steel sheet 17.8 cm (7 in.) from the side of the pan. The drain was placed so that the AFFF that was discharged into the pan would not go directly into the drain.

4.3.2 Burnback Apparatus

A 0.3 m (1 ft) x 0.3 m (1 ft) x 0.3 m (1 ft) pan was used to produce a running spill fire. As shown in Figure 11, a 5.7 cm (2.25 in.) deep and 20 cm (8 in.) wide cut was made in one side of the pan. Fuel was pumped into the pan through a 6 mm (0.25 in.) diameter pipe, located 15 cm (6 in.) from the bottom of the pan. A small ramp was placed against the cut-out section of the pan. A cover was used to protect the pan from the sprinkler spray. A 132 L (35 gal) pressure tank was used to supply fuel to the burnback apparatus. The pressure tank was charged with nitrogen and was set up outside the test building.

4.3.3 Low Level AFFF Extinguishing System

The AFFF system used in the confined fire scenario was used for the unconfined fire scenario (Section 4.2.3).

4.3.4 Overhead Sprinkler System

The sprinkler system used in the confined fire scenario was used for the unconfined fire scenario (Section 4.2.4).

4.3.5 Instrumentation

The instrumentation used in the confined fire scenario was used for the unconfined fire scenario (Section 4.2.4).

4.3.6 Procedures

Before each test, the fuel delivery tank was filled with JP-5 and charged with nitrogen. The fuel flow rate was set by adjusting the nitrogen pressure. The AFFF suppression system was

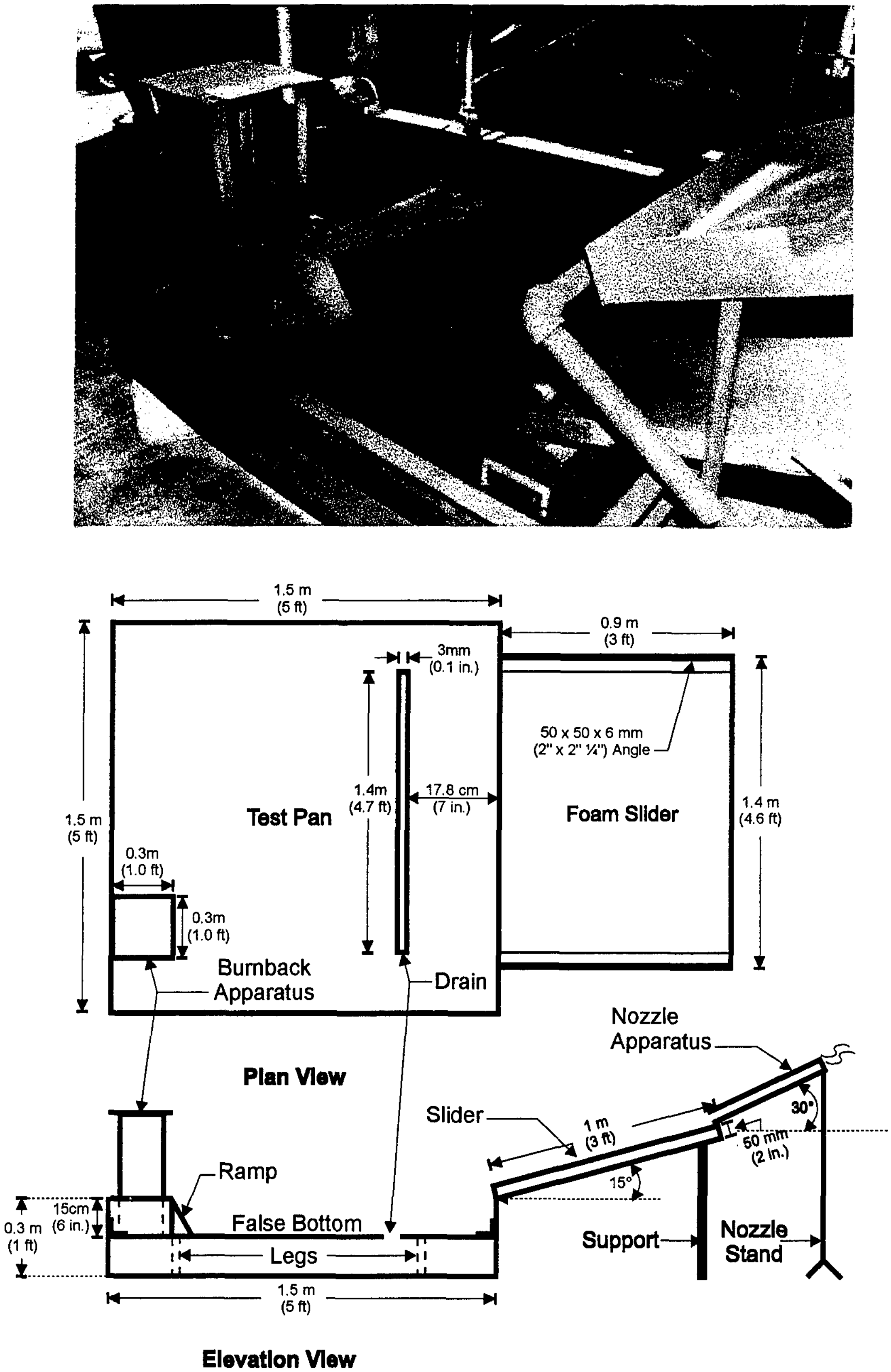


Fig. 10. Unconfined scenario test pan

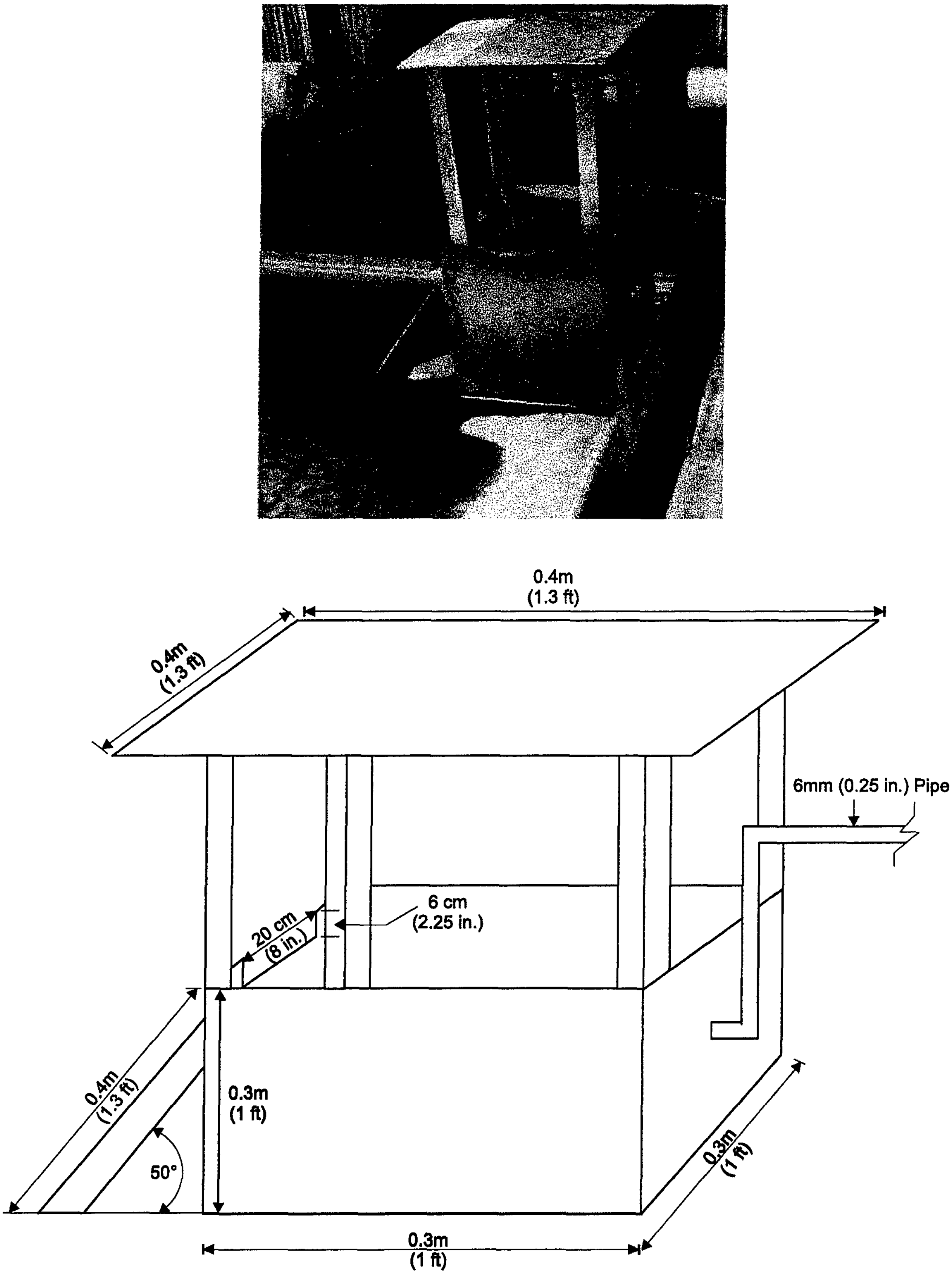


Fig. 11. Unconfined scenario burnback appartus

prepared as outlined in 4.3.3. The burnback apparatus was filled with 19 L (5 gal) of JP-5 and 0.5 L (0.1 gal) of heptane. The video recorder was started and a test board was shown to the camera. The stopwatch was started and the fuel was ignited and allowed to burn for three minutes. At the end of the three minute pre-burn period, fuel was pumped into the burnback apparatus at a rate of 3.1 Lpm (0.8 gpm). The suppression systems were activated 2.5 minutes later. By this time, the fuel had filled the box, spilled out into the fire pan, and reached a maximum spill size of approximately 0.9 m^2 (20 ft^2). This is shown in Figures 12a and 12b. The AFFF system discharged for one minute. The tests were terminated when the spill fire spread from the burnback apparatus as shown in Figures 13a and 13b, and created a burning pool fire with an area that was 25 percent of the size of the original fuel spill.

4.3.7 Evaluation Criteria (Unconfined Tests)

The only criterion used for judging the performance of the unconfined scenario tests was burnback time. Burnback time was defined as the time from the end of the foam discharge until the spill fire re-ignited 25 percent of the surface area of the spilled fuel.

5.0 TEST RESULTS

The results of the individual tests are shown in Table 1 for the confined tests and Table 2 for the unconfined tests. The burnback results are summarized in Table 3.

5.1 Confined Scenario

The results of the confined tests are shown in Table 1.

5.1.1 General Observations

Although non-air-aspirated AFFF was used in this test series, a thick layer of expanded AFFF still formed on top of the fuel surface. This was the result of the agitation created by the impact with the slider. This agitated foam had an average expansion ratio of 3.95:1. This layer of expanded foam was what is referred to as the foam blanket.

The foam blanket was almost completely destroyed by the overhead water sprinklers before the fuel re-ignited and spread over 25 percent of the fuel surface. The portion of the foam blanket exposed to the burnback apparatus flame usually broke down quickly. Therefore, the flame from the burnback apparatus appeared to make direct contact with the fuel surface early into the test. Evidently, an adequate amount of liquid foam solution remained on top of the fuel surface after the destruction of the foam blanket. This layer of liquid AFFF, combined with the cooling effect of the sprinklers, delayed the ignition and burnback until much later into the test.

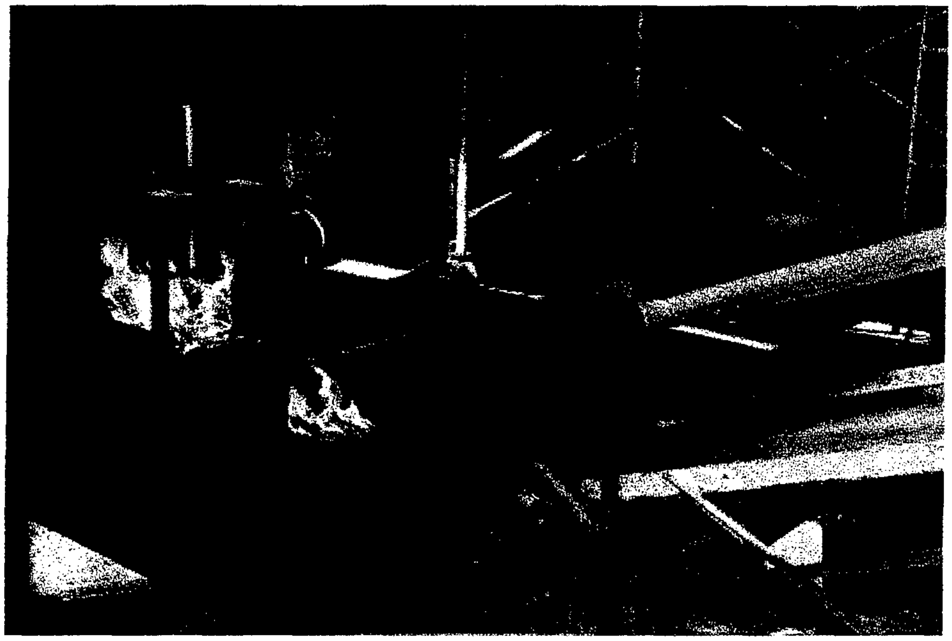


Fig. 12a. Unconfined scenario during fire growth

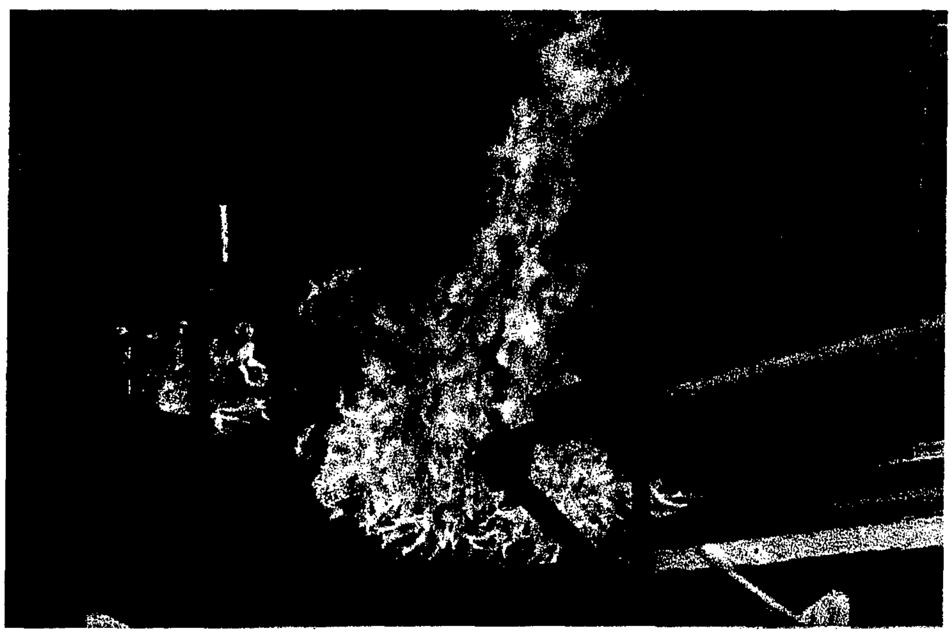


Fig. 12b. Unconfined scenario just prior to foam discharge

Fig. 13a. Unconfined scenario, burnback

Fig. 13b. Unconfined scenario during burnback showing fire spread

Table 1. Summary Data, Confined Tests

Test No.	Fuel Type	AFFF Application Rate Lpm/m^2 (gpm/ft^2)	Sprinkler Application Rate Lpm/m^2 (gpm/ft^2)	Sprinkler Activation Time	90% Ext. Time (sec)	99% Ext. Time (sec)	25% Burnback Time (sec)
1	JP-5	1.6 (0.04)	NA	No	71	104	366
2	JP-5	1.6 (0.04)	NA	No	85	108	390
3	JP-5	1.6 (0.04)	6.5 (0.16)	Simultaneous	30	39	273
4	JP-5	1.6 (0.04)	6.5 (0.16)	Delayed	73	99	241
5	JP-5	1.6 (0.04)	6.5 (0.16)	Simultaneous	31	36	221
6	JP-5	1.6 (0.04)	6.5 (0.16)	Delayed	68	93	226
7	JP-5	4.1 (0.10)	NA	No	28	32	560
8	JP-5	4.1 (0.10)	6.5 (0.16)	Simultaneous	22	23	457
9	JP-5	4.1 (0.10)	6.5 (0.16)	Delayed	29	33	295
10	JP-5	4.1 (0.10)	NA	No	25	28	669
11	JP-5	4.1 (0.10)	6.5 (0.16)	Simultaneous	21	25	405
12	JP-5	4.1 (0.10)	6.5 (0.16)	Delayed	27	31	387
13	JP-5	4.1 (0.10)	NA	No	25	30	618
14	JP-5	4.1 (0.10)	10.2 (0.25)	Simultaneous	18	24	1305
15	JP-5	4.1 (0.10)	10.2 (0.25)	Delayed	25	29	930
16	JP-5	4.1 (0.10)	10.2 (0.25)	Simultaneous	17	22	882
17	JP-5	4.1 (0.10)	10.2 (0.25)	Simultaneous	30	33	725
18	JP-8	4.1 (0.10)	NA	No	30	35	661
19	JP-8	4.1 (0.10)	10.2 (0.25)	Simultaneous	19	24	516
20	JP-8	4.1 (0.10)	10.2 (0.25)	Delayed	27	33	445
21	JP-8	4.1 (0.10)	NA	No	28	34	626
22	JP-8	4.1 (0.10)	10.2 (0.25)	Simultaneous	20	25	680
23	JP-8	4.1 (0.10)	10.2 (0.25)	Delayed	28	32	536
24	JP-8	4.1 (0.10)	NA	No	28	36	570
25	JP-8	4.1 (0.10)	10.2 (0.25)	Simultaneous	18	22	592
26	JP-8	4.1 (0.10)	10.2 (0.25)	Delayed	27	31	379
27	JP-5	4.1 (0.10)	10.2 (0.25)	Simultaneous	20	22	1000
28	JP-8	4.1 (0.10)	6.5 (0.16)	Simultaneous	20	NA	213
29	JP-8	4.1 (0.10)	6.5 (0.16)	Delayed	25	35	181
30	JP-8	4.1 (0.10)	6.5 (0.16)	Simultaneous	20	23	196
31	JP-8	4.1 (0.10)	6.5 (0.16)	Delayed	25	29	159
32	JP-5	8.2 (0.20)	NA	No	17	22	560
33	JP-5	8.2 (0.20)	6.5 (0.16)	Simultaneous	15	20	131
34	JP-5	8.2 (0.20)	6.5 (0.16)	Delayed	17	22	166
35	JP-5	8.2 (0.20)	NA	No	20	24	543
36	JP-5	8.2 (0.20)	6.5 (0.16)	Simultaneous	17	22	209
37	JP-5	8.2 (0.20)	6.5 (0.16)	Delayed	19	25	215

Table 2. Summary Data, Unconfined Tests

Test No.	Fuel Type	AFFF Application Rate Lpm/m² (gpm/ft²)	Sprinkler Application Rate Lpm/m² (gpm/ft²)	Sprinkler Activation Time	90% Ext. Time (sec)	99% Ext. Time (sec)	25% Burnback Time (sec)
38	JP-5	4.1 (0.10)	NA	No	NA	NA	367
39	JP-5	4.1 (0.10)	6.5 (0.16)	Simultaneous	NA	NA	51
40	JP-5	4.1 (0.10)	10.2 (0.25)	Simultaneous	NA	NA	51

Table 3. Effects of Variables on Burnback Time

Foam Application Rate (Lpm/m² (gpm/ft²))	Sprinkler Application Rate (Lpm/m² (gpm/ft²))	AFFF Only Burnback Time (sec)	Simultaneous Act. Burnback Time (sec)	Delayed Act. Burnback Time (sec)
Confined Scenario, Fuel Type JP-5				
1.6 (0.04)	---	378 [1,2]	---	---
1.6 (0.04)	6.5 (0.16)	---	247 [3, 5]	234 [4, 6]
4.1 (0.10)	---	617 [7, 10, 13]	---	---
4.1 (0.10)	6.5 (0.16)	---	431 [8, 11]	341 [9, 12]
4.1 (0.10)	10.2 (0.25)	---	1062 [14, 16, 27]	828 [15, 17]
8.2 (0.20)	---	552 [32, 35]	---	---
8.2 (0.20)	6.5 (0.16)	---	170* [33,36]	191* [34, 37]
Confined Scenario, Fuel Type JP-8				
4.1 (0.1)	---	619 [18, 21,24]	---	---
4.1 (0.1)	6.5 (0.16)	---	205 [28, 30]	170 [29, 31]
4.1 (0.1)	10.2 (0.25)	---	596 [19, 22, 25]	453 [20, 23, 26]
Unconfined Scenario, Fuel Type JP-5				
4.1 (0.1)	---	367 [38]	---	---
4.1 (0.1)	6.5 (0.16)	---	51 [39]	---
4.1 (0.1)	10.2 (0.25)	---	51 [40]	---

Notes: [ ] Test Numbers
The burnback times shown in table are the averages from the tests shown in the square brackets.
* Wind affected data.

5.1.2 AFFF Application Rate Evaluation

5.1.2.1 Low Level AFFF System

The affect of AFFF application rate on the control and extinguishment capabilities of the system is shown in Figure 14. When the AFFF density was held constant and the application rate was increased from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2), the extinguishment times for the tests conducted with JP-5 significantly decreased. Further increasing the application rate to 8.2 Lpm/m^2 (0.20 gpm/ft^2) had little effect on the extinguishment capabilities.

The burnback capabilities followed the same trends. An increase in AFFF application rate from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2) approximately doubled the burnback time for the tests conducted with JP-5. Further increasing the application rate to 8.2 Lpm/m^2 (0.20 gpm/ft^2) had little effect on the burnback capabilities of the system.

The control, extinguishment, and burnback capabilities of the low level AFFF system for the confined scenario were similar for the two test fuels, JP-5 and JP-8.

5.1.2.2 Combined System

The results of the tests conducted with a simultaneous activation of the overhead water sprinklers and low level AFFF systems are shown in Figure 15. Figure 15 shows that for a JP-5 fire with a fixed sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2), increasing the foam application rate from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2) decreased the extinguishment times. Further increasing the foam application rate to 8.2 Lpm/m^2 (0.20 gpm/ft^2) resulted in an additional decrease in the 90 percent extinguishment time but had little effect on the 99 percent extinguishment time.

For a fixed sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2), an increase in foam application rate from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2) also resulted in a significant increase in the burnback time of the system. Further increasing the foam application rate to 8.2 Lpm/m^2 (0.20 gpm/ft^2) resulted in a significant decrease in the burnback time of the system. This unprecedented decrease is considered as an anomaly in the data and is attributed to high winds on the day these tests were conducted.

5.1.3 Sprinkler Application Rate Evaluation

The effect of sprinkler application rate on the control and extinguishment capabilities of the system using a simultaneous activation is shown in Figures 16 and 17. For a fixed AFFF application rate of 4.1 Lpm/m^2 (0.10 gpm/ft^2), a sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2) decreased the extinguishment times to 80-90 percent of the times recorded for the low level AFFF system without sprinklers independent of the test fuel.

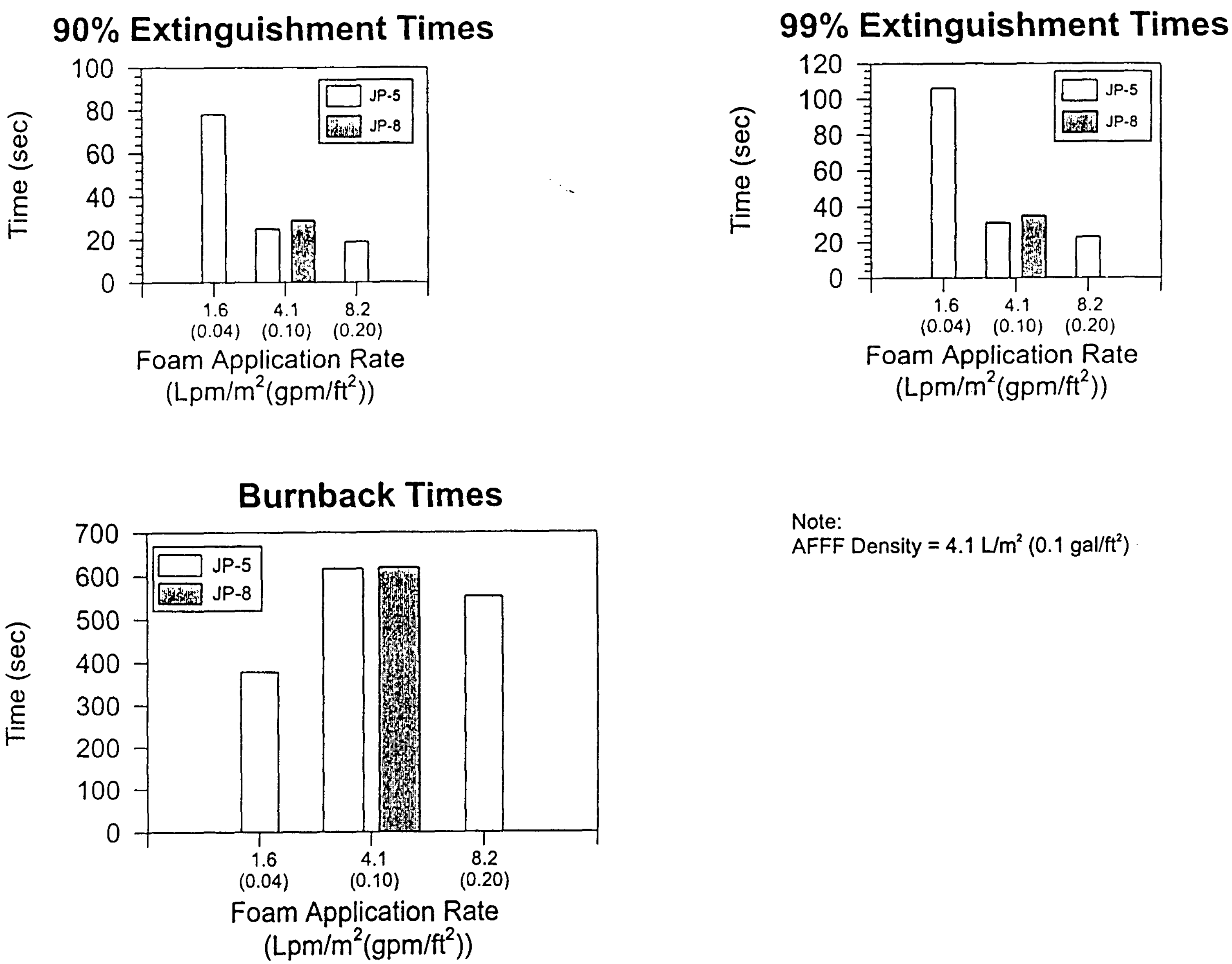


Fig. 14. Low level AFFF system results

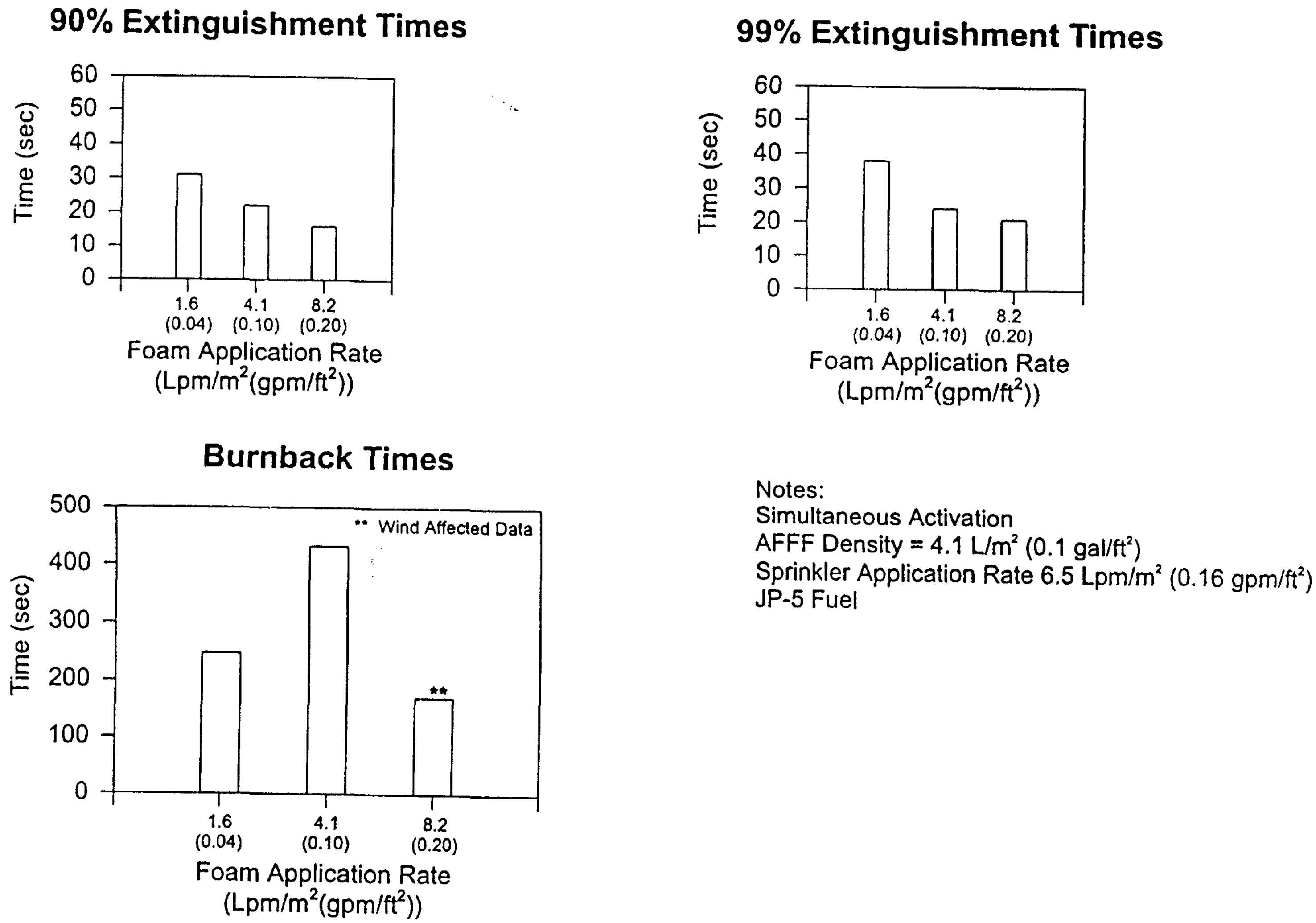
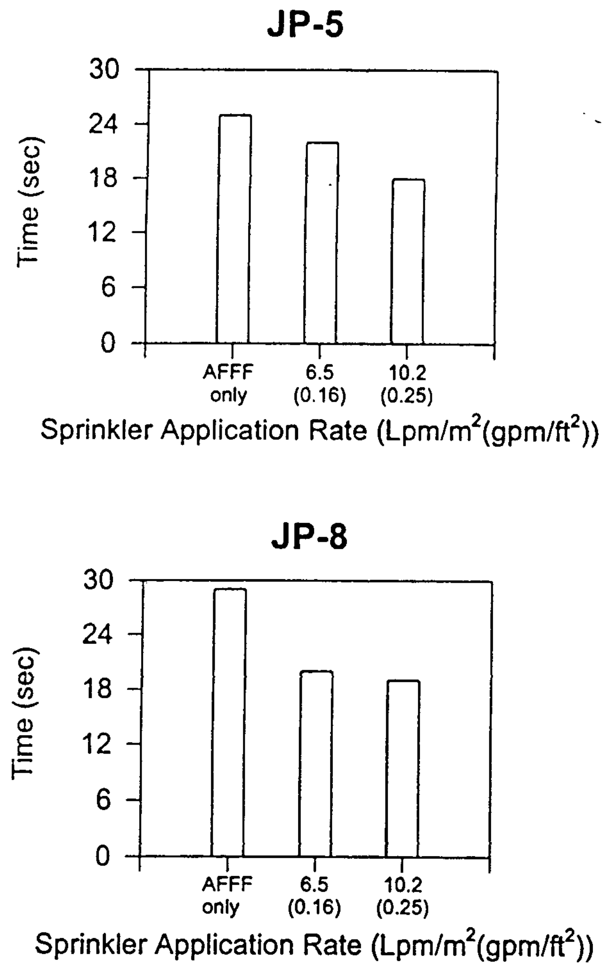
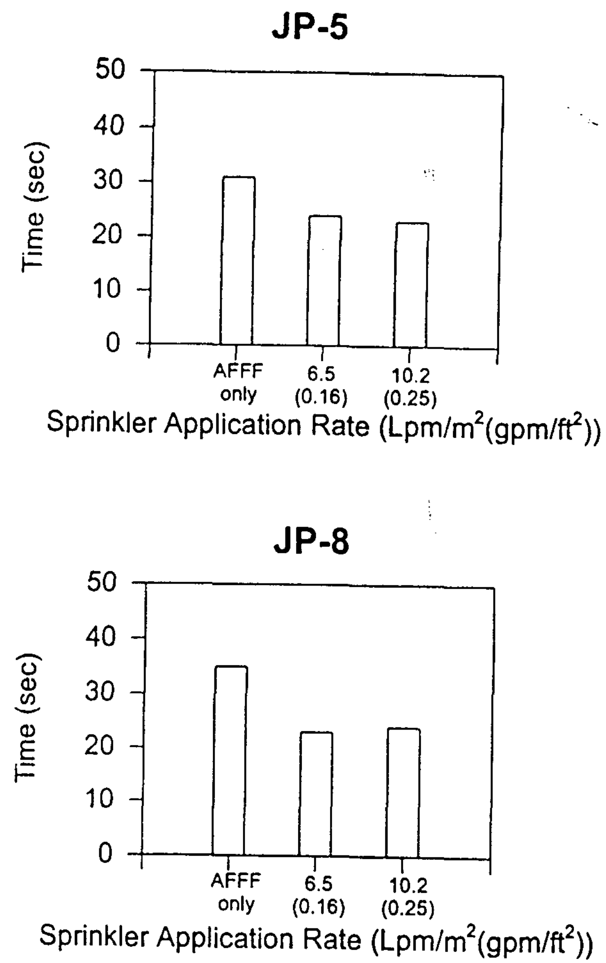


Fig. 15. Combined system results



Notes:
Combined System
Simultaneous Activation
AFFF Activation Rate 4.1 Lpm/m^2 (0.1 gpm/ft^2)
AFFF Density = 4.1 L/m^2 (0.1 gal/ft^2)
JP-5 Fuel

Fig. 16. The effect of sprinkler application rates on 90% extinguishment times



Notes:
Combined System
Simultaneous Activation
AFFF Application Rate 4.1 Lpm/m^2 (0.1 gpm/ft^2)
AFFF Density = 4.1 L/m^2 (0.1 gal/ft^2)

Fig. 17. The effect of sprinkler application rates on 99% extinguishment times

Figures 16 and 17 also show that further increasing the sprinkler application rate to 10.2 Lpm/m^2 (0.25 gpm/ft^2) further reduced the extinguishment times for the JP-5 fires but had little effect on the extinguishment capabilities of the system against the JP-8 fires.

Figure 18 shows the effect of sprinkler application rates on burnback times. These tests were conducted with a foam application rate of 4.1 Lpm/m^2 (0.10 gpm/ft^2). A sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2) decreased the burnback time of the system well below the times recorded for the low level AFFF system without sprinklers. The burnback time for the JP-5 fires was reduced by 30 percent and the burnback time for the JP-8 fires was reduced by almost 70 percent. When the sprinkler application rate was increased from 6.5 Lpm/m^2 (0.16 gpm/ft^2) to 10.2 Lpm/m^2 (0.25 gpm/ft^2), the burnback time for the JP-5 fires was longer than the times recorded for the low level AFFF system without sprinklers. The burnback time for JP-8 fires with the increased sprinkler application rate of 10.2 Lpm/m^2 (0.25 gpm/ft^2) was nearly the same as the low level AFFF system without sprinklers.

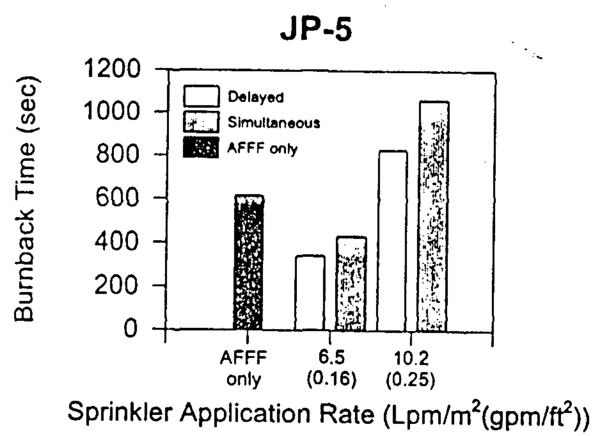
Figure 18 also shows the effect of delaying sprinkler application on burnback times. When the sprinkler activation was delayed until after the foam discharge period, the burnback times decreased to 80-90 percent of the simultaneous activation burnback times depending on the test parameters. This was true for both the JP-5 and JP-8 fires.

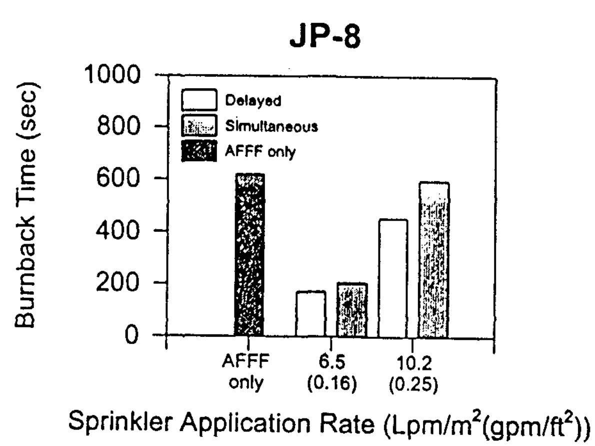
5.2 Unconfined Scenario

The results of the unconfined tests are shown in Table 2 and Figure 19. An AFFF application rate of 4.1 Lpm/m^2 (0.1 gpm/ft^2) for a period of one minute was used during the unconfined tests. When the sprinklers were activated over the foam blanket, the blanket became more fluid and quickly drained away. It was observed during the scoping tests that if the foam was allowed to flow for more than one minute, a thick foam blanket was formed on the plate, despite the presence of the drain. The thicker the foam blanket, the longer it took the sprinklers to break down and drain away the foam.

The unconfined tests showed a reversal in the trends observed during the confined test series. Sprinkler activation resulted in a dramatic reduction in burnback time, independent of the sprinkler application rate. The burnback times were reduced to approximately 20 percent of that observed for the low level AFFF system without sprinklers.

It is evident from these results that the hangar drainage system will result in the foam blanket breaking down and draining away significantly faster than would occur if drains were not present. It is also important to note that typical aircraft hangars have adequate AFFF concentrate to discharge for a period of five to ten minutes as opposed to the one minute discharge used in this test scenario. The longer discharge time will most likely result in a thicker foam blanket that will not drain as quickly as the foam blanket did in this test scenario. The longer discharge time also increases the duration of protection through the constant replenishment of AFFF to the protected area.





Notes:
Combined System
Simultaneous and Delayed Activation
AFFF Application Rate 4.1 Lpm/m^2 (0.1 gpm/ft^2)
AFFF Density = 4.1 L/m^2 (0.1 gal/ft^2)

Fig. 18. The effect of sprinkler application rates on burnback times

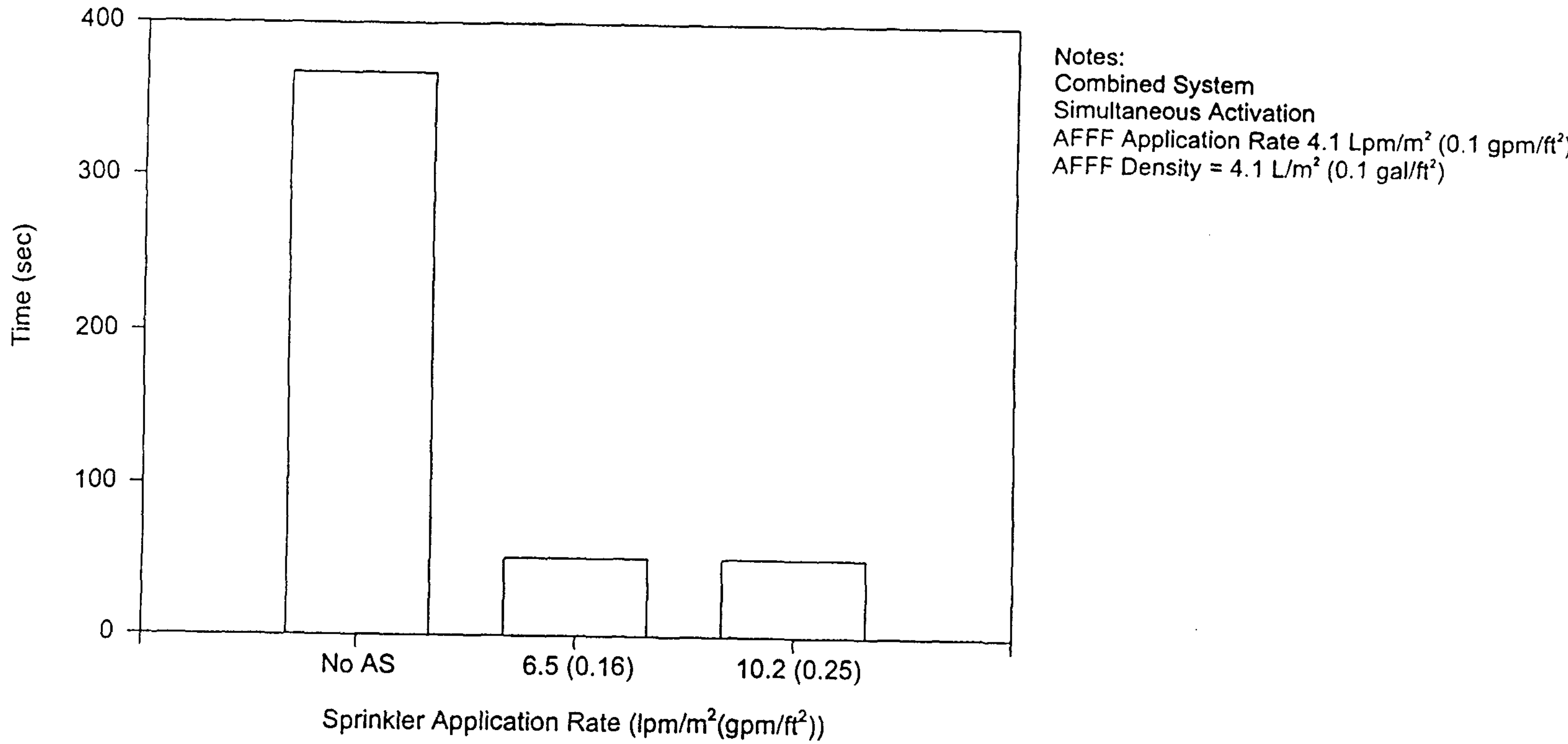


Fig. 19. Unconfined series burnback times

6.0 SUMMARY

The results of the tests conducted using only the low level AFFF extinguishing system follow the same trends found throughout the literature [12]. For the low level AFFF system without sprinklers, increasing the foam application rate from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2) decreased the extinguishment times of the system. The burnback resistance of the system was also improved. Increasing the foam application rate above 4.1 Lpm/m^2 (0.10 gpm/ft^2) had little effect on the capabilities of the system.

For a constant foam application rate of 4.1 Lpm/m^2 (0.10 gpm/ft^2) and a density of 4.1 L/m^2 (0.1 gal/ft^2), the use of sprinklers at an application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2) resulted in a decrease of the extinguishment times below that of the low level AFFF system without sprinklers. However, the burnback resistance of the system was significantly reduced. An increased sprinkler application rate of 10.2 Lpm/m^2 (0.25 gpm/ft^2) provided better burnback resistance for the JP-5 fires than the low level AFFF system without sprinklers. The higher sprinkler application rate also raised the burnback capabilities for the JP-8 fires to that comparable to the low level AFFF system without sprinklers.

When the foam application rate was increased from 1.6 Lpm/m^2 (0.04 gpm/ft^2) to 4.1 Lpm/m^2 (0.10 gpm/ft^2) for a fixed sprinkler application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2), the burnback and extinguishment capabilities of the system increased. Further increasing the foam application rate had little effect on the capabilities of the system.

During the unconfined tests, the presence of drains had a dramatic effect on the capabilities of the system. The use of sprinklers in the unconfined scenario dramatically reduced the burnback resistance of the system. The burnback times were reduced to approximately 20 percent of that observed for the low level AFFF system without sprinklers independent of the water sprinkler application rate.

The capabilities of the combined system varied for the two test fuels (JP-5 and JP-8). The extinguishment times for both fuels were observed to decrease with the use of sprinklers. However, the burnback times also decreased. The reduction in burnback time was much greater for JP-8 than it was for JP-5. Increasing the sprinkler application rate to 10.2 Lpm/m^2 (0.25 gpm/ft^2) was necessary to restore the burnback resistance to that of the low level AFFF system without sprinklers.

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APPENDIX A

Sprinkler Application Rate Data

Procedures for Sprinkler Application Density Tests

The sprinkler system for this test series was designed with two heads spaced 3.05 m (10 ft) apart. Two different sprinkler systems were used in this test series. Both systems used Central Model A upright sprinklers. The first system used two 1.27 cm (0.50 in.) orifice size sprinklers and the second system used two 1.35 cm (0.53 in.) orifice size sprinklers. To ensure that the sprinklers were applying the desired amount of water to the test area, the application density of the two systems was measured using collection pans.

Twenty five 0.09 m^2 (1 ft^2) collection pans were placed on the test floor to cover the area where the test pan was located during the fire tests. The sprinklers were then operated at the correct pressure for a period of two minutes. The sprinklers were then shut down.

The amount of water in each collection pan was then measured by pouring the water into a large graduated cylinder. The application density was calculated from these results. The results are included in the tables below.

Test #1 Average Amount of Water Collected per Minute in Each 0.09 m^2 (1.0 ft^2) Collection Pan (mL/min (gal/min))

Sprinkler Nozzle Pressure 179 kPa (26 psi), 1.27 cm (0.50 in.) Orifice Sprinkler

610 (0.16)	650 (0.17)	650 (0.17)	563 (0.15)	475 (0.13)
660 (0.17)	695 (0.18)	650 (0.17)	638 (0.17)	600 (0.16)
700 (0.18)	723 (0.19)	700 (0.18)	700 (0.18)	625 (0.17)
710 (0.19)	725 (0.19)	725 (0.19)	670 (0.18)	475 (0.13)
670 (0.18)	538 (0.14)	500 (0.13)	438 (0.12)	390 (0.10)

Average = 6.6 L/min·m^2 (0.16 gpm/ft^2)

Test #2 Average Amount of Water Collected per Minute in Each 0.09 m² (1.0 ft²) Collection Pan (mL/min (gal/min))

Sprinkler Nozzle Pressure 234 kPa (34 psi), 1.35 cm (0.53 in.) Orifice Sprinkler

1560 (0.41)	1290 (0.34)	938 (0.25)	750 (0.20)	620 (0.16)
1285 (0.34)	1225 (0.32)	775 (0.20)	900 (0.24)	775 (0.20)
990 (0.26)	1050 (0.28)	1005 (0.27)	975 (0.26)	863 (0.23)
745 (0.20)	890 (0.24)	950 (0.25)	900 (0.24)	713 (0.19)
570 (0.15)	725 (0.19)	750 (0.20)	713 (0.19)	655 (0.17)

Average = 9.7 L/min·m² (0.24 gpm/ft²)

Test #3 Average Amount of Water Collected per Minute in Each 0.09 m² (1.0 ft²) Collection Pan (mL/min (gal/min))

Sprinkler Nozzle Pressure 248 kPa (36 psi), 1.35 cm (0.53 in.) Orifice Sprinkler

1750 (0.46)	1138 (0.30)	710 (0.19)	668 (0.18)	600 (0.16)
1650 (0.44)	1368 (0.36)	818 (0.22)	863 (0.23)	800 (0.21)
1198 (0.32)	1300 (0.34)	1175 (0.31)	1075 (0.28)	975 (0.26)
775 (0.20)	950 (0.25)	1133 (0.30)	1175 (0.31)	900 (0.24)
525 (0.14)	675 (0.18)	893 (0.24)	888 (0.23)	838 (0.22)

Average = 10.0 L/min·m² (0.26 gpm/ft²)