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A COMPARISON OF THE FIRE SUPPRESSION PERFORMANCE OF COMPRESSED-AIR FOAM AND FOAM-WATER SPRINKLER SYSTEMS FOR CLASS B HAZARDS

by

A. K. Kim[1], G. P. Crampton[1] and J. P. Asselin[2]

INTRODUCTION

Fixed pipe compressed-air foam (CAF) systems have been developed over the past decade through a research collaboration between the National Research Council of Canada (NRCC) and the Department of National Defence. Prototype CAF systems have demonstrated, through full-scale testing [1-3], their superior fire suppression performance for controlling and extinguishing fires for a number of hazards, including flammable liquids. To date, however, no detailed comparison testing with other similar fire suppression systems for flammable liquids has been undertaken.

Fixed pipe CAF systems represent a major innovation in fire suppression technology. By injecting air into a foam-water stream in a mixing chamber, a significantly superior foam is produced primarily as a result of uniform, small bubble sizes. That foam is transported through a piping system to rotary nozzles which distribute foam over a prescribed area. There are currently no specific fire suppression performance or installation standards for CAF systems; thus, to assess the new technology for potential applications, comparisons must be made using existing standards for similar fire suppression systems.

[1] National Research Council of Canada

As a starting point for comparison, NFPA 16 – Standard for the Installation of Foam-Water Sprinkler and Foam-Water Spray Systems [4] has been selected since it describes a fixed pipe (overhead) fire suppression system using foam and water. Due to the differences in the technologies, it was realized from the outset that many aspects of NFPA 16 cannot be applied directly to CAF systems. It does, however, represent the best existing installation standard for these first comparisons. The fire suppression performance of foam-water sprinkler systems complying with NFPA 16 is evaluated in North America using UL-162 – Standard for Foam Equipment and Liquid Concentrates [5]. One of the fire suppression tests from UL-162 has been chosen in this research as a first basis for evaluating comparable fire suppression performance.

The research described in this report focuses on a parametric comparison of the fire suppression performance of fixed pipe CAF systems and foam-water sprinkler systems complying, to the extent that CAF systems can, with NFPA 16 and using fire testing as described in UL-162. The CAF systems used in this evaluation were Integrated Compressed Air Foam Systems manufactured by Fire Flex Systems Inc. under licence from the National Research Council of Canada (NRCC). The research on which this report is based was a joint research project between NRCC and Fire Flex Systems Inc.

EXPERIMENTAL SETUP

To evaluate the fire suppression performance of a foam system, UL-162 prescribes Class B fire tests using three different foam discharge methods: an overhead fixed piping system using sprinklers or spray nozzles, subsurface injection devices and topside discharge devices. For the current research project, only the overhead fixed piping system fire test was

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[2] Fire Flex Systems Inc.

used. While UL-162 prescribes a number of other tests for the nozzles, piping, etc., only the fire test described above was used in this research.

Nozzles and Sprinklers – Two types of CAF nozzle were used in the overhead fixed piping system fire tests. The first was a turbine action rotary (TAR) nozzle which has a 25 mm (1 in.) diameter body with an outlet opening piece attached to the body (see Figure 1). The outlet opening piece spins due to the momentum of the CAF flow through the nozzle. This spinning action distributes CAF uniformly over a 5.2 m (17 ft) diameter circle (approximately 21 m^2 (225 ft^2)). The second was a gear drive rotary (GDR) CAF nozzle which has a 101 mm (4 in.) diameter body with an outlet opening piece attached to it, as shown in Figure 1. The body contains a gear drive mechanism which rotates the outlet opening piece to distribute CAF uniformly over a 9.4 m (31 ft) diameter circle (approximately 70 m^2 (750 ft^2)).

The sprinklers used in the fire suppression tests were standard orifice, pendent sprinklers with a K-factor of 5.6. These sprinklers are used by one manufacturer for foam-water sprinkler systems.

Piping Layout – For the foam-water sprinklers and the TAR CAF nozzles, the piping system consisted of a 3.74 m x 3.74 m (12.25 ft x 12.25 ft) grid as shown schematically in Figure 2. Foam-water sprinklers and TAR nozzles were installed at each corner of the grid. This arrangement is identical to that required in UL-162. The grid, nozzles and sprinklers were located 4.42 m (14.5 ft) above the floor. The piping arrangement for the GDR nozzle is shown in Figure 3. For the GDR CAF nozzles, the grid was installed at the same height above the floor, however, due to the size of the nozzle, the nozzle discharge orifice was located 4.2 m (14 ft) above the floor. This GDR nozzle arrangement is a modification of the UL-162 setup since only one GDR nozzle was used to suppress the test fire rather than four sprinklers. The

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location and CAF coverage area for the GDR nozzle were determined as a result of preliminary testing.

Following a first series of tests with the piping grid located at 4.42 m (14.5 ft) above the floor, a second series was conducted with the piping grid located 7.62 m (25 ft) above the floor. This greater height is different from that specified in UL-162.

Fire Test Pan – The fire test pan was square, straight-sided, with an area of 4.65 m^2 (50 ft^2), and was made of 6.4 mm (1/4 in.) thick steel plate as required by UL-162. The height of the pan was 300 mm (12 in.) with a continuous horizontal lip of 38 mm (1.5 in.) wide projecting outwards on the top edge of all sides. The test fire was a heptane pool fire using commercial grade heptane fuel. The fire test pan was placed on the floor, centered below the piping grid for the foam-water sprinkler and TAR nozzle tests as shown in Figure 2. These details complied with UL-162. For the GDR nozzle tests, the test pan was placed on the floor, with its centre 2.22 m (7.3 ft) away from the point on the floor directly below the CAF nozzle.

The test pan contained a water layer of not less than 25.4 mm (1 in.) deep, with 100 or 205 L (26.4 or 54.1 US gal) of heptane poured over the water. With the rapid fire suppression by the CAF, it was found that there was excessive unburned fuel left over when 205 L (54.1 US gal) were used for a fire suppression test, thus creating an environmental problem. The fuel quantity was reduced to 100 L (26.4 US gal), however, the 203 mm (8 in.) distance from the top of the pan to the liquid surface, as required in UL-162, was maintained by adding additional water.

Foam Concentrates – Tests were conducted using "listed" Class B and Class A foam concentrates. The Class B foam concentrate was an Aqueous-Film-Forming-Foam (AFFF)

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used at 3% in the foam-water sprinkler tests and at approximately 2% in the CAF tests. The Class A foam concentrate, used only in the CAF tests, was at a concentration of approximately 1%.

TEST PROCEDURE

The heptane in the test pan was ignited and the resulting fire was allowed to burn freely for a period of approximately 15 s. At the end of the 15 s pre-burn, the CAF nozzle or foam-water sprinkler spray discharge was activated manually and allowed to continue operating for 5 min. During this period, as per UL-162, the time for complete extinguishment of the heptane pool fire was noted. Video records for all tests were made. In some tests, the pre-burn period was a few seconds longer as the manual operation of the CAF system was slightly delayed.

Following completion of the 5 min CAF or foam-water sprinkler discharge, the foam blanket formed on top of the fuel was left undisturbed for 15 min. During this 15 min period, a lighted torch was passed approximately 25.4 mm (1 in.) above the entire foam blanket, including the corners of the pan, in an attempt to re-ignite the fuel. This torch test was conducted twice during the 15-min period: immediately following the CAF or foam-water discharge, and 14 min following discharge completion – which was 1 min prior to the burn-back test. Each torch test lasted for a period of not less than 1 minute. This procedure is as required in UL-162.

The UL-162 test procedure for foam-water sprinklers requires that, following the 5 min foam-water discharge on heptane fuel, an additional 5 min of water (alone) discharge be allowed to occur. The water discharge is followed by a period of 10 min during which the foam is left undisturbed. Since a CAF system is not designed to flow water alone, it was decided to follow the 5 min foam discharge with a 15 min waiting period during which the foam was left

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undisturbed. This latter procedure of a 5 min foam discharge followed by a 15 min undisturbed period is an accepted alternative procedure in UL-162 when a polar solvent fuel is used. This same procedure (5 min discharge + 15 min undisturbed) was used for the foam-water sprinklers as well as the CAF nozzles to ensure a consistent basis of comparison.

At 15 min from the end of the CAF or foam-water discharge, a burn-back test was conducted as per UL-162. In this test, a 0.3 m (1 ft) diameter "stovepipe" was placed approximately 0.76 m (30 in.) from each of two adjacent sides of the test pan. The stovepipe was placed in the corner where the flame extinguished last, and was placed in such a manner that the foam blanket was not disturbed. The portion of the foam blanket that was enclosed by the stovepipe was removed. The fuel inside the stovepipe was ignited and allowed to burn for 1 min. The stovepipe was then slowly removed from the pan while the fuel continued to burn. After the stovepipe was removed, the time for the flame to spread across the remaining foam blanket over an area larger than 0.9 m^2 (10 ft^2) was measured. This procedure is as required in UL-162.

The pass/fail criteria used in these tests were those from UL-162 for overhead fixed piping systems with foam-water sprinklers which state that:

- The foam blanket must spread over and completely cover the test fuel surface.
- The fire must be completely extinguished during or at the end of the 5 min foam discharge.
- The test fuel blanketed with foam must not reignite, candle, flame, or flashover when a lighted torch is moved over all areas of the surface. (Minor flaming that self-extinguishes is permitted.)
- When the "stovepipe" is removed, the foam blanket must either:

1) Restrict, for 5 min, the spread of fire to an area not larger than 0.9 m^2 (10 ft^2), or

2) Flow over and reclose the burning area.

In some tests, the expansion ratio and drainage time of the CAF was measured. Also, several tests were conducted to determine the distribution pattern and density of the foam from the foam-water sprinklers, and the TAR and GDR CAF nozzles. The 16-pan distribution test protocol from UL-199 – Standard for Automatic Sprinklers for Fire Protection Services [6] was used to measure the distribution pattern of both the foam-water sprinklers and the CAF nozzles. This is different from the distribution pattern and density tests in UL-162. This UL-199 test method uses sixteen 30 cm x 30 cm x 30 cm (12 in. x 12 in. x 12 in.) pans installed side by side in a square in the centre of the discharge pattern of the sprinkler or nozzle. This pan arrangement was also used to confirm the application density of the CAF nozzles' discharge. This testing also differed from UL-199 in that the sprinklers and nozzles were 4.42 m (14.5 ft) above the pans rather than 2.3 m (7.5 ft).

RESULTS AND DISCUSSION

The results from the tests are grouped together to enable a comparison of the performance of the CAF system and the foam-water sprinkler system. The results with the piping grid at the 14.5 ft (4.42 m) and at the 25 ft (7.62 m) heights are presented separately. The following groups of results will be presented:

- Comparison of foam-water sprinklers and TAR CAF nozzles at 4.42 m (14.5 ft) and 7.62 m (25 ft).
- Comparison of foam-water sprinklers and GDR CAF nozzle at 4.42 m (14.5 ft) and 7.62 m (25 ft).

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- Comparison of the performance of a single sprinkler/nozzle.
- Assessment of the repeatability of results from CAF tests.
- Assessment of the impact of changing the height of nozzles/sprinklers above the fire.

Comparison of Foam-Water Sprinklers and Turbine Action Rotary CAF Nozzles

Tables 1 and 2 provide a summary of results of the tests conducted with foam-water sprinklers and TAR CAF nozzles at 4.42 m (14.5 ft) and 7.62 m (25 ft) heights. Figure 4 provides a photographic sequence of Test No. 2, one of the tests using TAR CAF nozzles.

Table 1 – Results of Foam-Water Sprinklers and TAR CAF Nozzles at 4.42 m (14.5 ft)

Test No.	1	2	3	4	5
Nozzle type	Foam-Water Sprinklers	TAR Nozzle	TAR Nozzle	TAR Nozzle	TAR Nozzle
No. of nozzles	4	4	4	4	4
Water flow rate GPM (L/min)	60 (227)	23.8 (90)	23.8 (90)	23.8 (90)	23.8 (90)
Air flow rate GPM (L/min)	N/A	239 (905)	239 (905)	239 (905)	239 (905)
Solution flow rate GPM (L/min)	61.8 (234)	24.3 (92)	24.3 (92)	24.0 (91)	24.0 (91)
Discharge density GPM/ft^2 $(L/min/m^2)$	0.1 (4.07)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class B	Class A	Class A
Foam conc. % (%)	3	2	2	1	1
Expansion ratio	3.5	10	10.9	10	8.62
Drainage time (min:s)	-	3 : 30	3 : 30	10 : 00	10 : 00
Extinguishment time (min:s)	2 : 32	0 : 50	0 : 49	0 : 59	1 : 16
Burn-back time (min:s)	9 : 00	23 : 35	17 : 15	10 : 10	6 : 15

At the 4.42 m (14.5 ft) height, Test Nos. 1, 2 and 3 provide a direct comparison of fire suppression performance using Class B foam between the foam-water sprinklers and the CAF system using TAR nozzles. As can be seen, the extinguishment time of the CAF system was less than half that of the foam-water sprinklers and the burn-back time of the CAF system was approximately double. In Tests 4 and 5, using Class A foam, the fire extinguishment time of the

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CAF system was again less than one-half that of foam-water sprinklers. The burn-back performance of the CAF system with Class A foam was, in Test No. 4, slightly better than the foam-water system but approximately two-thirds the foam-water system time in Test 5. The burn-back performance in both Tests 4 and 5 exceeded the minimum time of 5 min specified in UL-162.

It is suspected that the Extinguishment Time in Test 5 was 17 s greater than Test 4 since the pre-burn time was 2 s longer (13%) due to manual operation delays in CAF reaching the nozzles. This additional pre-burn time combined with a warmer ambient temperature (at least 3° C warmer) resulted in hotter pan walls that allowed small candle flames to burn longer at the sides of the pan. As well, the burn-back time was reduced due primarily to these two factors which elevate the temperature of the fuel below the foam blanket.

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Table 2 – Results of Foam-Water Sprinklers and TAR CAF Nozzles at 7.62 m (25 ft)

Test No.	6	7	8
Nozzle type	Foam-Water Sprinklers	TAR Nozzle	TAR Nozzle
No. of nozzles	4	4	4
Water flow rate GPM (L/min)	60 (227)	24 (90.8)	24 (90.8)
Air flow rate GPM (L/min)	N/A	248 (939)	248 (939)
Solution flow rate GPM (L/min)	61.8 (234)	24.5 (92.6)	24.3 (92)
Discharge density GPM/ft^2 (L/min/m^2)	0.1 (4.07)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class A
Foam conc. % (%)	3	2	1
Expansion ratio	3.5	10	10
Drainage time (min:s)	-	3 : 30	10 : 00
Extinguishment time (min:s)	2 : 16	0 : 50	1 : 09
Burn-back time (min:s)	9 : 21	23 : 40	6 : 37

At the 7.62 m (25 ft) height, the fire extinguishment and burn-back performance of the CAF system (using both Class B and A foams) was approximately the same as that for the 4.42 m (14.5 ft) height with extinguishment at approximately one-half the time of the foam-water systems. The CAF system with Class B foam burned back at approximately twice the time for the foam-water sprinklers and Class A foam burned back at approximately two-thirds the time. The CAF system exceeded the minimum fire extinguishment and burn-back benchmarks required by UL-162 using both the Class B and Class A foams. It should be noted that the ambient temperatures for the 7.62 m (25 ft) test series were all above 30°C. Higher temperatures have been observed to have a negative effect in this type of test, especially on burn-back.

Comparison of Foam-Water Sprinklers and Gear Drive Rotary CAF Nozzle

Tables 3 and 4 provide a summary of results of the tests conducted with foam-water sprinklers and the GDR CAF nozzle using both Class B and Class A foams. Figure 5 provides a photographic sequence of Test No. 10, one of the tests using a GDR CAF nozzle.

The closest comparison of the GDR nozzle with the foam-water sprinklers at the 4.42 m (14.5 ft) height is shown in Table 3 with Tests 9 and 10 compared to Test 1 (Class B foam). As with the TAR nozzles, the fire extinguishment time for the CAF system was approximately one-half the foam-water sprinklers and the burn-back time approximately double. With the GDR nozzle and Class A foam, the fire extinguishment performance of the CAF system was marginally better than the foam-water with Class B foam, however, the burn-back time was approximately 60% that of the foam-water system. Both extinguishment and burn-back times with Class A foam were within the UL-162 limits, however.

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Table 3 – Results of Foam-Water Sprinklers and Gear Drive Rotary CAF Nozzle at 4.42 m (14.5 ft)

Test No.	1	9	10	11	12	13
Nozzle type	Foam-Water Sprinkler s	GDR Nozzle	GDR Nozzle	GDR Nozzle	GDR Nozzle	GDR Nozzle
No. of nozzles	4	1	1	1	1	1
Water flow rate GPM (L/min)	60 (227)	25.9 (98)	26.4 (100)	30 (113.4)	29.9 (113)	29.9 (113)
Air flow rate GPM (L/min)	N/A	280 (1060)	280 (1060)	294.2 (1113.9)	294.2 (1113.9)	294 (1113)
Solution flow rate GPM (L/min)	61.8 (234)	26.4 (100)	26.9 (102)	30.2 (114.5)	30.1 (114)	30.1 (114)
Discharge density GPM/ft^2 (L/min/m^2)	0.1 (4.07)	0.035 (1.42)	0.035 (1.42)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class B	Class A	Class A	Class A
Foam conc. % (%)	3	2	2	1	1	1
Expansion ratio	3.5	10	11	10	9.1	8.6
Drainage time (min:s)	-	3 : 30	3 : 20	10 : 00	10 : 00	11 : 00
Extinguishment time (min:s)	2 : 32	1 : 23	1 : 10	1 : 53	1 : 44	2 : 05
Burn-back time (min:s)	9 : 00	19 : 35	18 : 35	5 : 37	5 : 57	5 : 35

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Table 4 – Results of Foam-Water Sprinklers and Gear Drive Rotary CAF Nozzle at 7.62 m (25 ft)

Test No.	6	14	15
Nozzle type	Foam-Water Sprinklers	GDR Nozzle	GDR Nozzle
No. of nozzles	4	1	1
Water flow rate GPM (L/min)	60 (227)	26.4 (100)	29.9 (113)
Air flow rate GPM (L/min)	N/A	280 (1060)	294 (1113)
Solution flow rate GPM (L/min)	61.8 (234)	26.9 (102)	30.1 (114)
Discharge density GPM/ft^2 (L/min/m^2)	0.1 (4.07)	0.035 (1.42)	0.04 (1.63)
Foam type	Class B	Class B	Class A
Foam conc. % (%)	3	2.3	1
Expansion ratio	3.5	10	10
Drainage time (min:s)	-	3 : 30	10 : 00
Extinguishment time (min:s)	2 : 16	1 : 02	1 : 23
Burn-back time (min:s)	9 : 21	12 : 30	4 : 35

At the 7.62 m (25 ft) height with the GDR nozzle using Class B foam, the fire extinguishment time was approximately 50% of the foam-water sprinklers and the burn-back time was approximately 1.3 times. For this arrangement with Class A foam, the fire suppression time was approximately 60% that of the foam-water sprinklers, however, the burn-back time was only 50% of the foam-water sprinklers and below the 5 min benchmark of UL-162.

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The reason for the marginal burn-back performance of the Class A foam with the GDR nozzle at the 7.62 m (25 ft) height appears to be partly due to the 203 mm distance to the pan lip above the liquid level in the test pan. With the 4 TAR nozzles, the entire pan surface was covered with foam quickly and all edges and corners were coated. With the 1 GDR nozzle spraying foam from only one direction, a slight shadow effect occurred adjacent to the pan wall on the GDR nozzle side. This shadow effect meant that extinguishment was delayed (due to more foam being carried up in the longer unsuppressed fire plume) thus not as much foam reached the liquid surface. The lesser thickness of the foam blanket appeared to be the reason for the burn-back problems with Class A foam. The superior film-forming capabilities of the Class B foam tended to compensate for this shadow effect with the GDR nozzle. As well, the higher ambient temperature for the 7.62 m (25 ft) tests also had a negative impact on performance as explained previously.

Comparison of Performance of a Single Sprinkler/Nozzle

While UL-162 requires a 4 foam-water sprinkler array with overlapping spray patterns in assessing the impact of fire suppression and burn-back performance, this research was extended beyond the UL-162 requirement to assess the impact of a single sprinkler/nozzle on fire suppression and burn-back performance. To assess this impact, some of the tests at the 4.42 m (14.5 ft) height were conducted with only one sprinkler/nozzle operating. A sketch of the set-up for the single sprinkler and nozzle tests is shown in Figure 6. The sprinkler/nozzle location was determined to ensure coverage of the entire test pan. The results of these tests with a single nozzle/sprinkler operating are shown in Table 5.

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Table 5 – Results of Foam-Water Sprinkler and TAR CAF Nozzle at 4.42 m (14.5 ft) to Assess Single Sprinkler/Nozzle Performance

Test No.	16	17	18
Nozzle type	Foam-Water Sprinklers	Foam-Water Sprinklers	TAR Nozzle
No. of nozzles	1	1	1
Water flow rate GPM (L/min)	15.1 (57)	24.0 (90.8)	5.9 (22.5)
Air flow rate GPM (L/min)	N/A	N/A	60 (227)
Solution flow rate GPM (L/min)	15. (59)	24.7 (983.5)	6.1 (23)
Discharge density GPM/ft^2 (L/min/m^2)	-	-	-
Foam type	Class B	Class B	Class B
Foam conc. % (%)	3	3	2.7
Expansion ratio	3.5	3.5	10
Drainage time (min:s)	-	-	3 : 30
Extinguishment time (min:s)	Not Ext.	2 : 32	2 : 49
Burn-back time (min:s)	N/A	5 : 57	11 : 35

In Test No. 16, the fire suppression performance of a single foam-water sprinkler in a 4-sprinkler array, with the minimum water flow rate (0.10 GPM/ft^2) specified in UL-162 was not sufficient to extinguish the test fire. The solution flow rate was increased to 0.16 GPM/ft^2 in Test No. 17. This resulted in fire suppression and burn-back performance meeting the UL-162 benchmarks and provided a basis for comparison with the single TAR CAF nozzle. The water flow rate for the TAR CAF nozzle was, however, the same as the single nozzle rate in the four-nozzle test and the solution flow rate only one-quarter that of the foam-water sprinkler. The discharge density was not measured in the single nozzle/sprinkler tests.

Comparing Test Nos. 17 and 18 using Class B foam for a single nozzle as shown in Figure 6, shows that the CAF system fire extinguishment time was 17 s greater than the foam-water sprinkler system but the burn-back time was approximately double. Both the CAF and foam-water sprinkler systems met the UL-162 benchmarks for extinguishment and burn-back performance.

Repeatability of CAF Test Results

An important issue that must be addressed in examining the results of fire suppression system tests is the repeatability of the fire suppression performance with as few changes as possible (preferably none) in the test parameters. In this research, four sets of nearly duplicate tests on CAF systems were run thus allowing a determination of the repeatability of results. These results are shown in Tables 6 and 7 for TAR and GDR nozzles, respectively.

In Repeatability Set 1 using TAR nozzles and Class B foam, it can be seen that the fire suppression time was within 1 s and the burn-back time within 6 min. With TAR nozzles and Class A foam (Repeatability Set 2), the fire extinguishment time was within 17 s and the burn-back time within 4 min. In all cases, the extinguishment and burn-back times were within the UL-162 limits.

Using GDR nozzles and Class B foam, it can be seen in Repeatability Set 3 that the fire extinguishment time was within 13 s and the burn-back time within 1 min. With GDR nozzles

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and Class A foam, the fire extinguishment time was within 12 s and the burn-back time within 2 s. In all cases, extinguishment and burn-back times were within the UL-162 limits.

Table 6 – Results of Tests to Determine Repeatability of Performance of CAF Systems Using TAR CAF Nozzles

	Repeatability Set 1		Repeatability Set 2	
Test No.	2	3	4	5
Nozzle type	TAR Nozzle	TAR Nozzle	TAR Nozzle	TAR Nozzle
No. of nozzles	4	4	4	4
Water flow rate GPM (L/min)	23.8 (90)	23.8 (90)	23.8 (90)	23.8 (90)
Air flow rate GPM (L/min)	239 (905)	239 (905)	239 (905)	239 (905)
Solution flow rate GPM (L/min)	24.3 (92)	24.3 (92)	24.0 (91)	24.0 (91)
Discharge density GPM/ft^2 (L/min/m^2)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class A	Class A
Foam conc. % (%)	2	2	1	1
Expansion ratio	10	10.9	10	8.62
Drainage time (min:s)	3 : 30	3 : 30	10 : 00	10 : 00
Extinguishment time (min:s)	0 : 50	0 : 49	0 : 59	1 : 16
Burn-back time (min:s)	23 : 35	17 : 15	10 : 10	6 : 15

Table 7 – Results of Tests to Determine Repeatability of Performance of CAF Systems Using GDR CAF Nozzles

	Repeatability Set 3		Repeatability Set 4	
Test No.	9	10	11	13
Nozzle type	GDR Nozzle	GDR Nozzle	GDR Nozzle	GDR Nozzle
No. of nozzles	1	1	1	1
Water flow rate GPM (L/min)	25.9 (98)	26.4 (100)	30 (113.4)	29.9 (113)
Air flow rate GPM (L/min)	280 (1060)	280 (1060)	294.2 (1113.9)	294 (1113)
Solution flow rate GPM (L/min)	26.4 (100)	26.9 (102)	30.2 (114.5)	30.1 (114)
Discharge density GPM/ft^2 (L/min/m^2)	0.035 (1.42)	0.035 (1.42)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class A	Class A
Foam conc. % (%)	2	2	1	1
Expansion ratio	10	11	10	8.6
Drainage time (min:s)	3 : 30	3 : 20	10 : 00	11 : 00
Extinguishment time (min:s)	1 : 23	1 : 10	1 : 53	2 : 05
Burn-back time (min:s)	19 : 35	18 : 35	5 : 37	5 : 35

Impact on Performance of Changing Height of Sprinklers/Nozzles

It can be argued that the performance of foam-water sprinkler and CAF systems with nozzles located at a greater height may be diminished, as a result of the water and foam droplets having greater difficulty in reaching the fuel surface due to the greater distance between the sprinkler/nozzle and the fire source and thus the greater effect of the buoyancy of the large fire plume. The UL-162 test procedure requires that fixed pipe foam suppression systems be located approximately 4.42 m (14.5 ft) above the test chamber floor. There are obviously many practical applications for foam systems that require a greater height of nozzles, such as aircraft hangars. To assess the impact of increasing the height of the foam-water sprinklers and CAF nozzles, the test series evaluated the fire suppression performance with piping grids located both 4.42 m (14.5 ft) and 7.62 m (25 ft) above the floor of the test chamber.

Tables 8 and 9 show the comparative fire extinguishment and burn-back performance at different heights for foam-water sprinklers and for TAR CAF nozzles and GDR CAF nozzles, respectively and using both Class B and Class A foams.

In examining Height Set 1 with foam-water sprinklers using Class B foam, it can be seen that the fire extinguishment time was 16 s less at the 7.62 m (25 ft) height and the burn-back time 21 s greater. These represent improvements in performance. With the TAR nozzle and Class B foam in Height Set 2, it can be seen that the fire suppression times were identical and the burn-back time was 5 s greater – again identical or better performance at the greater height. With the TAR nozzles and Class A foam (Height Set 3), the fire suppression time was 10 s longer and the burn-back time approximately 3.5 min less. While this represents a poorer performance at the greater height, the results at the greater height were still within the UL-162 benchmark times. As well, the 7.62 m (25 ft) tests were conducted at a higher ambient temperature with negative impacts as discussed earlier.

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Table 8 – Results of Tests to Determine Impact of Height Using TAR Nozzles

	Height Set 1		Height Set 2		Height Set 3	
	14.5 ft (4.42 m)	25 ft (7.62 m)	14.5 ft (4.42 m)	25 ft (7.62 m)	14.5 ft (4.42 m)	25 ft (7.62 m)
Test No.	1	6	2	7	4	8
Nozzle type	Foam-Water Sprinklers	Foam-Water Sprinklers	TAR Nozzle	TAR Nozzle	TAR Nozzle	TAR Nozzle
No. of nozzles	4	4	4	4	4	4
Water flow rate GPM (L/min)	60 (227)	60 (227)	23.8 (90)	24 (90.8)	23.8 (90)	24 (90.8)
Air flow rate GPM (L/min)	N/A	N/A	239 (905)	248 (939)	239 (905)	248 (939)
Solution flow rate GPM (L/min)	61.9 (234)	61.8 (234)	24.3 (92)	24.5 (92.6)	24.0 (91)	24.3 (92)
Discharge density GPM/ft^2 (L/min/m^2)	0.1 (4.07)	0.1 (4.07)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class B	Class B	Class A	Class A
Foam conc. % (%)	3	3	2	2	1	1
Expansion ratio	3.5	3.5	10	10	10	10
Drainage time (min:s)	-	-	3 : 30	3 : 30	10 : 00	10 : 00
Extinguishment time (min:s)	2 : 32	2 : 16	0 : 50	0 : 50	0 : 59	1 : 09
Burn-back time (min:s)	9 : 00	9 : 21	23 : 35	23 : 40	10 : 10	6 : 37

In examining Height Set 4 (in Table 9) with GDR nozzles and Class B foam, the fire extinguishment time was reduced by 21 s and the burn-back time reduced by approximately 7 min. This represents an improvement in fire extinguishment performance but a decrease in burn-back performance – still within the UL-162 limits. For GDR Nozzles and Class A foam (Height Set 5) at the greater height, the fire extinguishment time was 30 s less, however, the burn-back time was approximately 1 min less. The burn-back time in Test No. 15 fell below the

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UL-162 benchmark time for the reasons (explained previously) of impact of lip height and ambient temperature.

Table 9 – Results of Tests to Determine Impact of Height Using GDR Nozzles

	Height Set 1		Height Set 4		Height Set 5	
	14.5 ft (4.42 m)	25 ft (7.62 m)	14.5 ft (4.42 m)	25 ft (7.62 m)	14.5 ft (4.42 m)	25 ft (7.62 m)
Test No.	1	6	9	14	11	15
Nozzle type	Foam-Water Sprinklers	Foam-Water Sprinklers	GDR Nozzle	GDR Nozzle	GDR Nozzle	GDR Nozzle
No. of nozzles	4	4	1	1	1	1
Water flow rate GPM (L/min)	60 (227)	60 (227)	25.9 (98)	26.4 (100)	30.0 (113.4)	29.9 (113)
Air flow rate GPM (L/min)	N/A	N/A	280 (1060)	280 (1060)	294.2 (1113.9)	30.1 (1113)
Solution flow rate GPM (L/min)	61.8 (234)	61.8 (234)	26.4 (100)	26.9 (102)	30.2 (114.5)	30.1 (114)
Discharge density GPM/ft^2 (L/min/m^2)	0.1 (4.07)	0.1 (4.07)	0.035 (1.42)	0.035 (1.42)	0.04 (1.63)	0.04 (1.63)
Foam type	Class B	Class B	Class B	Class B	Class A	Class A
Foam conc. % (%)	3	3	2	2.3	1	1
Expansion ratio	3.5	3.5	10	10	10	10
Drainage time (min:s)	-	-	3 : 30	3 : 30	10 : 00	10 : 00
Extinguishment time (min:s)	2 : 32	2 : 16	1 : 23	1 : 02	1 : 53	1 : 23
Burn-back time (min:s)	9 : 00	9 : 21	19 : 35	12 : 30	5 : 37	4 : 35

CONCLUSIONS

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This research has compared the fire suppression and burn-back performance of foam-water sprinkler systems and compressed-air foam nozzle systems using Class A and Class B foams and the UL-162 fire test protocol. From the tests, it can be concluded that:

- Using TAR nozzles and either Class B or Class A foam, the fire extinguishment times for the CAF system were superior to foam-water sprinklers in all tests and, in most cases, the burn-back times were superior. This was consistent at both the 4.42 m (14.5 ft) and 7.62 m (25 ft) height above the test room floor.
- Using GDR nozzles and Class B foam, the fire extinguishment and burn-back times were superior to foam-water sprinklers. With Class A foam, the fire extinguishment time was superior, however, the burn-back time was less, in one case falling below the UL-162 benchmark.
- In evaluating the performance of a single nozzle and Class B foam, the CAF fire extinguishment time was marginally higher, however, the burn-back time was almost double the foam-water sprinkler. It should be noted that the solution flow rate for the foam-water sprinkler was increased above the one-quarter flow rate of the four sprinkler array and was over 4 times the flow rate of the CAF nozzle.
- CAF system performance for both TAR and GDR nozzles was repeatable within a small margin in essentially duplicate tests.
- Foam-water and CAF system performance was only marginally affected by changing the height of the nozzles with some better and some lesser performances with changing height.

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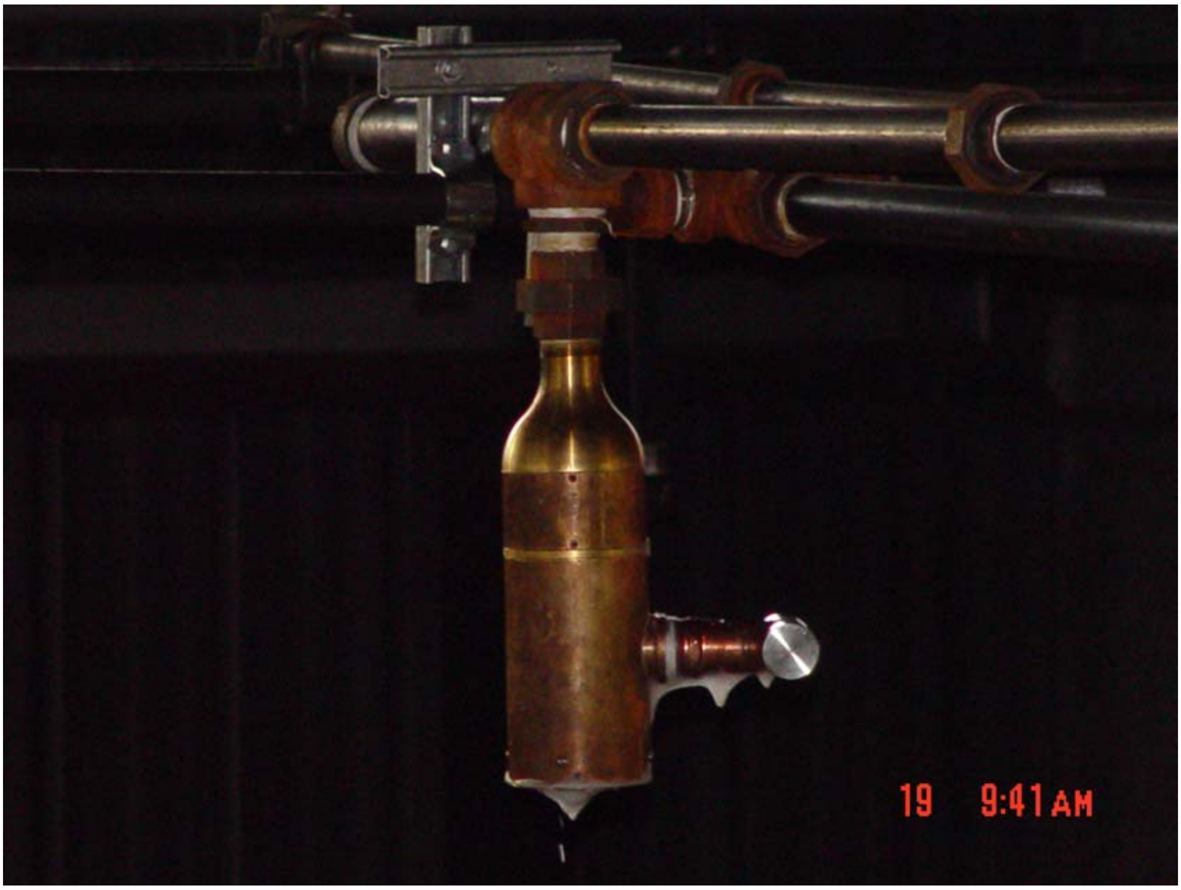
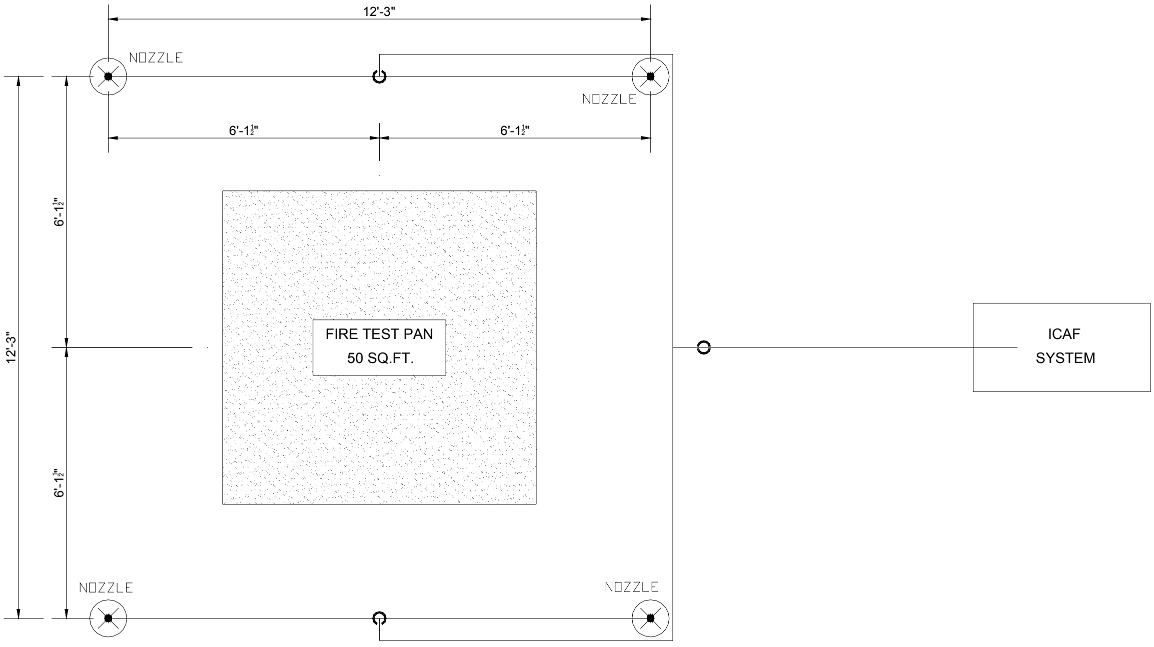
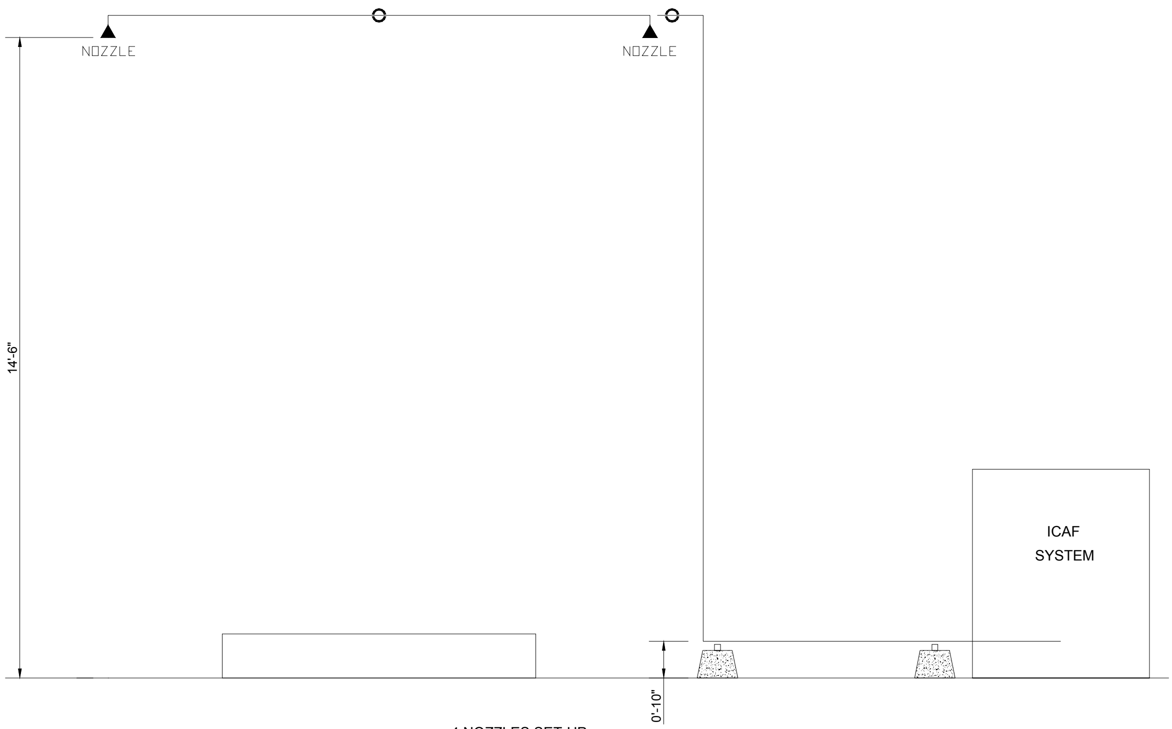


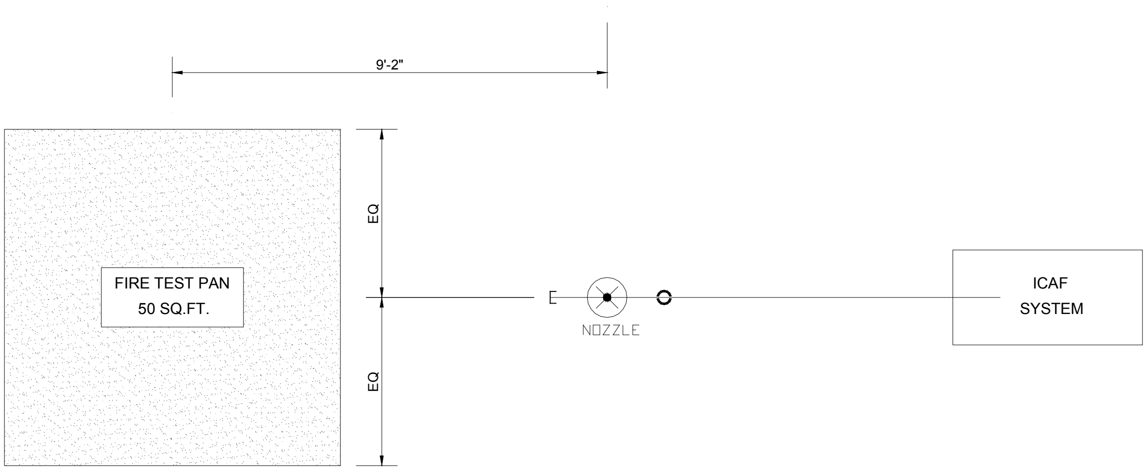
Figure 1 – TAR (top) and GDR (bottom) Nozzles



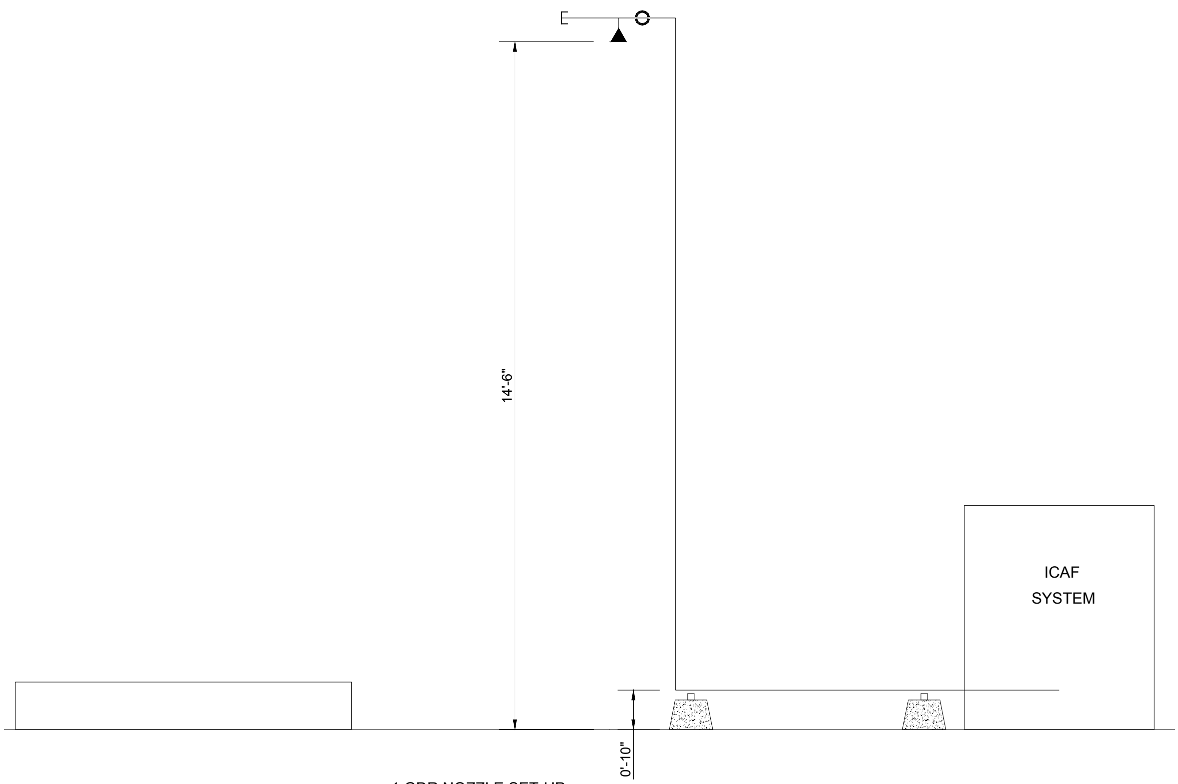
4 NOZZLES SET-UP
PLAN VIEW



4 NOZZLES SET-UP
ELEVATION



1 GDR NOZZLE SET-UP
PLAN VIEW



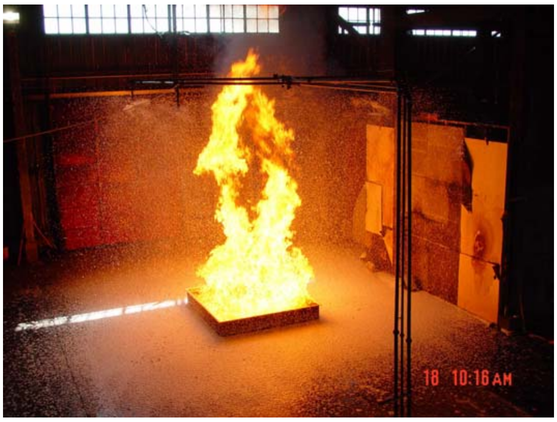
1 GDR NOZZLE SET-UP
ELEVATION

Figure 3 – Setup with 1 GDR Nozzle

Ignition (0 s)

Fire fully developed (10 s)

CAF activation (17 s)



Reduced fire size (38 s)

Figure 4 Fire extinguishment by CAF system with 4 nozzles, using Class B foam concentrate

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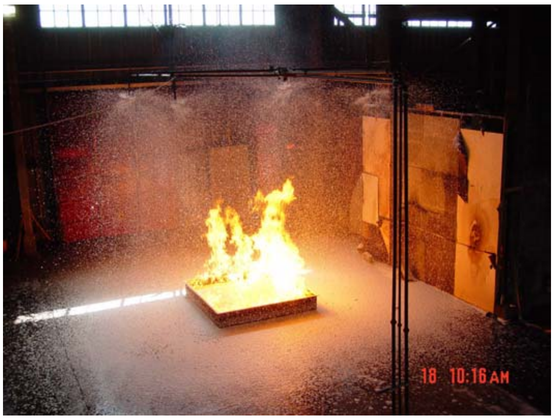

Fire suppressed (44 s)

Fire suppressed (50 s)

Almost extinguished (60 s)

Fire extinguished (67 s)

Figure 4 Fire extinguishment by CAF system with 4 nozzles, using Class B foam concentrate (Cont.)

Ignition (0 s)

Fire fully developed (12 s)

CAF activation (16 s)

Reduced fire size (34 s)

Figure 5 Fire extinguishment by CAF system with one large rotary nozzle, using Class B foam concentrate

Fire suppressed (44 s)

Fire suppressed (64 s)

Almost extinguished (74 s)

Fire extinguished (86 s)

Figure 5 Fire extinguishment by CAF system with one large rotary nozzle, using Class B foam concentrate (Cont.)

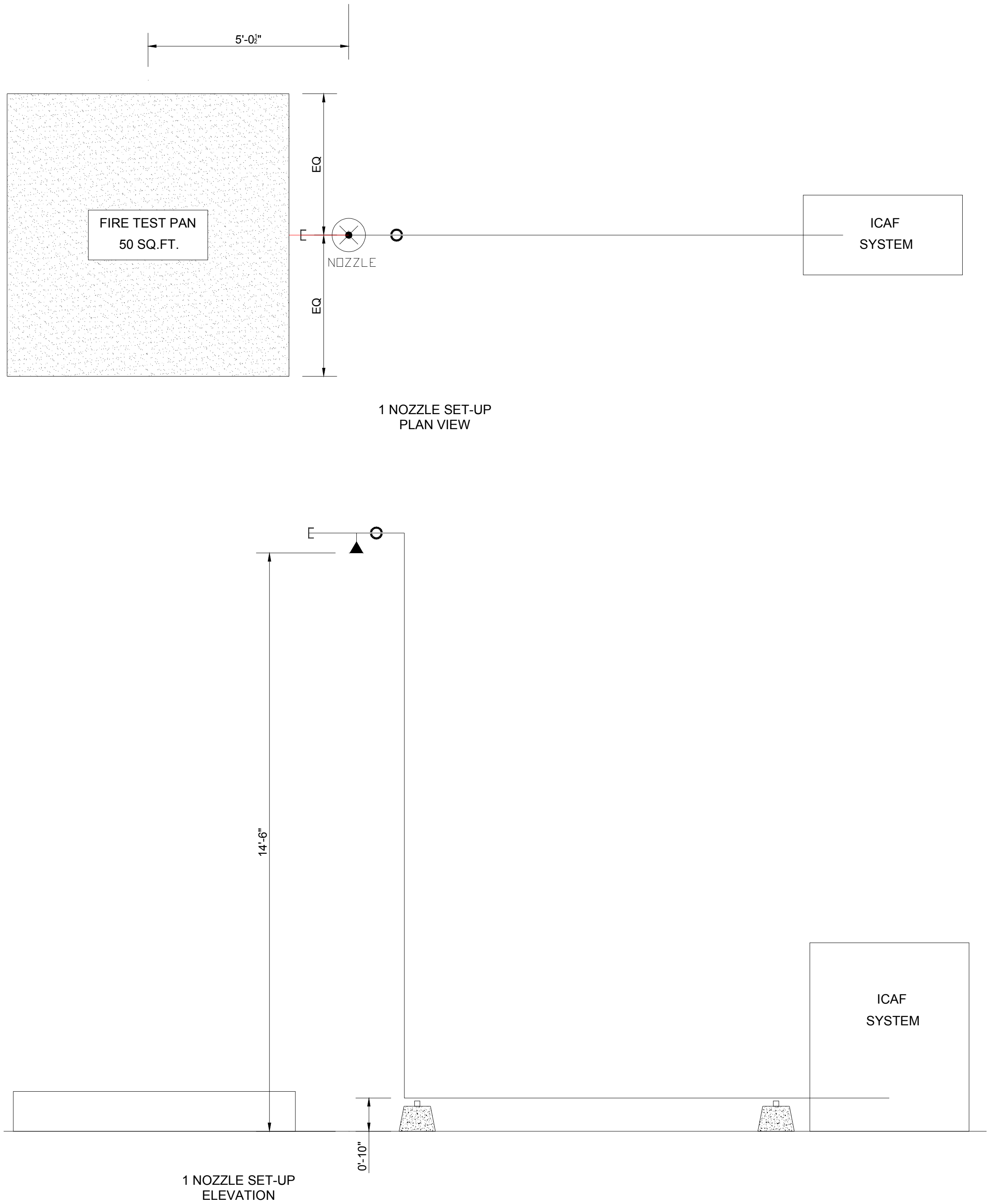

Figure 6 – Setup for Single Nozzle Tests