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EVALUATION OF PYROTECHNIC FIRE SUPPRESSION SYSTEM FOR SIX PYROTECHNIC COMPOSITIONS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A test program was conducted to evaluate the effectiveness of water deluge systems in combating fires from various pyrotechnic materials and also to assess the detectability of pyrotechnic material fires including smoke mixes. Deluge tests were conducted on six pyrotechnic materials varying the quantity of pyrotechnic mix, the shape of the mix, the condition of the mix (wet or dry), the ignition point, the number of detectors, the height of the deluge system above the mixer, and the water application rate. Tests were conducted on the smoke

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20. ABSTRACT (cont)

mixes using standard UV detectors and a prototype dual mode smoke/UV detector.

The conclusions and recommendations were formulated from analysis of the recorded test data.

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The authors would like to express their appreciation to William R. Herrera and Luis R. Garza of Southwest Research Institute and Stuart Nemiroff of the Production Base Modernization Agency for their technical guidance and assistance during the course of this program. The authors would also like to thank the personnel at Longhorn and Lone Star Army Ammuntion Plants, Pine Bluff Arsenal, Crane Army Ammunition Activity, and Lake City Army Ammunition Plant for their cooperation during the course of this program. The authors would like to express their appreciation to M. Ray Burgamy, Mark R. Castle, Ernest R. Garcia, Jr., and Steven W. Olson of Southwest Research Institute in conducting the fire suppressive tests.

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INTRODUCTION

The program entitled, "Pyrotechnic Safety Enhancement-Fire Suppression System Evaluation," is a continuation program aimed at improving the safety of personnel involved in the manufacture and processing of pyrotechnics through the use of a fire suppression system. This program is part of an overall effort to increase safety in pyrotechnic mixing operations under MM&T Project 4548, Pyrotechnic Safety Enhancement. The previous program*, had as its prime objective the evaluation of the effectiveness of a deluge system in combatting pyrotechnic starter mix fires. Tests were conducted varying the quantity of pyrotechnic mix, the ignition point, the nozzle spray pattern, and the water application rate.

The previous program demonstrated that a fire suppression system could be developed to combat pyrotechnic starter mix fires; the objectives of this program were to expand on the previous work and determine the effectiveness of the deluge system on different types of pyrotechnic material, i.e., magnesium-based mixes and smoke mixes, as well as larger quantities of starter mix. Included in this work was an assessment of those pyrotechnic materials amenable to water and those requiring other agents, and an assessment of the detectability of pyrotechnic material fire. Fire suppression system tests were conducted on six pyrotechnic materials placed in a simulated mix muller with the following parameter being varied: quantity of mix, shape of the mix (cone-shaped or flat), condition of the mix (wet with solvent or dry), ignition point, number of detectors, height of the deluge above the mix and water application rate. In addition, tests were conducted on the smoke mixes using stardard UV detectors and a prototype dual mode smoke/UV detector.

This report details the assessments performed, the fire suppression tests, and the analysis of the data, as well as conclusions and recommendations developed.

* L. M. Vargas, R. M. Rindner, W. M. Stirrat, "Fire Suppression System Safety Evaluation," ARRADCOM Contract Report ARLCD-CR-83031, December 1963.

ASSESSMENTS

As part of this program, Southwest Research Institute (SwRI) was to perform a number of preliminary assessments of extinguishing agents and detection systems that could be readily adapted to fires involving pyrotechnic materials. These assessments were divided into two principal areas: (1) assess the pyrotechnic materials amenable to water extinguishment and those requiring other extinguishment agents, and (2) assess the detectability of pyrotechnic material fires including smoke mixes using commercially available UV, IR, and radiometric detectors. These assessments are discussed in detail in this section of our report.

Materials Amenable to Water

Historically the design of a fire suppression system for combatting fires involving energetic materials, i.e., propellants, explosives and pyrotechnics has primarily centered around the usage of a water deluge system. Water deluge systems have been designed, and demonstrated as effective in combatting propellant fires and hydrocarbon fires as well as structural fires. Water is an effective suppressant in that it will quench the flames, cool the fuel, and also inert the immediate area through the exclusion of air. The advent of protein foams, halons and light water extinguishing systems has provided fire fighters with increased capability and flexibility. However, these systems function primarily on the basis of isolation of either the fuel or the oxidizer. In the case of pyrotechnic mixes, however, the isolation of either the fuel or the oxidizer is almost impossible. Therefore, since isolation is impractical the only feasible way to extinguish or control a pyrotechnic fire is to penetrate the fireball and quench/cool the material; the most practical suppression system to do this appears to still be water. As was demonstrated in the previous program* penetrating a pyrotechnic mix fireball requires a tight water spray pattern (15° full cone) with the water being delivered at a relatively high rate (152 liter/min (40 gal/min) per nozzle and at a pressure at the nozzle of 276 kPa (40 psi)). A potential hazard associated with the use of water on pyrotechnic mix fires is the possible formation of hydrogen which could then detonate. Some of the pyrotechnic materials, predominantly flares and illuminates, use magnesium powder as the fuel. If the water being applied to the fire is not applied at a high enough rate and with a tight spray pattern, then the water may not be able to penetrate the fireball and as a result will be steamed off. Contact between the steam that is produced and the hot magnesium particles that may be lofted into the air could produce hydrogen which in an enclosed bay could create a hazardous situation in terms of a flammable or perhaps detonable mixture. The use of a high delivery deluge system which will penetrate the fireball and thereby quench the pyrotechnic fire should minimize the hydrogen generation problem by reducing the burn time, thereby reducing the time that hydrogen can be generated. The probability of hydrogen generation is very difficult to quantify due to the fact that little if any data are available on the rate and quantity of hydrogen produced by the interaction of steam and magnesium particles. This potential problem area is worthy of further investigation to determine the rate and quantity of hydrogen generation for various water flow rates, nozzle spray patterns and pyrotechnic mixes.

Detectability of Pyrotechnic Material Fires

The use of ultraviolet (UV) light detectors for pyrotechnic fire suppression systems is an accepted fact and SwRI demonstrated the effectiveness of UV detectors in sensing pyrotechnic fires in an earlier program*. UV detectors manufactured by Det-Tronics Corp. were used in this program to detect fires for six pyrotechnic materials, i.e., starter mix, M206 flare mix, MK45 flare mix, green smoke, yellow smoke, and HC smoke. The UV detectors were very successful in detecting fires involving the starter mix and the two flare mixes. Tests using the pyrotechnic smoke mixes and the UV detectors were not very successful, however, due to the fact that the smoke produced by burning of the material obscured the line of sight of the detector and precluded their detection of any UV radiation emitted by the burning material. A new dual mode smoke/UV detector is currently being developed by Det-Tronics Corp. and SwRI was able to obtain one of the prototype detectors for use in this program. This dual mode detector has been designed for use where hazardous materials may be expected to give off UV absorbing vapors or smoke prior to bursting into flame. When the presence of smoke is detected, or if a flame is detected, the system will emit a signal through a controller to give an alarm and function a deluge system. The UV portion of the detector operates under the same principals as a standard UV detector. The smoke detection portion, however, uses an adaptation of the standard UV automatic optical integrity technique to detect any UV absorbing smokes or vapors. A UV emitting source tube located in the base of the detector is activated producing a known quantity of radiation. A prism in the base of the detector directs the radiation into an external path parallel to the length of the detector. The UV beam then reenters the detector at an orifice under the detector's cap and is then reflected toward the UV sensing tube. The system monitors the strength of the external UV beam and if the beam is being attenuated by smoke for a period of time (approximately 8 seconds) the system will sense the decrease in signal and will trigger a "smoke alarm." A typical response time for smoke detection is approximately 20 seconds and the fastest response time possible is eight seconds. A severe decrease in the signal will result in the controller declaring the optics to be impaired or dirty and will result in a "smoke fault" instead of a "smoke alarm." This particular piece of logic resulted in a large number of erroneous faults when the system was tested with the smoke mix. Details on these and all the other tests performed as part of this program are presented later in this report.

Two other types of pyrotechnic fire detection systems were investigated, infrared (IR) detectors and radiometers. It is well known that IR detectors are very effective in detecting fires particularly in a closed system, i.e., where there is no extraneous light. However, in an open system such as the mix muller bays and granulator bays where extraneous light is readily available from artificial lighting, sunlight, etc., the IR system is prone to false trigger. This susceptibility to false triggering in an open system precluded any further investigation or experimental evaluation of the IR system. The second type of detector investigated involved the use of radiometers. Radiometers or radiation thermometers are used to measure the amount of radiation being generated by temperature rises in a material. Every body above absolute zero in temperature emits radiation dependent on its temperature. As the temperature is increased, the radiation levels being emitted also increase. The bulk of the radiation-temperature sensors operate with radiation whose wavelengths lie in the visible and infrared portions of the spectrum (0.3 to 40 μ) Unfortunately, however, emittances of radiation from a body are not simple material properties such as densities but rather depend on the size, shape of the body, surface roughness, and the angle of viewing. Calibration of a radiation thermometer for pyrotechnic applications, therefore, is very difficult and not very reliable. In addition the response time of a radiation thermometer is in the "second" range and not as fast as would be needed for pyrotechnic application. Commercially available radiation thermometers are expensive and are either too slow or do not encompass the necessary temperature range for pyrotechnics. For these reasons, the use of radiation thermometers was not investigated further.

TEST PROGRAM

As part of this program SwRI was tasked to perform a series of fire suppression/deluge tests using small and intermediate quantities of six pyrotechnic materials selected as representative of the materials currently being manufactured. The purpose of this test program was to evaluate the effectiveness of the water deluge system in detection, extinguishment, and control of each particular pyrotechnic material in a simulated mix-muller and also to determine thresholds of effectiveness for the deluge system. The following paragraphs present details on the test plans generated for this task, as well as descriptions of the experimental set-up and the preliminary as well as the actual deluge tests.

Test Plans

As previously mentioned, the purpose of this program was to evaluate the effectiveness of the water deluge system and to determine thresholds of effectiveness. A number of key parameters identified for this program were instrumental in the development of the test plans and in the execution of the test program. These key parameters included the following:

- Type of pyrotechnic material involved
- Quantity of pyrotechnic material involved
- Condition of pyrotechnic material involved (with or without solvent/binder)
- Ignition scenario (bottom or top ignition, electric matches or booster ignitors)
- Detector response time
- Water application rates
- Water line pressure
- Degree of confinement.

The deluge system used in the previous program was reassembled and installed at the test site for use on this program. This deluge system was designed to simulate the water suppression/deluge systems in use at Longhorn AAP. The water line pressure, detector type and stand-off distance were again selected to simulate actual plant conditions. For this program, all of the pyrotechnic mixes were tested in a simulated mix muller (the previous program tested the mix in an open drying tray). The simulated mix muller consisted of a section of 0.84 m (2.75 ft) I. D. pipe with a 1.9 cm (0.75 in.) steel plate welded to one end of the pipe to simulate the floor of the mixer as shown in Figure 1. The section of pipe was 25.4 cm (10 in.) high to simulate the walls of the mixer. The nozzles used in this program were the 15° full cone nozzles used in the previous program. Details on the flow loop, the nozzle manifold, and the detection system used are presented later in this report.

The data recorded for each of the deluge tests included the following:

- Type of pyrotechnic material
- Quantity of pyrotechnic material involved
- Condition of pyrotechnic material (wetted with solvent or dry)
- Water line pressure
- Water application rate
- Number of nozzles and spray pattern

- Detector response time
- Water actuation time
- Water at the nozzle time
- Water on the fire time
- Total burn time.

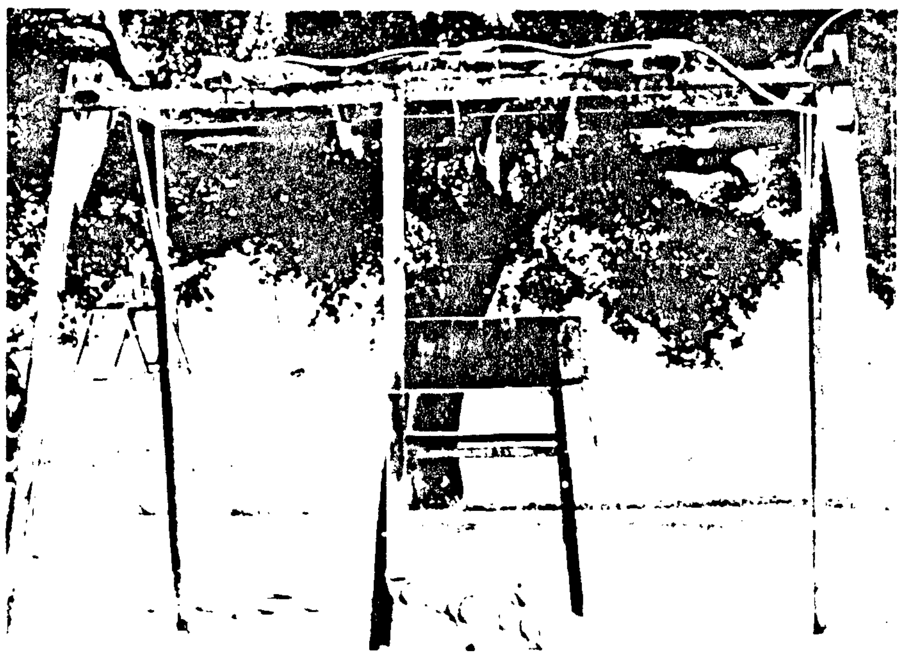

Figure 1. Fire Suppression System Test Set-Up

A test data sheet was prepared and a sample has been included here as Table 1. The experimental matrices developed for each material tested are included here as Tables 2 through 5.

Table 1.

Sample Data Sheet

PYROTECHNIC SAFETY
DELUGE TESTS
DATE:

TEST NO: _____

CHARGE SIZE (shape): __________________

IGNITER TYPE (position): ______ __________

ENGINE RPM: ______________

LINE PRESSURE: _________

NOZZLE TYPE (No.): _____________

UV DETECTOR TYPE (NO.): __________

NOZZLE POSITION
(Overhead View)

0_4 0_5

0_3

0_1 0_2

TAPE RECORDER TIMES

UV DETECTOR: __________________

PRIMAC: ______________________

FLOW METER GPM: _______________

WATER AT THE NOZZLE TIME
(msec)

NOZZLE 1: ______

NOZZLE 2: ______

NOZZLE 3: ______

NOZZLE 4: ______

NOZZLE 5: ______

VIDEO RECORDER TIMES

IGNITION: __________

FIRST FLAME __________

WATER ON: ________

WATER ON FIRE: ______

END BURN: __________

BURN TIME __________

COMMENTS:

Table 2. Test Matrix for Starter Mix Tests

No. of Tests	Detectors Type/No.	Water Application Rate-lit/min (gal/min)	Quantity of Mix kg (lb)	Ignition Point
1	UV/4	851 (225)	0.100 (0.22)	Bottom Center
1	UV/4	851 (225)	2.26 (5)	Bottom Center
1	UV/4	851 (225)	4.54 (10)	Bottom Center
1	UV/4	851 (225)	6.81 (15)	Bottom Center
1	UV/4	851 (225)	11.35 (25)	Bottom Center
1	UV/4	851 (225)	4.54 (10)	Bottom Center

Table 3. Test Matrix for M206 Flare Mix Tests

No. of Tests	Detector Type/No.	Water Application Rate liter/min (gal/min)	Quantity of Mix kg (lb)	Mix Condition (wet/dry)	Ignition Point
1	UV/4	757 (200)	2.27 (5)	Dry	Bottom Center
1	UV/2	757 (200)	1.36 (3)	Dry	Bottom Center
1	UV/4	757 (200)	1.36 (3)	Dry	Bottom Center
1	UV/4	757 (200)	2.27 (5)	Dry	Bottom Center
1	UV/4	757 (200)	0.59 (1.3)	Wet	Bottom Center
1	UV/4	757 (200)	1.8 (3.9)	Wet	Bottom Center
1	UV/4	757 (200)	2.95 (6.5)	Wet	Bottom Center
1	UV/4	757 (200)	5.9 (13)	Wet	Bottom Center
1	UV/4	567 (200)	2.95 (6.5)	Wet	Top Center
1	UV/4	757 (200)	4.54 (10)	Wet	Bottom Center
1	UV/4	757 (200)	2.95 (6.5)	Wet	Bottom Center
1	UV/4	757 (200)	5.9 (13)	Wet	Bottom Center
1	UV/4	946 (250)	9.1 (20)	Wet	Bottom Center
1*	UV/4	946 (250)	0.45 (1)	Dry	Bottom Center
1*	UV/4	946 (250)	0.45 (1)	Dry	Bottom Center
1*	UV/4	946 (250)	1.36 (3)	Dry	Bottom Center

* Tests performed with the deluge manifold closer to the mix (approximately 1 meter).

Table 4. Test Matrix for MK45 Flare Mix Tests

No. of Tests	Detector Type/No.	Water Application Rate liter/min (gal/min)	Quantity of Mix kg (lb)	Shape	Ignition Point
1	UV/4	757 (200	0.91 (2)	Cone	Bottom Center
1	UV/4	757 (200)	0.91 (2)	Cone	Bottom Center
1	UV/4	757 (200)	1.23 (2.7)	Flat	Bottom Center
1	UV/4	757 (200)	1.36 (3)	Cone	Bottom Center
3	UV/4	757 (200)	2.27 (5)	Cone	Bottom Center
2	UV/4	757 (200)	2.27 (5)	Flat	Bottom Center
1	UV/4	946 (250)	2.27 (5)	Cone	Bottom Center
2	UV/4	946 (250)	4.54 (10)	Flat	Bottom Center
1*	UV/4	946 (250)	2.27 (5)	Flat	Bottom Center
1*	UV/4	946 (250)	2.95 (6.5)	Cone	Bottom Center
1*	UV/4	946 (250)	4.54 (10)	Flat	Bottom Center

* These tests performed with the deluge manifold closer to the mixer.

Table 5. Test Matrix for Each Smoke Mix

No. of Tests	Detector Type/No.	Quantity of Mix kg (lb)	Ignition Point
1	UV/4	0.454 (1)	Bottom Center
1	UV/4	2.27 (5)	Bottom Center
1	UV/4	4.54 (10)	Bottom Center
1	Dual UV/Smoke	0.454 (1)	Bottom Center
1	Dual UV/Smoke	0.91 (2)	Bottom Center
1	Dual UV/Smoke	2.27 (5)	Bottom Center

Experimental Setup

The experimental deluge system consisted of a flow loop subsystem, a nozzle manifold subsystem and an ultraviolet light detection subsystem. This deluge system was very similar to the prototype system assembled for the previous program*. Details on each of these subsystems are presented in the the following subsections of this report.

Flow Loop Subsystem

The flow loop used in this program consisted of a water reservoir, a high pressure-high delivery pump, an in-line Primac high-speed valve, and associated plumbing as shown in Figure 2. The pump used to deliver water to the nozzle manifold was a Hale Model No. 50 FB pump which was capable of flowing over 1000 gallons per minute at discharge pressures in excess of 175 psi. The pump was powered by a Chrysler industrial engine, and by varying the engine revolutions per minute (rpm) the output of the pump could be varied. A calibration curve of engine rpm versus pump output in liter/min (gal/min) is shown in Figure 3. This curve was developed using the 15-degree full cone nozzles. The pump was connected to an in-line Primac high-speed valve utilizing 4-inch polyvinyl chloride (PVC) piping. The Primac valve used an explosive primer (Hercules MK131) to shear a holding pin at which time the water pressure forces open a valve thereby releasing water to the nozzles. Prior to testing, all of the lines were primed with water up to the nozzles. In order to allow for priming the water lines prior to each test, plastic blow-off caps were installed on the nozzles. Downstream from the Primac High-Speed valve, standard 6.35 cm (2.5 in.) water pipe was used. The short run from the manifold line to the nozzle used 5.08 cm (2 in.) water pipe. As shown in Figure 2, a pressure transducer and a flow meter were installed in the flow loop to measure line pressure and water flow rates at specific engine rpm's. Pressure gauges were installed next to the nozzles using standard "Tee" connections. These pressure gauges were used to verify the primed line pressure as well as the nozzle dynamic pressure once the system was actuated.

Flow tests were also performed using the Auto-Spray Pilot body developed by the Automatic Sprinkler Corp. The 15° full cone nozzles were attached to the upper body of the Auto-Spray system. The Auto-Spray system consists of a two-piece body threaded together and sealed with an "O" ring. The upper half of the body has a connection for the Pilot line through which a cylinder and poppet receive pilot pressure. The poppet has an "O" ring seal and a rubber seal on its face which seats against an orifice located in the lower half of the body. When the nozzle is in its normally closed position, the poppet is held against the discharge orifice by pressure within the poppet cylinder. When pilot line pressure drops, the main line pressure overcomes the differential pressure forces and the poppet up, thereby opening the discharge orifice. When pressure to the pilot line is restored, the poppet will reseat, closing the orifice. Four Auto-Spray bodies (Series 165 which has a 1.27 cm (0.5 in.) main line inlet connection) were available and were mounted in the manifold and tested. A curve of engine rpm versus pump output in liter/min (gal/min) is shown in Figure 4.

In order to compare flow capability of the Primac system and the Auto-Spray Pilot system, a calibration curve was developed for the Primac system with only four nozzles. This curve is presented here as Figure 5. As can be

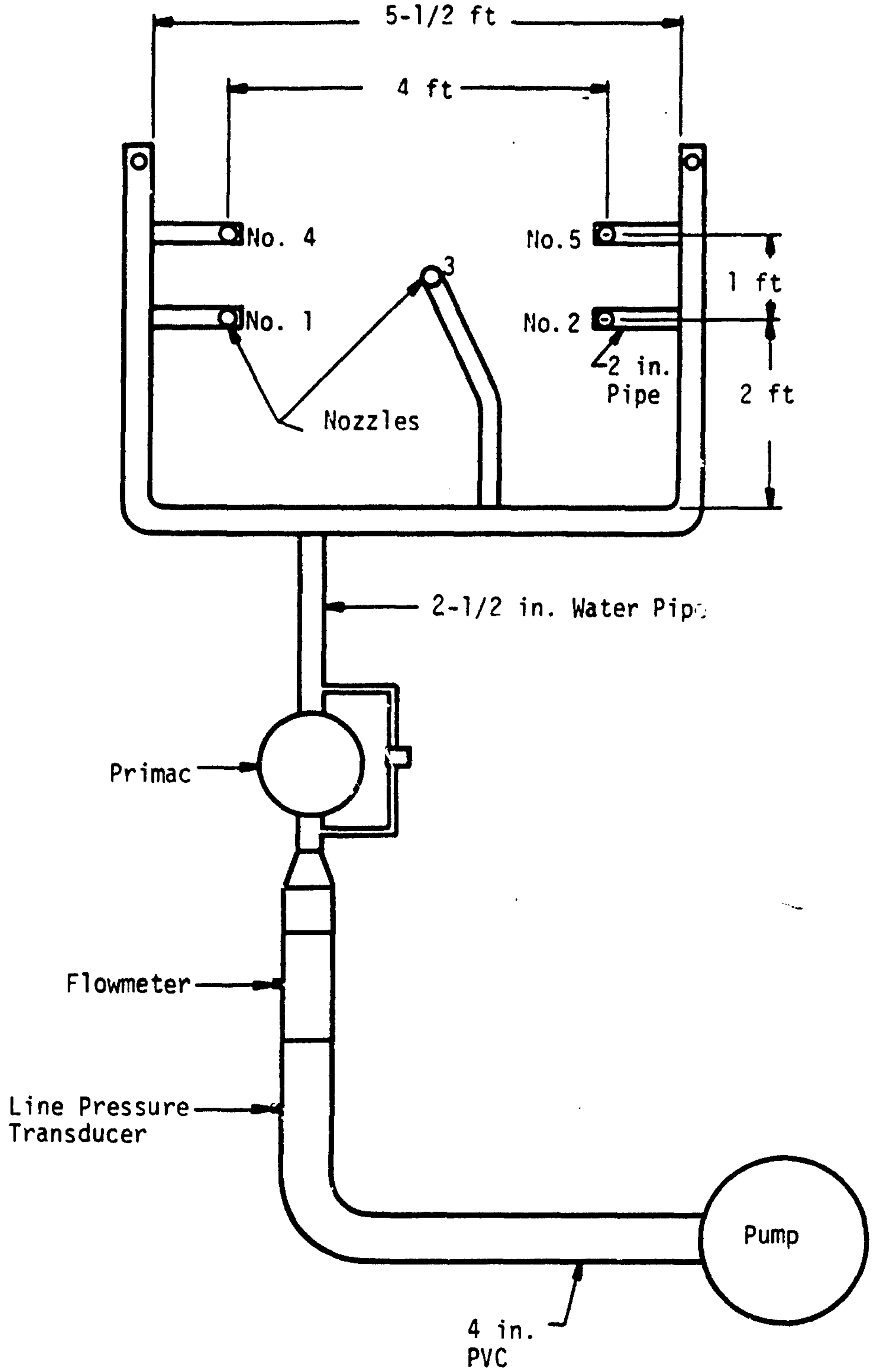

Figure 2. Flow Loop

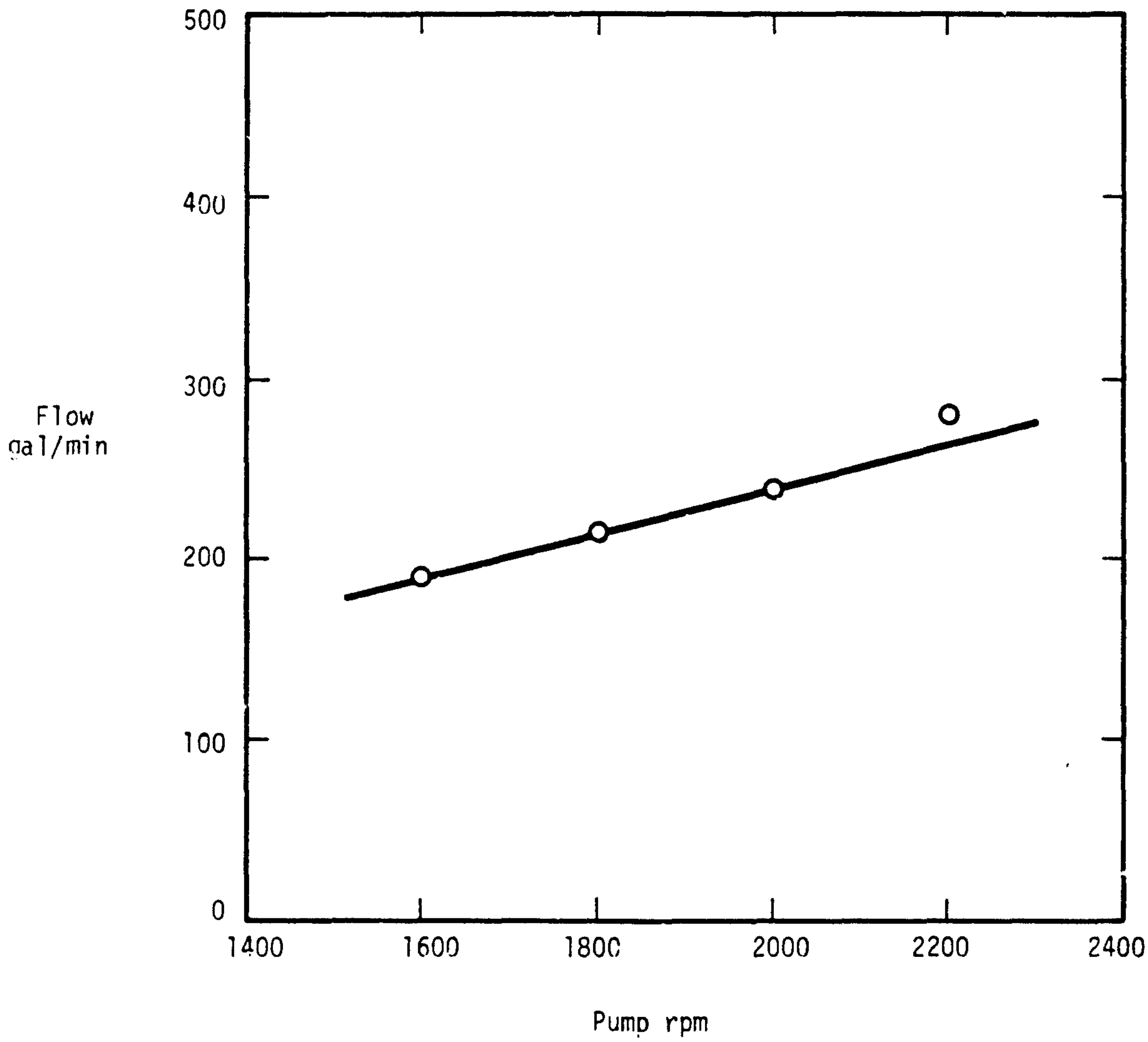

Figure 3. Flow Rate vs Pump rpm for Primac System

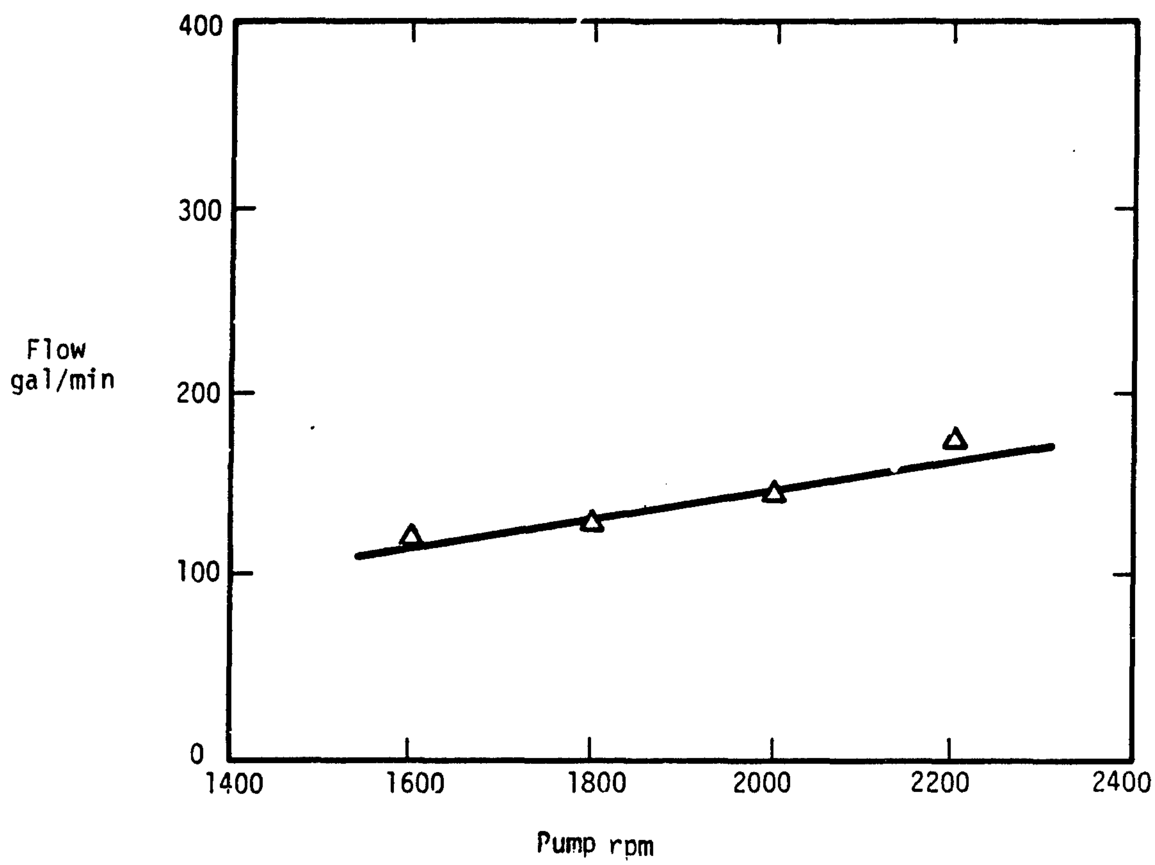

Figure 4. Flow Rate vs Pump rpm for Pilotex System

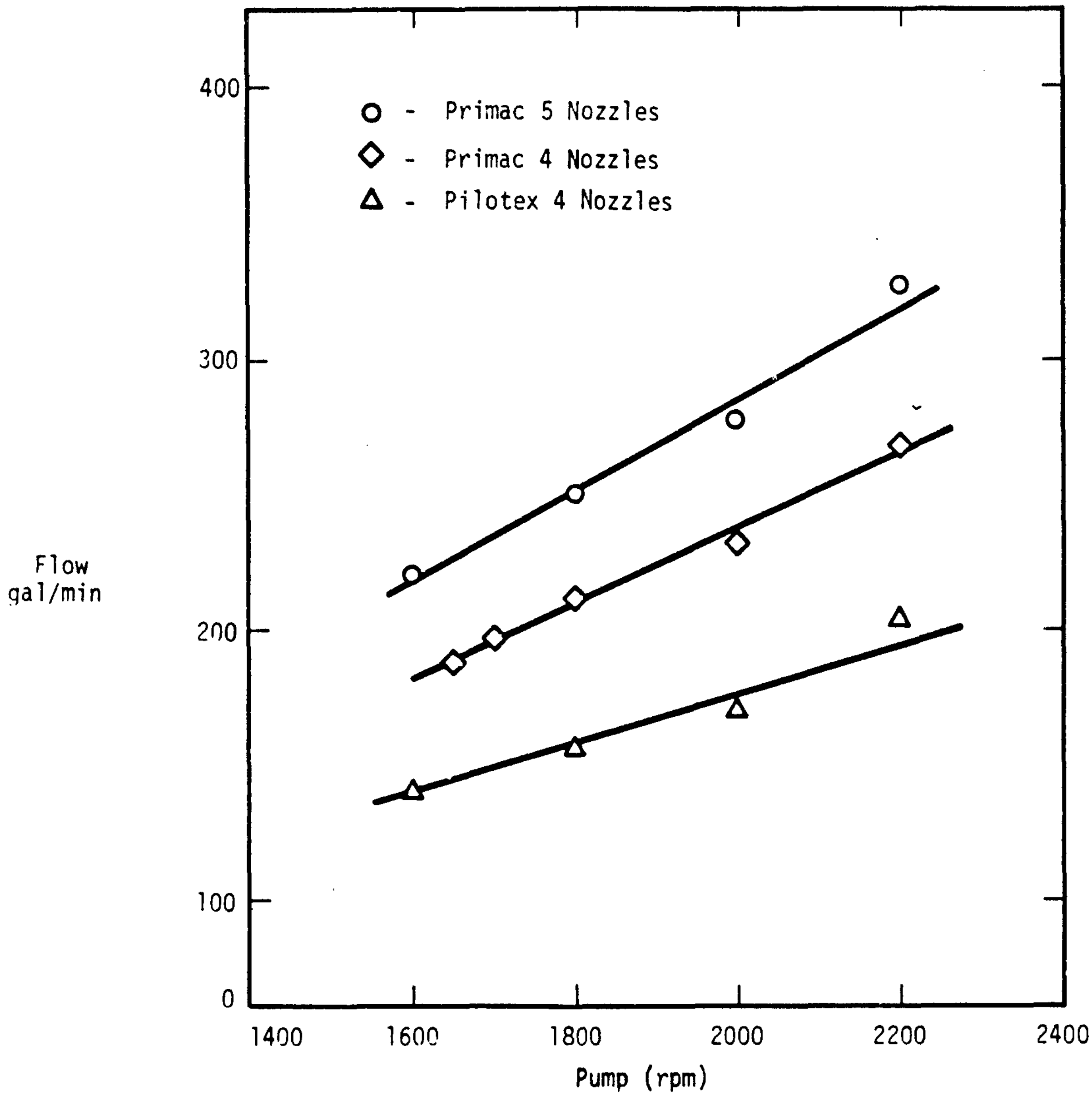

Figure 5. Flow Rate vs Pump rpm

seen in Figure 5, the Primac system is able to deliver more water at a specified rpm than the Auto-Spray Pilot system. A curve of main water line pressure versus water output for both systems is presented in Figure 6. As can be seen in Figure 6, the Primac system delivers a larger amount of water at a specified line pressure than does the Auto-Spray Pilot system. As shown in the previous program, water delivery rates of approximately 152 liters/min (40 gal/min) per nozzle are desirable; however, for the Auto Spray Pilot system to deliver 152 liter/min (40 gal/min) per nozzle (608 liter/min (160 gal/min) for the four nozzles) requires a main water line pressure of approximately 587 kPa (85 psi) which is much higher than the Primac system. This higher pressure is due to the fact that the Auto-Spray Pilot system connects to the main water line through a 1.27 cm (0.5 in.) connection which severely restricts the flow. Since the Primac system delivered the necessary quantity of water at lower pump rpm and line pressures it was decided to continue to use the Primac System.

Nozzle Manifold Subsystem

Five nozzles were mounted on a manifold as shown in Figure 7. The nozzles were mounted at a distance of approximately 1.57 meters (5.17 ft) from the simulated mixer containing the pyrotechnic mix. The distance between the nozzles and the mixer was selected to optimize the area coverage for the nozzles. One nozzle (nozzle 3 in Figure 7) was mounted directly above and centered over the simulated mixer. The four side nozzles (two each per side of the manifold) were mounted such that horizontally they were located directly above the edge of the mixer and vertically 1.57 meters (5.17 ft) above the mixer as shown in Figure 7. The four side nozzles were rotated 7.5 degrees towards the center of the mixer in order to maximize the mixer area coverage and direct the bulk of the water into the mixer.

As previously mentioned, all of the deluge tests were performed using the Full Jet 15° full cone nozzles. The nozzles were equipped with blow-off caps which allowed for priming of the lines up to the nozzle with water at approximately 138 kPa (20 psi). Thin wires were attached to the blow-off caps which broke when the cap was blown off of the nozzle by the functioning of the deluge system. These "break" wires were connected to a direct current power supply and were used to determine water-at-the-nozzle time as evidenced by a recorded loss of power.

UV Detection Subsystem

As part of this program, SwRI surveyed and evaluated alternate methods for detecting pyrotechnic fires other than ultraviolet (UV). The two alternate methods investigated were infrared (IR) and radiometry. Neither of these detection methods appeared to be as fast, efficient and reliable as the UV system; therefore, the test program was conducted using the UV detectors. The sensors used were Det-Tronics Model DE 1777 and the controller to which the sensors send their signals was a Det-Tronics Model No. 7303. Upon receiving the signals from the detectors that a fire was present, the controller closed a relay and sent the necessary voltage through the relay contacts to function the Primac High-Speed Valve. The previous program utilized two detectors to sense the pyrotechnic fires; however, for this program in an attempt to speed up the sensing time, four UV detectors were used, two located 1.83 meter (6 ft) away from the center of the mixer and two

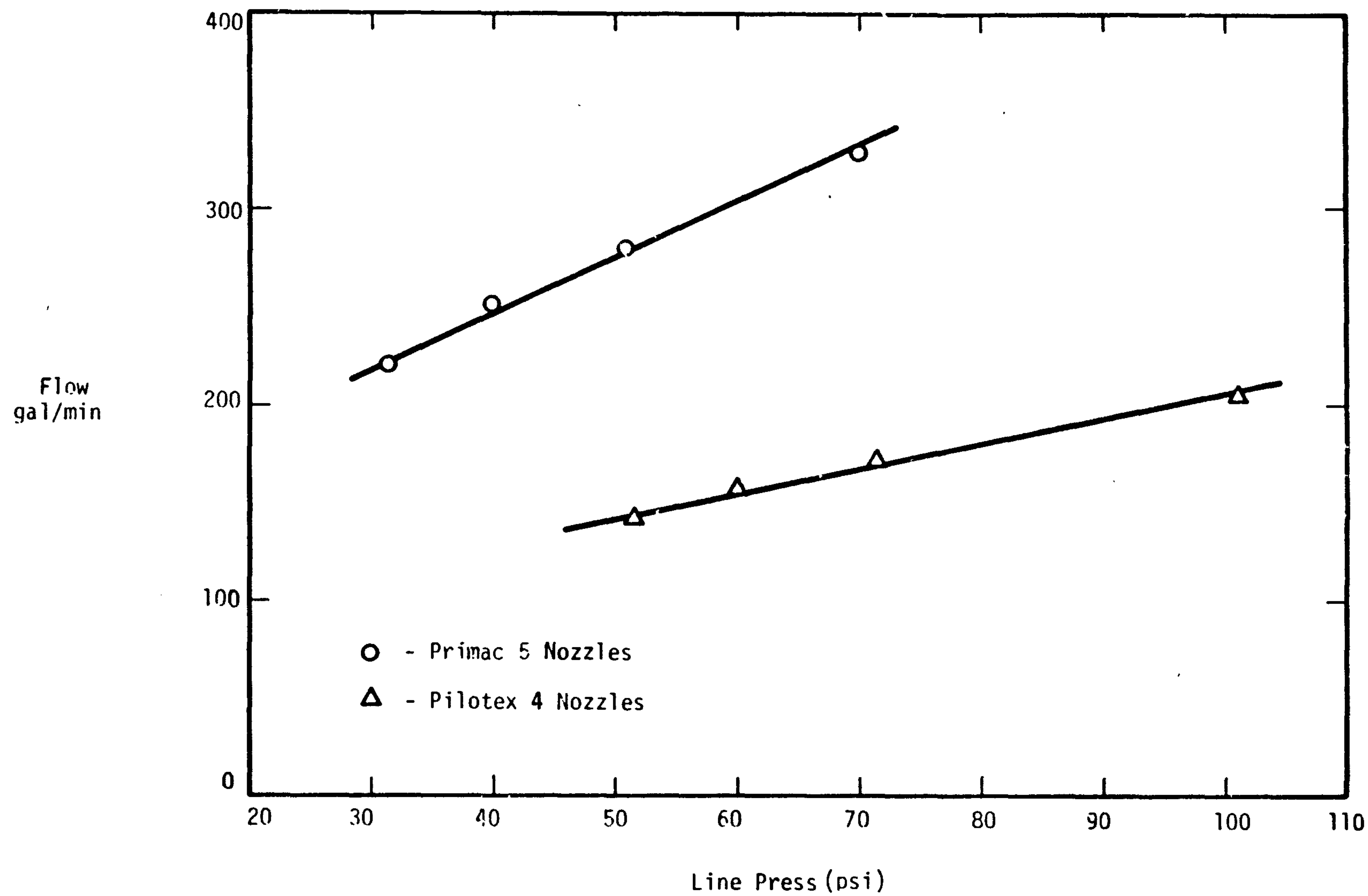

Figure 6. Flow Rate vs Line Pressure

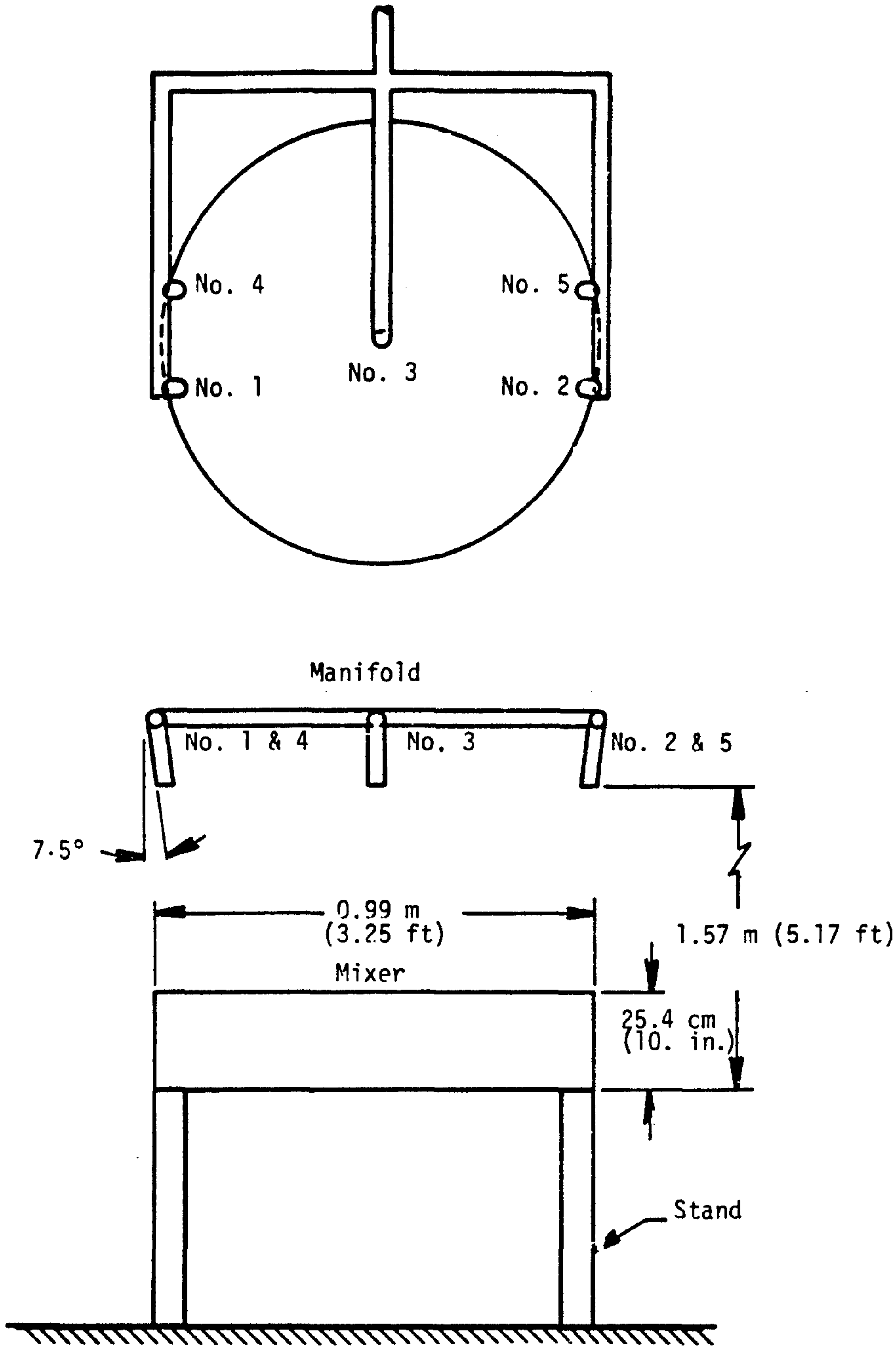

Figure 7. Nozzle Set-up

located 2.44 meters (8 ft) away from the center of the mixer. The controller electronics is designed to sum up the outputs of each of the detectors; therefore, the more detectors that are used, the faster the controller will confirm a fire. The time required by four detectors to confirm a fire is approximately twice as fast as the time required by two detectors. In order to verify this increase in response time, SwRI performed a number of UV detection time tests using small quantities (100 grams) of the M206 flare mix contained in a drying tray. Tests were conducted using one, two and four detectors mounted 1.22 m (4 ft) away from the center of the mixer. SwRI received and checked-out two new improved detector tubes with enhanced electronics from Det-Tronics Corp. The tests performed with four detectors utilized two of the detector tubes used in the previous program and the two new detector tubes. Table 6 presents a summary of the response time tests performed using the M206 mix. As can be seen in Table 6, the tests performed with two detectors, Tests 1-3 (using the older detection tubes) resulted in response times varying between 43 milliseconds for the fastest response and 150 milliseconds for the slowest response time. An average response time appears to be approximately 90 milliseconds which is considerable faster than the response times recorded on the previous programs in a starter mix. The average response time measured in the previous tests was approximately 221 milliseconds after ignition. The variation between the response times for the M206 mix, i.e., 43 milliseconds for the fastest and 150 milliseconds for the slowest might be due in part to the large variation in particle size of the M206 mix. The M206 mix was found to contain a significant amount of grains or pellets approximately 1/8-inch and 1/4-inch in diameter. SwRI experienced a number of misfires where the electric matches (two matches were used to light the mix) went off but the mix did not ignite. It is felt that this ignition problem is due in part to the large particles of M206 mix being in contact with the matches and not igniting. Tests were performed using the four detectors to determine if in fact the response time would be faster. The four detector tests are tests 5, 6, 14 and 15. As can be seen in Table 6, the response times for tests 5, 6 and 14 were much faster than those for tests using only two detectors, with an average response time of 50 milliseconds. Test 15 was a test with four detectors; however, the detectors were placed 1.52 m (5 ft) from the mix instead of the 1.22 m (4 ft) used on all of the other detection tests.

Deluge Extinguishment Tests

Tests using small and intermediate size quantities of material were performed on six pyrotechnic materials selected as being representative of the materials currently being manufactured. These six materials included the following: starter mix manufactured at Pine Bluff Arsenal; M206 flare mix manufactured at Longhorn AAP; MK45 flare mix manufactured at Crane AAA; HC smoke mix manufactured at Pine Bluff Arsenal; and green and yellow smoke mixes also manufactured at Pine Bluff Arsenal. The following paragraphs describe in detail the tests performed on each of the materials.

Starter Mix Test

The starter mix used in these tests was the same mix used in the previous program and consisted of the the following ingredients: silicon (26%), potasium nitrate (35%), iron oxide (22%), aluminum powder (13%), charcoal (4%) and nitrocellulose (3%). A total of six tests were performed using this mix.

Table 6. UV Response Times

Date	Test No.	Charge Wt. (gms)	No. of UV	UV Distance (ft)	Detector Time (msec)	Primac Relay Time (msec)
9/30/83	1	100	2	4	56	68
9/30/83	2	100	2	4	90	102
9/30/83	3	100	2	4	100	110
9/30/83	4	100	1	4	200	210
10/3/83	5	100	4 (2 new tubes)	4	52	63
10/3/83	6	100	4 (2 new tubes)	4	49	61
10/3/83	7	100	2 (new tubes)	4 matches	fired but mix	did not ignite
10/3/83	7 (repeat)	100	2 (new tubes)	4	43	55
10/3/83	8	100	2 (new tubes)	4 matches	fired but mix	did not ignite
10/3/83	9	100	2 (new tubes)	4	51	63
10/3/83	10	100	2 (new tubes)	4 matches	fired but mix	did not ignite
10/3/83	10 (repeat)	100	2 (new tubes)	4 matches	fired but mix	did not ignite
10/3/83	11	100	2 (new tubes)	4	82	95
10/3/83	12	100	2 (new tubes)	4	150	162
10/3/83	13	100	2 (new tubes)	4	125	136
10/3/83	14	100	4 (2 new tubes)	4	58	70
10/3/83	15	100	4 (2 new tubes)	5	98	110
10/3/83	16	100	4 (2 new tubes)	5 matches	fired but mix	did not ignite

Starter Mix Test 1 - The first starter mix test that was performed used 100 grams of starter mix located in the simulated mixer. The purpose of this test was to check out the instrumentation used in the deluge. Four UV detectors with protective hoods were mounted 1.52 meters (5 ft) away from the mix. The UV controller (Model 7303) was modified to trigger on 10 counts per second instead of 25 counts per second. It was hoped that this increase in sensitivity would result in faster detection of the fire. The Instantaneous Relay, i.e., a mechanical relay in the controller that was used to initiate the Primac detonator, was replaced with a much faster solid state relay. The mix was initiated using two electric matches and the UV detectors saw the fire in 222 msec. The solid state instantaneous relay closed approximately 0.2 msec later. Previous tests using the mechanical relay demonstrated a time delay of approximately 12 msec from the time that the UV detectors saw the fire to relay closure. The use of the solid state relay eliminated this 12 msec delay thereby allowing for much faster response.

Starter Mix Test 2 - This test utilized 2.27 kg (5 lb) of mix in the high-walled simulated mixer. The purpose of this test was to determine whether the radiative heat reflecting off of the mixer walls back onto the mix would alter the mix's burn characteristics. The mix was placed in a tray and ignited using two electric matches in the bottom center of the mix. Once again, the deluge system was not used; however, the four UV detectors with protective hoods were positioned 1.52 meters (5 ft) away from the mix. The UV detectors saw the fire in 108.3 msec and the primac relay (instantaneous relay) closed 109 msec after ignition, i.e., 0.7 msec after the detectors responded. The mix was consumed in 6.2 seconds and did not appear to burn any differently in the mixer than in a tray.

Starter Mix Test 3 - Test 3 was a deluge extinguishment test involving 4.52 kg (10 lb) of starter mix placed in the simulated mixer. One electric match was placed in the bottom corner of the mix as the ignition source. The four UV detectors equipped with protective hoods were located 1.52 meters (5 ft) away from the center of the mix. The water deluge pump was configured to run at 1800 rpm dynamic, i.e., once the primac valve had opened, at a main water line pressure of approximately 359 kPa (52 psi) dynamic pressure. In this configuration, the pump would deliver approximately 757 liter/min (200 gal/min) through five 15° full cone Full Jet nozzles. Each nozzle was equipped with a blow-off cap allowing the lines to be primed with water to a pressure of approximately 138 kPa (20 psi). Break wires were attached to each blow-off cap thereby allowing for measuring "water-at-the-nozzle" time. The electric matches were fired and the UV detectors sensed the fire in 175 msec. Relay closure occurred approximately at the same time (176 msec) and water was at the first nozzle 314 msec after ignition. Water was delivered to the fire at a rate of 863 liter/min (228 gal/min). The fire was quickly extinguished, and a total burn time was 1.12 sec. Large quantities of unburned mix were washed out of the mixer.

Starter Mix Test 4 - This deluge extinguishment test involved 6.81 kg (15 lb) of starter mix in the simulated mixer. Two electric matches were positioned at the bottom center of the mix. The deluge pump was set at 1800 rpm and four UV detectors with protective hoods were positioned 1.52 m (5 ft) from the mix. The UV detectors saw the fire 256 msec after ignition and closure of the instantaneous (primac) relay occurred within 1 msec from the detectors' response. Water was delivered at a rate of 825 liter/min (218 gal/min) at a main water line dynamic pressure of 366 kPa (53 psi). Water was at the fastest nozzle in 456 msec after ignition; however, one of the blow-off caps did not come off of the nozzle (Nozzle 4). As a result, the deluge successfully extinguished the fire with only four active nozzles. The nozzles had been primed with water at a pressure of 104 kPa (15 psi) prior to the test. Total burn time was calculated at 0.65 sec using the video tape records and quantities of unburned mix were washed over the sides of the mixer.

Starter Test 5 - Test 5 involved 11.35 kg (25 lb) of starter mix in the simulated mixer. Two electric matches were placed at the bottom center of the mix. As in the previous tests, four UV detectors with protective hoods were positioned 1.52 meters (5 ft) away from the mix. The deluge pump was set to deliver approximately 757 liter/min (200 gal/min) through the five 15° full cone Full Jet nozzles and the lines were pre-primed with water at a pressure of 138 kPa (20 psi). The electric matches were fired and the UV detectors responded in 144 msec. The instantaneous relay also functioned in 144 msec after ignition. Water was delivered through the five nozzles at a rate of 840 liter/min (222 gal/min) at a main water line pressure of 338 kPa (49 psi). Water was observed at the first nozzle 167 msec after ignition which was considerably faster than any of the other tests performed. Normally, water is measured at the nozzle approximately 120-150 msec after relay closure. In this test, however, water was at the nozzles 23 msec after relay closure. The fire was very quickly extinguished and total burn time was held down to 1.26 sec. This test was completely successful and large quantities of unburned mix were washed over the side.

Starter Mix Test 6 - The last test performed using the starter mix was performed on 4.54 kg (10 lb) of mix with ignition in the bottom center using electric matches. The deluge pump was set at 1800 rpm dynamic in order to delivery approximately 757 liter/min (200 gal/min). Following ignition, the UV detectors sensed the fire in 163 msec with relay closure also at 163 msec after ignition. Water was delivered through the five nozzles at a rate of 848 liter/min (224 gal/min) at a line pressure of 331 kPa (48 psi). The deluge system recorded water at the fastest nozzle in 292 msec after ignition and almost instantly extinguished the fire. The total burn time for this test was measured as being 0.36 seconds using the video tape record of this test. Large quantities of unburned mix were washed out over the sides of the mixer.

M206 Flare Mix Tests

A total of two preliminary tests and 13 full deluge tests were performed using the M206 mix. The mix consists of magnesium, Teflon, Hycar rubber and methylethylketone (MEK). The following paragraphs describe these tests in detail.

Preliminary Tests

Two preliminary deluge tests were performed to evaluate the overall deluge system response time, as well as check out instrumentation. The tests were performed using 100 grams of M206 mix placed in a large film canister. The four UV detectors were positioned 1.52 m (5 ft) from the mix and ignition was achieved using two electric matches located at the bottom of the mix. In order to facilitate nozzle positioning and test turnaround time, the detectors and the table holding the canister of mix were not positioned directly underneath the deluge nozzles but were offset to the side of the test pad. This offset in no way affected any of the system response times. The following are brief descriptions of these two tests.

1. Preliminary Test 1 - Prior to the test, the pump throttle was set at 2000 rpm which would deliver approximately 757 liter/min (200 gal/min) (once the Primac valve opens, the pump loses approximately 200 rpm; therefore, the pump will be operating at 1800 rpm during the actual test and will deliver about 757 liter/min (200 gal/min)). The 100 grams of M206 was initiated and the UV detectors saw the fire in 72 msec. The mechanical Primac relay closed approximately 13 msec later and water was at the nozzle in 178 msec for nozzle 4 and 200 msec for nozzle 2. Unfortunately, only two of the nozzle break-wire systems, which give water-at-the-nozzle times, functioned, so data were not obtained for the other three nozzles. The flowmeter indicated that 214 gal/min were being delivered at a main line pressure of 44 psi.

2. Preliminary Test 2 - This test was basically a repeat of Test 1; again 100 grams of M206 were used. The mix was ignited using the two electric matches, and the four UV detectors saw the fire in 110 msec. The mechanical Primac relay functioned 12 msec later and water was at the nozzles in 225 msec (nozzles 1 and 3). Nozzle 2 saw water at 230 msec while nozzles 4 and 5 saw water in 250 and 240 msec, respectively. The flowmeter measured 218 gal/min at a line pressure of 304 kPa (44 psi).

In comparison to the tests performed on the previous program using the starter mix, the detector response times and water-at-the-nozzle times were much faster for the M206 tests due to the fact that the M206 mix is a much faster burning mix and burns more vigorously than the starter mix.

Deluge Extinguishment Tests

SwRI performed a total of 13 deluge tests varying the condition of the pyrotechnic mix (dry or wet), the quantify of pyrotechnic mix, and the quantity of MEK. All of the tests were performed in a simulated mix muller. Detailed descriptions of each of the 13 tests are presented in this section of the report.

M206 Mix Test 1 - The first deluge extinguishment test was performed using 2.27 kg (5 lb) of dry mix located in the center of the simulated mix muller. Four UV detectors were placed 1.52 meters (5 ft) away from the mix. Ignition was obtained using two electric matches which were positioned at the bottom center of the mix. The deluge pump was configured to deliver approximately 757 liter/min (200 gal/min) through the five 15" full cone nozzles. The UV detectors saw the fire in 100 msec and closure of the mechanical Primac relay occurred 12 msec later. Water was at the first nozzle in 238 msec and at the last nozzle in 250 msec. The pump delivered water to the fire at a rate of 840 liter/min (222 gal/min) at a main line pressure of 331 kPa (48 psi). A review of the video recording of this test showed that a very large quantity of the M206 mix was consumed before the deluge system activated. In addition, the burning material lofted and was burning about 1.52 to 2.1 meters (5 to 7 ft) above the "mixer." The material that was still in the "mixer" was also burning vigorously. By the time that the water hit the "mixer," it appears that almost all of the mix had been consumed. A post-test inspection revealed that only a very small quantity of residue was at the bottom of the "mixer." The deluge manifold itself was severely burned and all of the nozzle pressure gages were destroyed. Several of the blow-off caps used to prime the nozzles with water were severely scorched. The UV detectors were covered with combustion products and the detector cover caps, i.e., the quartz glass in front of the detector, were completely covered with burned mix. A subsequent inspection of the detector covers and attempts at cleaning the glass showed the quartz glass to be severely pitted. Some of the covers could not be cleaned sufficiently to get all of the combustion products off of the glass and were replaced with new caps.

M206 Mix Test 2 - This test involved 1.36 kg (3 lb) of dry M206 mix centered in the bottom of the simulated mixer at a depth of approximately 3.8 cm (1.5 in.). The purpose of this test was to check out the responses of the UV detectors since for this test, the detectors were outfitted with protective hoods and were positioned 2.44 meters (8 ft) away from the mix. In addition, since this test would not use the water deluge system, it would allow for measuring fireball size as well as total burn time. The matches were fired and the UV detectors saw the fireball within 108.3 msec. For this and subsequent tests, the UV controller was modified to react to a 10 count per second setting instead of the 25 count per second setting previously used. Also, the faster solid state instantaneous relay was used instead of the slower mechanical relay (the mechanical relay takes approximately 12 msec to close once the UV detectors have responded, while the solid state relay only takes about 0.2 msec). The instantaneous relay closed 109 msec after ignition of the matches which was 0.7 msec after the detectors responded. A review of the video tape for this test showed that the fireball was up to the nozzles in approximately 100 msec after ignition of the matches (approximately 1.5 meter (5 ft) high). The bulk of the mix was lofted above the manifold and burned violently. Total height of the fireball was estimated to be about 6.1 meters (20 ft). The bulk of the mix was consumed in about 500 msec, and total burn time, i.e., no noticeable fire, was measured at 1.82 msec. For this particular test, the deluge system would have probably been of little effect since the mix burned so fast and was lofted above the manifold.

M206 Mix Test 3 - This test was a repeat of Test 2; however, for this test, the water deluge system was activated. A total of 1.36 kg (3 lb) of dry M206 mix was placed in the mixer and two UV detectors with protective hoods were placed 1.52 m (5. ft) away, and the other two UV detectors with protective hoods were placed 3.0 meters (10 ft) away. The deluge pump was set at 1800 rpm and the electric matches with 3 cc of MEK to aid in igniting the mix were functioned. The UV detectors saw the fire in 87 msec and instantaneous relay closure also occurred in 87 msec. Water was delivered through the five nozzles at a rate of 829 liter/min (219 gal/min); however, an instrumentation problem precluded the measurement of water-at-the-nozzle times. As was the case in Test 2, the initial fireball climbed up past the nozzles in 100 msec. The bulk of the mix was lofted above the mixer and proceeded to burn above the manifold. The deluge system, however, did seem to have some effect on the fire since it was observed on the video tape that some unburned mix was washed out of the mixer. In addition, the total burn time for this test was 0.7 second. For this test, it appeared that the bulk of the mix was also consumed within the first 500 msec and the effectiveness of the water deluge was again questionable due to the lofting of the mix and the large fireball above the manifold. The fireball was estimated to be about 6.1 meter (20 ft) above the mixer.

M206 Mix Test 4 - This test was a burn test of 2.27 (5 lb) of M206 mix without the water deluge system in an attempt to size the fireball and measure total burn time. The 2.27 kg (5 lb) were placed in the mixer and two electric matches were placed at the bottom center. Three cc of MEK were poured near the matches to assist in igniting the mix. The UV detectors with protective hoods were moved in to within 1.52 meter (5 ft) of the mixer. The UV detectors saw the fire in 100 msec and relay closure also occurred 100 msec after ignition. As was the case in the previous test using dry mix, the bulk of the mix was lofted above the manifold and was consumed 500 msec after ignition of the matches. Total burn time where fire was no longer visible was 1.63 seconds. A review of the video tape for this test showed that the fireball was so fast and so severe that in 210 msec after ignition of the matches the fireball is 2.44 meter (8 ft) high and 1.52 meters (5 ft) wide; in 320 msec the fireball is 3.97 meters (13 ft) high and 2.44 (8 ft) wide and the maximum fireball height is in excess of 6.1 meters (20 ft). Once again, the fire is so fast and since the bulk burns above the manifold, it appears that the deluge has little effect on this type of fire.

M206 Mix Test 5 - This test was performed using 0.454 kg (1 lb) of M206 mix and 0.136 kg (0.3 lb) of MEK (24 percent by weight ratio) to simulate the actual wet mix condition encountered during the mixing process. The wet mix was placed in the simulated mix muller and two electric matches were positioned at the bottom center of the mix. Since this test was run with the water deluge system active, the water pump was pre-set to operate at 1800 rpm dynamic (once the Primac valve has opened). The five 15° full cone Full Jet nozzles were outfitted with blow-off caps and the system was pre-primed with water at 138 kPa (20 psi). Two UV detectors with protective hoods were positioned 1.52 meters (5 ft) from the mix and two UV detectors were positioned 2.44 m (8 ft) from the mix. The electric matches were fired and the UV detectors saw the fire in 213 msec. Instantaneous relay closure also occurred at 213 msec after ignition of the matches. Water was delivered through the five nozzles at a rate of 795 liter/min (210 gal/min) at a main water line pressure of 331 kPa (48 psi). Water was present at the first nozzle (nozzle 4) at a time of 321 msec after ignition. For this test, the deluge system appeared to be effective. Since the material was wet, lofting did not occur and the water was on the fireball before it reached the manifold. The deluge system appeared to control the size of the fireball; however, the material continued to burn vigorously even though it was being drenched with water. The total burn time was measured from the video tape as 11.4 second.

M206 Mix Test 6 - This test involved 1.36 kg (3 lb) of M206 mix and 0.408 kg (0.9 lb) of MEK, simulating wet mixing conditions. The mix was placed in the mixer and two electric matches were used to ignite the mix. The depth of the mix at ignition was approximately 38 mm (1.5 in.). Once again, the two UV detectors were positioned 1.52 meters (5 ft) away from the mix and the other two detectors were positioned 2.44 meters (8 ft) away. The deluge pump was set at 1800 rpm and the manifold system was primed with water at a pressure of 138 kPa (20 psi). The UV detectors responded in 82.4 msec and closure of the instantaneous relay occurred at 82.6 msec. Water was delivered through the five nozzles at a rate of 878 liter/min (232 gal/min) at a main water line pressure of 365 kPa (53 psi). Water was measured at the first nozzle (nozzle 5) in 190 msec. As was the case in Test 5, severe lofting of the material did not occur and the deluge system functioned just prior to the fireball reaching the manifold. Test 3 was a test with 1.36 kg (3 lb) also; however, the material was dry and lofted and burned above the manifold. With the material being wet, the deluge does have a chance at controlling the fire. As was the case in Test 5 with the 0.454 kg (1 lb) wet mix, the material continued to burn even though it was being drenched with water. The simulated mixer appeared to fill with water and some sporadic burning could still be seen. A review of the video tape showed the quantities of unburned mix did wash over the sides of the mixer; however, sporadic burning was evident. The mix burned for a period of 3.85 seconds and a post-test inspection revealed a significant amount of unburned mix still in the mixer and on the floor surrounding the mixer. The test showed that for a wet mix, the deluge does control and eventually extinguishes the fire; however, there still is a rather large fireball at the beginning of the burn.

M206 Mix Test 7 - This test involved 2.27 kg (5 lb) of M206 and 0.680 kg (1.5 lb) of MEK used to wet the mix simulating actual mixing conditions. The wet mix was placed in the simulated mixer at a depth of 38 mm (1.5 in.) to 51 mm (2 in.). Two electric matches were placed at the bottom center of the mix. Two UV detectors with protective hoods were situated 1.52 m (5 ft) away from the mix. The deluge pump was set to operate at 1800 rpm once the primac valve actuated and the five 15° Full Jet nozzles were outfitted with blow-off caps. The lines were also primed with water at a pressure of about 103 kPa (15 psi). The two electric matches were fired and the UV detectors responded in 116 msec. Instantaneous relay closure also occurred at 116 msec. The pump was delivering water at a rate of 825 liter/min (218 gal/min) at a main line pressure of 324 kPa (46 psi). Water was present at the first nozzle 228 msec after ignition of the matches. In this test, the deluge system functioned just as the fireball reached the manifold. The fireball growth was faster than that encountered in the 1.36 kg (3 lb) wet test but much slower than the fireball growth of the dry mix. The deluge system was effective in controlling the fire (with the exception of the initial fireball) and quickly knocked the fire down. The fire continued to burn even though the deluge system was pumping water on it. The mix burned for a total of 22.7 seconds but it was a controlled burn. Post-test inspection revealed a large quantity of residual material inside of the mixer and a large quantity of residual material was also washed out onto the floor.

M206 Mix Test 8 - Test 8 was a test of 4.54 kg (10 lb) of M206 mix and 1.36 (3 lb) of MEK used to simulate the wet mix condition. The mix was wetted with the MEK in the simulated mixer and three electric matches were placed at the bottom of the mix. Two of the UV detectors were positioned 1.52 meters (5 ft) away and the other two detectors were positioned 2.44 meters (8 ft) away from the mix. The pump was configured to operate at 1800 rpm once the Primac valve was opened and the five Full Jet nozzles were outfitted with blow-off caps. The lines were primed with water to the nozzle. The electric matches were initiated and the UV detectors saw the fire in 101 msec. The instantaneous relay closed at approximately the same time (101 msec) and water was present at the first nozzle 231 msec after ignition. Water was delivered at a rate of approximately 825 liter/min (218 gal/min). (Due to electronic problems, the flow was not recorded and was calculated using line pressure.) A replay of the video tape for this test showed that water was on the fireball just before the fireball reached the manifold. As was the case on all of the previous tests with a "wet" mix, the mix continued to burn even though the water was impacting directly on it. The mix burned for a total of 36.2

seconds; however, the burn was a controlled burn. Post-test inspection revealed a considerable amount of unburned residual both in the mixer and on the ground adjacent to the mixer.

M206 Mix Test 9 - This test was a repeat of Test 7 (2.268 kg (5 lb) of M206 mix and 0.680 kg (1.5 lb) of MEK); however, on this test the water application rate was reduced from a targeted 757 liter/min (200 gal/min) to 379 liter/min (100 gal/min). The wet mix was located in the simulated mixer and the UV detectors were positioned as before, two at 1.52 meters (5 ft) and two at 2.44 meters (8 ft). Two electric matches were used to ignite the mix and the pump was configured to operate at 1400 rpm when the Primac valve opened (the pump was set at 1600 rpm with the Primac valve closed). The two electric matches were fired and the UV detectors saw the fire in 112 msec. Relay closure occurred approximately at the same time and water was at the first nozzle at a time of 146 msec. Water was delivered at a rate of 413 liter/min (109 gal/min) at a mainline pressure of 200 kPa (29 psi). Due to the lower water pressure, the second nozzle functioned at 150 msec and the third nozzle at 950 msec. Two nozzle blow-off caps did not come off the nozzles and therefore, the fire was fought with only three nozzles. The fireball eventually reached above the manifold but was much less violent than those observed with the dry mix. The mix continued to burn even though the mixer filled with water and overflowed spilling unburned mix on the ground. The fire was significantly controlled by the deluge even though it did burn for 60.1 seconds which was much longer than any of the other burns. A review of the video tape showed that the reduced water pressure resulted in less unburned material being washed over the side; however, it was noticed that several large chunks of burning material that did wash over burned on the ground for a considerable amount of time and even ignited some of the material being washed over the sides. The deluge system appeared effective in this test because it controlled the fire, with the exception of the initial fireball, even though the burn duration was longer.

M206 Mix Test 10 - Test 10 involved 3.402 kg (7.5 lb) of dry mix and 1.134 kg (2.5 lb) of MEK simulating 4.54 kg (10 lb) of wet mix with a solvent to total wet mix ratio of 25 percent. The 4.54 kg (10 lb) of wet mix was tested in the mixer configuration and two electric matches were used to ignite the mix. The UV detectors were positioned as had been done in the previous tests; two at 1.52 meters (5 ft) and two at 2.44 meters (8 ft). The deluge pump was configured at 2000 rpm static and reducing to 1800 rpm once flow was initiated. The five 15° full cone nozzles were equipped with blow-off caps and were primed with water to a pressure of approximately 103 kPa (15 psi). The electric matches were functioned, the mix ignited and the UV detectors responded in 71.2 msec. Relay closure occurred at 71.2 msec also, and water was at the first nozzle at 176 msec. Water was delivered onto the fire at a rate of 821 liter/min (217 gal/min) at a main water line pressure of 379 kPa (55 psi). The initial fireball was very rapid and had reached and slightly passed the deluge manifold before water was present at the nozzle. There was concern that during the application of the MEK that not all of the mix was wetted and having some dry mix present could account for the rapid fireball growth. The deluge system was effective in controlling the fire and succeeded in knocking down the fireball and controlling the burn. The mix burned for a total of 22 seconds even though the bulk of this burn time occurred with the water impinging directly on the fire and with the mixer full of water. The burning, however, was controlled to occasional flaring and small quantities of ignited mix washed over the side of the mixer.

M206 Mix Test 11 - This test was run to determine what effect a larger ratio of solvent to total mix (34% solvent) would have on the fire and the effectiveness of the deluge. A total of 1.95 kg (4.3 lb) of dry mix were wetted with 1.0 kg (2.2 lb) of MEK and the resulting wet mix was tested in the simulated mixer. Two electric matches were used to ignite the mix and again four UV detectors (two at 1.52 meters (5 ft) and two at 2.44 meters (8 ft)) with protective hoods were used. The deluge pump was set to operate at 1800 rpm flowing through the nozzles and the five nozzles were primed and equipped with blow-off caps. The electric matches were fired and the UV detectors saw the fire in 181 msec. The Primac relay closed at the same time and water was delivered at a rate of 787 liter/min (208 gal/min) at a main water line pressure of 351 kPa (51 psi). Water was present at the first nozzle in 364 msec. A review of the video tape of this test showed that the fireball grew to the left side of the manifold and had almost reached the manifold when the first nozzle activated. The mix burned in the mixer for a total of 13.6 seconds as compared to 22.7 seconds for Test 7 which had a solvent to total weight ratio of 25 percent. A post-test inspection revealed a large amount of residual material which was collected and weighed. The residual mix weighed 1.52 kg (3.35 lb) which indicated that approximately 0.48 kg (1.05 lb) of mix (25%) was consumed in the fire. This would indicate that the deluge system was very effective in controlling the fire.

M206 Mix Test 12 - This test was a repeat of Test 8 (a total weight of 5.9 kg (13 lb) only with a higher solvent ratio then before, i.e., 2.0 kg (4.4 lb) of MEK as compared to the 1.36 kg (3 lb) used in Test 8. The wet mix was tested in the simulated mixer and ignited with three matches at the bottom center of the mix. Four UV detectors were used and the nozzles were primed with water to a pressure of 103 kPa (15 psi). The UV detectors sensed the fire in 238 msec and the Primac relay closed at the same time. Water was present at the first nozzle at a time of 384 msec after ignition of the matches and was being delivered at a rate of 833 liter/min (220 gal/min) at a main water line pressure of 393 kPa (57 psi). A review of the video tape of this test showed that the initial fireball reached the manifold just as the nozzle functioned. The fireball was knocked down with a considerable amount of fire branding and the fire continued to burn in the simulated mixer, but in a controlled state. The fire burned for a total of 7.2 seconds and was limited to occasional flashing and some ignited mix being washed over the side. A post-test inspection showed a very large amount of residual materials which were collected and weighed. The residual mix weighed a total of 3.28 kg (7.24 lb) indicating that of the 3.90 kg (8.6 lb) of mix only 0.64 kg (1.4 lb) were consumed (it was assumed that the bulk of the MEK evaporated so the residuals were actual mix). Once again the deluge appeared to be very effective in controlling the fire (excluding the initial fireball) and limiting the amount of material burned.

M206 Mix Test 13 - Test 13 was a test involving 9.08 kg (20 lb) of total material 5.99 kg (13.2 lb) of mix and 3.13 kg (6.9 lb) of MEK. The wet mix was tested in the simulated mixer and ignited using three electric matches located in the bottom center of the mix. Four UV detectors equipped with protective hoods were used in this test, two detectors at 1.52 meters (5 ft) and two detectors located at 2.44 meters (8 ft). The deluge nozzles were outfitted with blow-off caps and primed to a pressure of 103 kPa (15 psi). The deluge pump was configured and the matches ignited. The UV detectors saw the fire in 72.8 msec with Primac relay closure occurring also at 72.8 msec. Water was delivered at a rate of 840 liter/min (222 gal/min) at a main line pressure of 393 kPa (57 psi) and was present at the first nozzle in 188 msec after ignition of the matches. A review of the video tape showed that the fireball had reached the manifold when the nozzles actuated. Once again, the fire was controlled and limited to burning inside the mixer. The mix burned for a total of 11.8 seconds and a post-test inspection revealed a very large quantity of unburned material in the mixer and on the ground surrounding the mixer. Due to the large quantity of mix dispersed on the ground no efforts were made to collect the residuals; however, it appeared that approximately 80 to 85 percent of the material was not ignited. This test also showed the deluge to be effective in controlling and limiting the fire.

M206 Mix Tests with Lowered Deluge

A total of three tests were performed using small quantities of M206 mix in the simulated mixer and with the deluge manifold lowered by approximately 0.61 meters (2 ft). The manifold was lowered in order to speed up the delivery of water to the fire. With the water exiting the nozzles at a velocity of 19.8 meters/sec (66 ft/sec), the water would reach the fire in approximately 46 msec which was 31 msec faster than the original manifold setup.

Test 14 - The first M206 test performed with the lower manifold involved 0.454 kg (1 lb) of dry M206 mix centered in the simulated mixer. A 5 grain booster of IMR 4227 propellant and an electric match were placed at the bottom center of the mix and were used to ignite the M206. Four UV detectors were placed 1.75 meters (5.75 ft) away from the center of the mixer. The mix was ignited and the UV detectors sensed the fire in 112 msec. The deluge pump delivered water to the fire at a rate of 905 liter/min (239 gal/min) at a main water pressure of 545 kPa (239 psi). Water was present at the first nozzle at a time of 185 msec after ignition of the electric match and booster (73 msec after detection) and water was present at the last nozzle at a time of 223 msec after ignition of the electric match and booster (111 msec after detection). For this particular test, the fireball was above the manifold when the nozzle actuated. As observed in the earlier tests involving the dry M206, the mix tended to loft and burn above the manifold. Even with the nozzles closer to the mix, it does not appear that the deluge is very successful in extinguishing the fire.

Test 15 - This test was a repeat of Test 14 with the exception that the booster and electric match were placed at the top of the mix. The four UV detectors situated 1.75 meters (5.75 ft) away from the center of the mixer detected the fire at 375 msec after ignition. The deluge pump delivered 928 liter/min (245 gal/min) of water to the fire and at a line pressure of 573 kPa (83 psi). Water was present at the nozzle 494 msec after ignition of the match (119 msec after detection) and present at the slowest nozzle at a time of 500 msec after ignition of the match (125 msec after detection). A review of the video tape recording of this test showed that the water was flowing out of the nozzles before the fireball rose above the sides of the mixer. The water deluge system had such an excellent jump on the fire, that the burning mix was not able to loft above the manifold and was extinguished almost immediately.

Test 16 - Test 16 was performed using 1.59 kg (3.5 lb) of dry M206 mix in the simulated mixer. On this particular test, a failure of a blow-off cap due to excessive priming pressure occurred and the mix was thoroughly wetted with water. The booster and electric match were replaced and the new one was placed at the bottom center of the water wet M206 mix and functioned. The M206 mix ignited and the UV detectors sensed the fire in 99 msec after ignition. The deluge pump delivered 882 liter/min (233 gal/min) of water to the fire at a line pressure of 524 kPa (76 psi). Water was present at the first nozzle at 149 msec after ignition of the electric match and booster (50 msec after detection) and at the slowest nozzle at 182 msec after ignition of the electric match and booster (83 msec after detection). Even though the M206 mix was initially wet with water, the mix ignited rapidly and the fireball was above the manifold when the nozzles functioned. The burning mix lofted above the manifold and burned violently to a height of about 4 meters (13 ft) above the mixer. This test showed that the lowered manifold is not effective in extinguishing the dry M206 mix when ignited at the bottom. Some control on the fire is obtained but the initial fireball is so severe that the deluge's overall effectiveness is minimal.

MK45 Flare Mix Tests

Four preliminary and fifteen full deluge tests were performed using the MK45 mix. The mix consists of magnesium, sodium nitrate and an epoxy binder. The MK45 mix was blended without the hardener portion of the epoxy binder in order to ensure that the mix would not set and harden during shipment to SwRI. It was felt that although this mix did not simulate the material that exists during actual mixing operations, it did represent as close as possible the fire hazard that exists during the mixing process without actually carrying out the fire suppression tests during the actual mixing process itself.

Preliminary Tests

A total of four preliminary tests were performed to allow for familiarization with the burn characteristics and ignition sensitivity of the mix. In addition, these tests allowed for the evaluation and check out of the deluge system and recording instrumentation. The first three preliminary tests were performed without the deluge system operable and were primarily designed to evaluate the UV response time. The MK45 mix was found to be very difficult to ignite using electric matches only. A booster consisting of one electric match and 5 grains of IMR 4227 smokeless propellant was therefore used to ignite the mix. Tests were run using the booster by itself with 2 UV detectors to confirm that the booster itself would not function the deluge system and the two UV detectors could not detect the booster functioning.

Test 1 - Preliminary test 1 consisted of 150 grams of mix ignited by a booster located at the bottom center of the mix. The resultant pyrotechnic fire was sensed by the two UV detectors situated 1.83 meters (6 ft) from the mix in 510 msec.

Tests 2 and 3 - The second and third preliminary tests were performed using 300 grams (0.66 lb) of mix and boosters located at the bottom center of the mix. The two UV detectors sensed the fire for tests 2 and 3 in 366 msec and 367, respectively.

Test 4 - The fourth preliminary test was performed using 0.9 kg (2 lb) of mix and utilized the full deluge system. The two UV detectors were again situated 1.83 meters (6 ft) from the center of the mix and initiation was achieved using a booster placed at the bottom center of the mix. The UV detectors detected the fire in 846 msec which was considerably longer than in any of the other tests. The first nozzle to function did so at 958 msec after initiation of the booster (112 msec after the detectors saw the fire), and the last nozzle functioned at 972 msec after initiation of the booster. Water was delivered at a measured rate of 746 liter/min (197 gal/min). A review of the video tape of the test showed that the mix burned rather slowly and that water was at the nozzle prior to the fireball itself reaching the nozzle manifold. The fire was quickly knocked down and extinguished by the water.

Deluge Extinguishment Tests

SwRI performed a total of 15 deluge tests varying the quantity of pyrotechnic mix, the shape of the pile of mix (cone-shaped or flat) and water application rates. All of these tests were performed using the simulated mix muller. The first test was performed using two UV detectors located 1.82 meters (6 ft) from the mix; however, all subsequent tests were performed using four UV detectors; two located 1.82 meters (6 ft) away and two detectors 2.44 meters (8 ft) away from the center of the mix. Prior to using the four UV detectors, tests were performed using only the booster to see if the detectors could see the booster function and they indeed could (approximately 150 msec). Tests were then performed on boosters which were covered with inert pyrotechnic material simulants to see if the detectors could pick up the booster and the UV detectors could not. It was therefore decided to continue to use the booster located at the bottom of the mix and four UV detectors to sense the fire.

Test 1 - Test 1 consisted of 0.9 kg (2 lb) of mix in a cone shape located in the center of the simulated mix muller. The two UV detectors were situated 1.82 meters (6 ft) from the mix and a booster was placed at the bottom center of the mix. The deluge pump was configured to deliver approximately 757 liter/min (200 gal/min) of water through the five 15° full-cone nozzles. The booster was initiated and ignited the mix. The fire itself was detected in 416 msec and water was at the first nozzle 519 msec after ignition of the booster. Water was delivered at a rate of 729 liter/min (193 gal/min) and at a main water line pressure of 426 kPa (61.7 psi). The video tape of this test showed that the water was again at the nozzles prior to the fireball reaching the manifold and the water deluge very effectively knocked down the fire and quickly extinguished it. Total burn time was calculated from the video recording and was 1.54 second.

Test 2 - Test 2 was a repeat of the first test with the difference being that the pile of mix was flattened out with a thickness of approximately 2.54 cm (1 in.) instead of cone shaped, and four UV detectors were used instead of two. An electric match and a 5 grain smokeless propellant booster were placed at the bottom center of the mix and were used to ignite the mix. The deluge pump was configured to deliver approximately 757 liter/min (200 gal/min) of water through the five nozzles. The booster was initiated and the UV detectors sensed the fire in 793 msec which is considerably slower than on the previous tests. Water was delivered to the fire at a rate of 848 liter/min (224 gal/min) at a main lines pressure of 433 kPa (62.7 psi) and water was present at the nozzle 942 msec after ignition of the booster (149 msec after the UV detectors saw the fire). The fireball itself was quickly knocked down and extinguished. A total burn time calculated from the video recording of this test was calculated at 1.5 seconds.

Test 3 - The third test performed using the MK45 mix consisted of 1.23 kg (2.7 lb) of mix placed in the simulated mixer spread out in a flat shape. The mix was ignited using an electric match and a 5 grain smokeless powder booster located at the bottom of the mix. Two UV detectors were located 1.82 meters (6 ft) from the center of the mix and two UV detectors were placed 2.44 meters (8 ft) from the center of the mix. Once again, the deluge pump was configured to deliver 757 liter/min (200 gal/min) of water. The mix was initiated and the fire was detected 287 msec after ignition of the booster which was much faster than the previous test. Water was present at the first nozzle at 387 msec after booster initiation and present at the last nozzle at 393 msec after booster initiation. Water was being delivered to the fire at a rate of 787 liter/min (208 gal/min) and at a main water line pressure of 454 kPa (65.8 psi). A review of the video recording of this test showed that the water was present at the nozzle prior to the fireball reaching halfway up to the manifold. The fireball was very quickly controlled and extinguished. This test showed the deluge to be be very effective in controlling this size of fire.

Test 4 - The fourth test was conducted using 1.36 kg (3 lb) of mix placed in the simulated mixer in a cone shape. The electric match and booster were placed at the bottom center of the cone of material. Four UV detectors were used on this test, two detectors 1.82 meters (6 ft) away and two detectors 2.44 meters (8 ft) away. The booster was remotely initiated and the UV detectors sensed the fire 411 msec after ignition. The deluge pump was delivering water to the fire at a rate of 306 liter/min (213 gal/min) through the five nozzles, and at main water line pressure of 471 kPa (68.3 psi). Water was present at the quickest nozzle at a time of 510 msec after booster initiation and present at the slowest nozzle at a time of 518 msec after booster initiation. A review of the video record for this test showed that the water was at the nozzles prior to the fire reaching the manifold. The fire itself was quickly extinguished by the deluge and total burn time was calculated to be 1.17 seconds.

Test 5 - Test 5 was performed using 2.27 kg (5 lb) of mix centered in the simulated mix muller. The mix was placed in a cone shape with the electric match and booster located in the bottom center of the mix. The mix was remotely ignited and detection by the UV detectors occurred 434 msec after ignition. The deluge pump delivered water to the fire at a rate of 806 liter/min (213 gal/min) through the five nozzles and at a main water line pressure of 460 kPa (66.7 psi). Water was present at the first nozzle at a time of 521 msec after ignition of the electric match and booster. Water was at the nozzle at approximately the same time that the fireball reached the manifold, and even though the water was being applied the mix continued to burn for approximately 1.59 seconds. The resultant fireball and smoke cloud enveloped the manifold and rose approximately 1.82 meters (6 ft) above the manifold. The deluge did eventually extinguish the fire as evidenced by an amount of unburned residual mix still in the mixer.

Test 6 - The sixth test performed also used 2.27 kg (5 lb) of mix in a cone shape. The electric match and booster were placed at the bottom center of the mix and the four UV detectors were positioned. The booster was ignited and the four UV detectors sensed the fire in 447 msec after ignition. The deluge delivered 825 liter/min (218 gal/min) of water at a main water line pressure of 466 kPa (67.5 psi). Water was present at the first nozzle 527 msec after booster ignition and present at the last nozzle in 542 msec after booster ignition. A review of the video tape recording of this test showed that the fireball was approximately three-fourths of the way up to the manifold before the water was at the nozzles. As was the case in the previous test, the fire continued to burn even though the water was being applied (the fire burned for approximately 2.0 seconds) and the resultant fireball enveloped the manifold. The fireball rose to a height of about 1.82 to 2.44 meters (6 to 8 ft) above the manifold. A post-test inspection of the mixer showed an amount of unburned material in the mixer and on the floor around the mixer, indicating that the deluge did in fact control the burn.

Test 7 - Test 7 was another repeat test using 2.27 kg (5 lb) of mix. All initial conditions were identical to those of the previous tests and following ignition of the booster, the UV detectors sensed the fire in 431 msec. Water was delivered through the five nozzles at a rate of 806 liter/min (213 gal/min) at a main water line pressure of 460 kPa (66.7 psi). Water was present at the first nozzle at a time of 516 msec after ignition of the booster and present at the last nozzle 533 msec after booster ignition. The fireball had risen up almost to the manifold when the water started coming out of the nozzles. The mix burned for approximately 1.66 sec under the water deluge and once again the resultant fireball enveloped the manifold. It appears that the fireball rose to a height of approximately 1.82 meters (6 ft) above the manifold. A post-test inspection of the mixer and the surrounding area again revealed a quantity of unburned mix. It appears from the results of this test and the two previous tests, that the deluge does extinguish the fire with some unburned mix left; however, there is a sizeable fireball that must be contended with.

Test 8 - Test 8 was performed using 2.27 kg (5 lb) of mix; however, for this test, the mix was flattened out to a thickness of about 3.8 cm (1.5 in.). The electric match and booster were placed in the bottom center of the mix and the four UV detectors were positioned. Following ignition of the mix, the UV detector sensed the fire in 466 msec. Water was delivered through the five nozzles at a rate of 825 liter/min (218 gal/min) at a line pressure of 483 kPa (70 psi). Water was present at the first nozzle in 531 msec and present at the last nozzle in 551 msec after ignition of the electric match and booster. On this test, the fireball barely got over the mixer sides before water was at the nozzles. The fire burned for 1.67 sec and rose only up to the manifold before it was knocked down and extinguished. A number of large firebrands were observed on this test. A post-test inspection revealed a considerable amount of unburned material both in the mixer and on the ground. The deluge appears to be much more effective in controlling this fire and this is probably due to the mix being flat and not conical. The cone-shaped tests allow a much larger amount of mix to become involved before the deluge functions than does the flat tests. Since there is less mix initially involved in the flat test, the deluge has a much better chance at extinguishing the fire as evidenced by this test.

Test 9 - This test was a repeat of the previous test with the mix in a flat condition. The electric match and booster were placed at the bottom center of the 2.27 kg (5 lb) mix. Following ignition of the mix, the UV detectors sensed the fire in 339 msec which was approximately 25% faster than the previous test. Water was delivered at a rate of 825 liter/min (218 gal/min) through the five nozzles at a main line water pressure of 449 kPa (65 psi). Water was present at the first nozzle at a time of 422 msec after ignition of the match and booster and at the last nozzle at 444 msec after ignition of the electric match and booster. The fire burned for approximately 2 seconds and the fireball had risen halfway up to the manifold when the nozzles actuated. As was the case in Test 8, the resultant fireball was not as large as was the case with the cone-shaped tests. The fireball reached the manifold and was then extinguished. Some firebrands were observed in this test and a post-test inspection showed a significant amount of unburned mix in the simulated mixer and on the ground. The deluge system proved to be very effective in this particular test.

Test 10 - Test 10 was a repeat of test 7 with 2.27 kg (5 lb) of mix in a cone shape. However, for this test, the pump was configured to deliver a higher rate of water, approximately 1022 liter/min (270 gal/min). The mix was ignited using an electric match and a 5 grain smokeless booster. Four UV detectors were used in this test, two detectors 1.83 meters (6 ft) away and two detectors 2.44 meters (8 ft) away. The deluge lines were primed to the nozzles with water at a pressure of 138 kPa (20 psi); however, just prior to ignition, the center nozzle blow-off cap came off releasing the "priming" water. Rather than abort the test, the mix was ignited and detection occurred 600 msec after ignition of the electric match and booster. The deluge pump delivered water through the nozzles at a rate of 988 liter/min (261 gal/min) at a line pressure of 656 kPa (95 psi). Since the blow-off cap on the center nozzle came off prematurely, a water at the nozzle time for the center nozzle was not measured. Water was present at the second nozzle at 675 msec after ignition of the electric match and booster (75 msec after the detector saw the fire). The water at the nozzle time was comparable to that of the previous tests; therefore, not having water up to the nozzles did not really affect this test. The resultant fireball was three-fourths of the way up to the nozzles when the remaining four nozzles with caps functioned. The center nozzle without the cap started spraying water on the fire approximately 40 msec before the other four nozzles. The fireball rose slightly above the manifold before it was finally extinguished and the total burn time as measured from the video recording was 1.55 sec. This test was similar to the previous tests with the mix in a cone shape, in that the fireball continued to rise even though water was being applied and eventually rose above the manifold.

Test 11 - This test was performed using 4.54 kg (10 lb) of mix in a flat configuration. The mix was centered in the simulated mix muller and was approximately 5.08 cm (2 in.) deep. The deluge pump was again configured to deliver the larger quantities of water, i.e., 1022 liter/min (270 gal/min), and again four UV detectors were used. The mix was ignited using an electric match and a booster centered at the bottom of the mix. The lines were primed with water to the nozzle at a pressure of 138 kPa (20 psi). The UV detectors sensed the fire 721 msec after ignition, and water was delivered to the fire at a rate of 988 liter/min (261 gal/min) through the five nozzles. Main water line pressure was measured at 662 kPa (96 psi) which is close to the safe maximum for the PVC used in the deluge system. Water was present at the first nozzle at 801 msec after ignition (80 msec after the detectors saw the fire). The fire burned for approximately 3 sec and the fireball had risen one-third of the way up to the manifold at the time that the water functioned. The fireball never got any higher than two-thirds of the way up to the manifold and was quickly knocked down. The fire, however, did continue to burn in the mixer for some time before the fire was extinguished. This test appeared to be the most successful of all the tests.

Test 12 - Test 12 was performed using 4.54 kg (10 lb) of mix spread out in the mixer in a flat shape approximately 3.8 cm (1.5 in.) thick. The electric match and 5 grain booster were placed at the bottom of the mix. Two UV detectors were placed 1.82 meters (6 ft) and two UV detectors were placed 2.44 meters (8 ft) away. The mix was initiated remotely and the UV detectors sensed the fire in 829 msec after ignition of the match. The deluge pump delivered water to the fire at a rate of 924 liter/min (244 gal/min) and at a main water line pressure of 587 kPa (85 psi). Water was present at the fastest nozzle at a time of 882 msec after ignition of the electric match and booster and at the slowest nozzle at 934 msec after ignition of the electric match and booster. A review of the video tape recording of this test showed that the fire was 0.75 meters (2.5 ft) above the bottom of the mixer at the time that water was first present at the nozzles. The water did control the fire even though there was a significant initial fireball. The fireball was estimated to be approximately 2.44 meters (8 ft) high. Total burn time for this test was 2.77 seconds. A post-test inspection revealed unburned material both in the simulated mixer and on the ground adjacent to the mixer.

MK45 Flare Mix Tests With Lowered Deluge - A total of three additional deluge tests (No. 13-15) were performed using the MK45 mix in the simulated mix muller. Tests 13-15 were performed with the deluge 0.61 meters (2 ft) closer to the mixer. The velocity of the water as it exited the nozzle was calculated to be approximately 19.8 meters/sec (65 ft/sec). The time required to travel the 1.52 meters (5 ft) from the nozzle to the mixer for the standard deluge setup was approximately 77 msec which agreed with the times measured off of the video tape recordings for several tests. By lowering the deluge manifold 0.61 meters (2 ft), the time for water to reach the bottom of the mixer was shortened by 31 msec. Detailed descriptions of the three tests are given in the the following paragraphs.

Test 13 - This test was the first test performed with the lower deluge manifold. The manifold was positioned 0.91 meters (3 ft) above the bottom of the mixer bowl. This test utilized 2.27 kg (5 lb) of the MK45 mix spread out in a flat shape approximately 3.8 cm (1.5 in.) deep. The electric match and booster were placed at the bottom of the mix. The four UV detectors were placed at a distance of 1.75 meters (5.75 ft) away from the center of the simulated mixer. The mix was initiated remotely using an electric match and a 5 grain booster of smokeless propellant. The UV detectors sensed the fire in 520 msec and the deluge pump delivered water to the fire at a rate of 943 liter/min (249 gal/min) at a main line pressure of 545 kPa (79 psi). Water was first present at the nozzle at a time of 575 msec after booster ignition. Water was present at the last nozzle at 590 msec after booster ignition. For this particular test, the fire was approximately 0.46 meters (1.5 ft) above the bottom of the mixer when the water activated. The maximum fireball height was measured from the video tape recording and measured 0.91 meters (3 ft). Total burn time for this test was 0.98 seconds and a post-test inspection revealed large quantities of unburned mix still in the mixer and on the ground.

Test 14 - This test was performed using 2.95 kg (6.5 lb) of mix placed in a cone shape in the simulated mix muller at a height of approximately 10 cm

(4 in.). This test was performed with the lower manifold and with the four UV detectors placed at a distance of 1.75 meters (5.75 ft) away from the center of the simulated mixer. The mix was initiated using an electric match and a booster and the UV detectors sensed the fire 381 msec after booster initiation. The water was delivered at a rate of 882 liter/min (233 gal/min) at a main water line pressure of 531 kPa (77 psi). Water was first present at the nozzles at 432 msec after booster ignition and at the slowest nozzle at 503 msec after booster ignition. A review of the video tape showed that the fire was 0.91 meter (3 ft) above the bottom of the mixer when the water actuated at the fastest nozzle. The ensuing fireball was very large and violent and was estimated to be approximately 6 meters (20 ft) above the mixer. The total burn time for this test was 1.18 seconds. A post-test inspection, however, revealed small quantities of unburned mix still in the mixer and on the ground where the deluge blew it out of the mixer. Although there was a severe initial fireball, the deluge did in fact put the fire out before all of the mix was consumed; however, its effectiveness can be questioned because of the severity of the initial fireball.

Test 15 - Test 15 was performed using 4.54 kg (10 lb) of mix spread out in the simulated mixer at a height of about 3.8 cm (1.5 in.). This test was also performed with the lower manifold and the UV detectors at 1.75 meters (5.75 ft). The electric match and booster were functioned, igniting the mix and the UV detectors sensed the fire in 283 msec which was the fastest response of any of the previous tests. Water was delivered to the fire at a rate of 924 liter/min (244 gal/min) at a main water line pressure of 587 kPa (85 psi). Instrumentation problems precluded the recording of the water-at-the-nozzle times; however, they were estimated using the video recording of the test. The time of the fastest nozzle to respond was estimated to be 360 msec after ignition of the electric match or 78 msec after the UV detectors sensed the fire. The slowest nozzle had water present 400 msec after ignition or 118 msec after the detectors sensed the fire. For this test, the response of the deluge was so fast that fire was not visible over the side of the mixer which is 25.4 cm (10 in.) high. The water almost immediately extinguished the fire and flames were never visible. On this test, the deluge performed superbly and easily extinguished the fire without the formation of any kind of fireball.

Smoke Mix Tests

Green Smoke Mix

Two tests involving the green smoke mix were performed with the mix in the simulated mix muller. Details on these tests are presented in the following paragraphs.

Test 1 - The first test involved 4.54 kg (10 lb) of mix placed in the center of the simulated mix muller. The smoke mix was ignited using an electric match and a 5 grain smokeless propellant booster. Since the purpose of this test was to determine if the four UV detectors would see the fire, the water deluge was not used. Following ignition, the smoke mix continued to burn routinely and generated considerable amounts of smoke. At approximately 63 seconds after ignition, the UV detectors detected fire and a check of the video recording of the test showed a considerable amount of flame present for a very short period. The UV detectors were reinitialized and the mix continued to burn for approximately another two minutes and during this time no flames were visible or detected by the UV detectors. Once the bulk of the smoke mix was consumed the UV detectors picked up the red hot residuals.

Test 2 - A second test using 2.27 kg (5 lb) of green smoke mix was performed to determine whether the UV detectors would see the fire in a smaller involvement. The mix was again ignited using an electric match and a 5 grain smokeless propellant booster located at the bottom center of the mix. The mix ignited producing a considerable amount of smoke and the UV detectors never sensed any fire. Once the bulk of the mix was consumed and the smoke had diminished considerably, the UV detectors sensed the burning residuals or ashes. Detection time occurred 118 sec after ignition at which time the bulk of the smoke mix had been consumed.

Yellow Smoke Mix

A total of three tests were performed using the Yellow Smoke Mix in the simulated mix muller. Details on these tests are presented in the the following paragraphs:

Test 1 - The first test performed using the yellow smoke mix involved 2.27 kg (5 lb) of mix in the simulated mix muller. The purpose of this test was to determine whether the UV detectors could detect any fire, and therefore, the deluge system was not armed. The mix was ignited using an electric match and a 5 grain smokeless propellant booster. Four UV detectors were positioned, two detectors at 1.82 meters (6 ft) away from the mix and two detectors at 2.44 meters (8 ft) away from the mix. The mix was ignited and it started producing quantities of thick yellow smoke. At approximately 35 seconds after ignition the detectors sensed the fire. At the same time, the smoke changed colors from a thick yellow to a thick black smoke. The smoke continued to burn for an additional 113 seconds. Once the bulk of the mix was consumed, the smoke changed colors back to yellow for a few seconds before totally going out.

Test 2 - The next test performed utilized 4.54 kg (10 lb) of yellow smoke mix placed in the mixer. The purpose of this test was to determine whether the four UV detectors would sense a large fire faster than they did the smaller fire in test 1. The mix was again ignited using an electric match and a smokeless propellant booster. The four UV detectors were positioned with two detectors 1.82 meters (6 ft) from the mix and the other two detectors 2.44 meters (8 ft) from the mix. On ignition, the mix started generating quantities of yellow smoke. Shortly after ignition, the smoke turned darker (almost black) and fire was visible. The UV detectors sensed the fire 10.7 seconds after ignition. The mix continued to burn for a total of 2 minutes and 35 seconds and flames were intermittently visible. As the fire died down due to the bulk of the mix being consumed, the color of the smoke changed back to yellow. It appears that in an unconfined state, the rate of combustion of the mix increases as evidenced by the sudden emergence of visible fire and the change in color. As the mass burning rate decreases due to the bulk of the mix being consumed, the mix starts burning normally as evidenced by the change in color back to yellow.

Test 3 - This test was a repeat of the first test with 2.27 kg (5 lb) of mix only this time the deluge system was activated. The mix was centered in the mixer and ignition was achieved using an electric match and a smokeless propellant booster. The pump was configured to deliver 757 liter/min (200 gal/min). The mix was ignited and the UV detectors sensed the fire at 32 seconds. Water was delivered to the fire at a rate of 624 liter/min (165 gal/min) through four of the nozzles. (The blow-off cap on one of the nozzles did not come off.) Main line water pressure was measured to be 426 kPa (61.7 psi). The smoke mix fire was quickly extinguished and a significant amount of residual material was left. Water was present at the first nozzle 86 msec after the UV detectors sensed the fire. Water was present at the fourth nozzle 133 msec after detection of the fire.

HC Smoke Tests

Three preliminary tests using the HC smoke mix were performed to determine whether the UV detectors would detect any fire. As previously mentioned, considerable difficulty was encountered in igniting the HC mix. A number of different booster charges were tried and ultimately a booster consisting of 5 grains of starter mix was successful in igniting the HC smoke mix. The booster itself was ignited using an electric match. A number of tests were performed using only the electric match and the starter mix booster to determine whether the UV detectors would sense the booster. A total of nine tests with just the booster were performed and the UV detectors sensed all the fires. The fastest detection of the booster occurred at 132 msec, and the slowest detection occurred at 340 msec after ignition. The average response time was 175 msec after ignition.

The three tests performed using the HC smoke mix were performed with the electric match and booster placed at the bottom of the mix. The UV detectors sensed the fire in each test and the detector response times were 425 msec, 458 msec and 423 msec after ignition, respectively. In each test, a considerable amount of fire was present.

Tests with Dual Mode UV/Smoke Detector

A number of tests were performed using the prototype Det-Tronics Corp. detector. Since this system will annunciate the presense of fire and of smoke individually, both output channels were recorded for each test. A number of preliminary tests using green, yellow, and HC smoke were performed. Since the emphasis of these tests was to measure detector response time, the water deluge system was not put into operation for these tests. The following paragraphs describe the tests performed.

Booster Tests

In order to ensure that the dual mode UV/smoke detector would not respond to the fire produced by the booster (5 grains of starter mix), tests were performed using the booster by itself, and then with the booster covered by a quantity of inert material simulating the smoke mix. Tests with the booster and electric match by themselves resulted in actuation of the detector. However, when the booster was covered with approximately 0.454 kg (1.0 lb) of inert material, the dual mode detector did not see actuation of the booster. It was therefore decided that all smoke tests would be performed with the 5 grain starter mix booster at the bottom of the mix.

Green Smoke Test 1 - The first test performed using the green smoke mix involved 0.454 kg (1 lb) of mix centered in the simulated mix muller. The dual mode detector located directly above the mixer was 0.91 (3 ft) away from the mix. The 5 grain starter mix booster and electric match were centered at the bottom of the pile of mix. The booster was remotely functioned and the smoke ignited. The smoke cloud became very thick and rose straight up engulfing the detector. The thickness and obscurity of the smoke cloud fooled the detector into "thinking" that the optics were dirty and the controller responded with a smoke "fault" instead of the expected smoke "alarm." Once the controller has issued a smoke "fault" it ignores any smoke detector inputs and will only recognize a "fire alarm." Fire was never detected throughout the duration of the test. The detectors being fooled by a very thick and obscure smoke cloud could pose a problem in a closed mixing bay in that the controller will think that the optics are dirty and will ignore the smoke detector inputs. If flame is not visible by the UV portion of the detector the deluge system will not be activated.

Green Smoke Test 2 - The second test was a repeat of Test 1 except that this test used 0.91 kg (2 lb) of mix. The booster was functioned igniting the smoke and once again a very dense smoke was produced. As was the case in Test 1, the controller was fooled by the thick smoke into thinking that the optics were dirty and a smoke "fault" condition was issued instead of the smoke "alarm" which would have functioned the deluge. The UV portion of the detector did not see any fire.

Yellow Smoke Test 1 - The first test using the yellow smoke involved 0.225 kg (0.5 lb) of smoke centered in the mixer. The dual detector was again placed above the mix at a distance of 1 meter (3 ft). A 5 grain starter mix booster was placed at the bottom of the mix and ignited. The subsequent smoke rose and engulfed the detector resulting in a signal of "fire" in 470 milliseconds after ignition. The detector sensed a "smoke alarm" at a time of 71.4 seconds after ignition.

Smoke Mix Tests in an Enclosed Bay

One of the test facilities at SwRI was modified to simulate a typical bay for use in testing of the smoke mixes and the dual mode UV/smoke detector. The bay is 3.4 meters wide (11 ft), 3.7 meters long (12 ft) and 2.4 meters deep (8 ft). One of the sides of the bay was covered with a clear polyethylene sheet to allow for visual observation of the smoke being generated. Tests were performed using all three smoke mixes, i.e., yellow, green, and white and five different detector positions were used: the detector centered over and looking at the mix, the detector mounted across the top of the doorway, the detector mounted across the top of the outer wall covered by plastic, the detector mounted above and across the smoke mix, and the detector mounted at the top of the back wall. Since the primary emphasis of these tests was to determine the detector's ability to sense smoke, the UV portion of the detector was not positioned facing the burning mix in the majority of the tests. The following paragraphs summarize the results of the tests performed:

Detector Centered Over and Facing Mix

Three tests using 0.454 kg (1 lb) of yellow smoke mix were performed with the detector positioned at the roof of the bay and facing the mix. The mix was ignited using a 5 grain starter mix booster comprised of starter mix and an electric match. The booster was placed at the bottom of the mix and ignited remotely. In all three tests, the UV portion of the detector sensed a fire (30.0 sec, 194.5 sec, and 11.6 sec, respectively). The "smoke" portion of the detector, however, was fooled by the large quantity of smoke produced and in all tests a "smoke fault" was triggered indicating the optics were dirty and the expected smoke "alarm" was never issued by the detector/controller.

Detector Positioned Across Door

The detector was repositioned over the door and oriented facing across the door instead of facing the mix. A total of four tests were performed, two tests using 0.454 kg of yellow smoke mix, and one test using 0.454 kg (1 lb) each of the green and white smoke mixes. In all tests, the mix was ignited using a 5 grain starter mix booster and an electric match with the booster placed at the bottom of the mix. Upon ignition, the smoke mixes produced large quantities of smoke filling up the bay and subsequently venting through the doorway. In the first yellow smoke mix test, the combined UV/smoke detector issued a smoke "alarm" 33.0 seconds after ignition. At the time that the smoke "alarm" was issued, the yellow smoke had just started to vent through the door and was not very thick. The detector/controller was reset and as the venting smoke started to thicken, the detector/controller started issuing smoke "faults" indicating the optics were dirty. The second yellow smoke mix test was a repeat test; however, on this test the detector/controller issued smoke "faults" due to the thick smoke. It was not until the mix had quit burning and the smoke had thinned out almost completely that the detector/controller issued a smoke "alarm." The alarm occurred 129.2 seconds after ignition.

The test with the green smoke mix utilized 0.454 kg (1 lb) of mix ignited using a 5 grain starter mix booster and an electric match yielded similar results to the second yellow smoke test with the detector/controller issuing numerous smoke "faults" during burning of the mix. Again the detector/ controller did not issue a smoke "alarm" until after all burning had been completed and the bay was clearing out. The smoke alarm occurred at 141.2 seconds after ignition.

The test performed with 0.454 kg (1 lb) of the white smoke mix resulted in continuous erroneous smoke "faults" and no smoke alarms. After each smoke fault issued by the detector/controller, the system was reset and a total of 30 smoke "faults" were issued during this test.

Detector Positioned on Outside Wall

The UV/smoke detector was relocated to the top of one of the outside walls. For this position, two tests were performed using the green and yellow smoke mixes. Both tests involved 0.454 kg (1 lb) of mix ignited by an electric match and booster placed at the bottom of the mix. The test on the green smoke resulted in a total of 11 erroneous fault indications and the appropriate smoke alarm was never issued. The test with the yellow smoke also resulted in numerous smoke "fault" indications; however, a smoke alarm signal was issued 179 seconds after ignition. This alarm was issued after all the smoke mix had been consumed and the bay was clearing out.

Detector Positioned Over and Across Mix

The UV/smoke detector was moved and positioned over the smoke mix; however, this time the UV detector was not positioned facing the smoke mix. Tests were performed using 0.454 kg (1 lb) quantities of the green, yellow, and white smoke. On all tests, the UV/smoke detector issued numerous erroneous smoke "fault" and flame "fault" indications. The detector/controller did not issue the correct smoke "alarm" until after the individual smoke materials had been consumed and the bay was clearing out.

Detector Positioned on Back Wall

The last detector position tested had the detector mounted at the top of the back wall. Once again, the three smoke mixes, i.e., yellow, green and white were tested and test quantities of 0.454 kg (1 lb) were used. As in the previous tests, a number of false smoke "faults" were issued by the detector/controller and legitimate smoke "alarms" were not issued until after the bulk of the smoke material was consumed and the bay was airing out.

DATA ANALYSIS

As previously mentioned in this report, a number of pertinent parameters were recorded for each of the tests performed. For each material tested, the key parameters recorded included the following: quantity of pyrotechnic material involved, condition of the material (with solvent/binder or dry), water line pressure, water application rate and spray pattern, detector response time, water actuation time, water at the nozzle time, water on the fire time and total burn time. This section of the report presents the analysis of the deluge test data recorded for each of the materials tested.

Starter Mix

A table summarizing the results of the six deluge tests performed using the starter mix has been prepared and is included here as Table 7. As shown in Table 7, the time required for the UV detectors to sense the fire ranged from a minimum of 108 msec for Test 2 to a maximum time of 256 msec for Test 4, with an average time being 178 msec after ignition. Since the controller system was equipped with a solid state relay instead of a mechanical relay, the Primac valve received the actuation signal within a millisecond and therefore, the detector time and Primac valve actuation time were considered to be the same. Water at the nozzle time varied between a minimum of 23 msec for Test 5 and a maximum of 200 msec for Test 4 after detector response. The average water-at-the-nozzle time for the four tests performed with the water deluge was 122 msec after detector response. The average water-at-the-nozzle time for the deluge test using the same starter mix performed in the earlier program* was 127 msec after UV detector actuation so the data agreed very well.

Table 7. Test Summary of Starter Mix

Test No.	Charge Size kg (lb)	Igniter	Engine rpm	Line Press kPa (psi)	Detector Time (msec)	Flow lit/min (gal/min)	Water Nozzle (msec)	Burn Time (sec)
1	100 gm	2 EM	N/A	N/A	222	N/A	N/A	2.53
2	2.27 (5)	2 EM	N/A	N/A	108.3	N/A	N/A	6.16
3	4.54 (10)	1 EM-BTM Corner	1800	359 (52)	176	863 (228)	314	1.12
4*	6.81 (15)	2 EM-BTM Center	1800	366 (53)	256	825 (218)	456	0.65
5	11.35 (25)	2 EM-BTM Center	1800	338 (49)	144	840 (222)	167	1.26
6	4.54 (10)	2 EM-BTM Center	1800	331 (48)	163	848 (224)	292	0.36

The longest burn duration of any of the tests performed was 1.26 seconds on Test 4 which was an 11.35 kg (25 lb) test with a bottom center ignition. The next longest burn time was 1.12 seconds on Test 3 which involved 4.54 kg (10 lb) of mix with a bottom corner ignition. The shortest burn time was 0.36 seconds on Test 6 and an average burn time for the four deluge tests was 0.85 seconds.

M206 Tests

A table summarizing the results of the 16 deluge tests has been developed and is included in this report as Table 8. Seven tests were performed using the dry M206 (three of these tests were performed with the deluge lowered by 0.61 meters (2 ft)) and nine tests were performed using the wet M206 mix. For the seven tests performed with the dry mix, The time required by the UV detector system to sense the pyrotechnic fire varied from a minimum of 75 msec (Test 2) to a maximum of 373 msec (Test 15). The detection times for the remaining five tests were very close, with a minimum time of 87 msec and a maximum time of 112 msec. The average time for these five tests was calculated to be 99.6 msec. Two of the aforementioned tests, 2 and 3, were performed without the deluge system being active so water at the nozzle times were measured only on four tests. These times varied from a minimum of 50 msec after the detector response for Test 16 to a maximum of 138 msec after the detector response for Test 1. The average water at the nozzle time was calculated to be 91 msec after the UV detector response.

The UV detector response times for the nine tests performed using the solvent wet M206 mix varied from a minimum of 71 msec for Test 10 to a maximum of 238 msec for Test 12. The average response time for the nine tests was calculated to be 132 msec. If the minimum and maximum times are eliminated the average detection time for the remaining seven tests is 125 msec which is slightly faster than the total average time. Water at the nozzle times varied from a minimum of 34 msec after fire detection for Test 9 to a maximum of 183 msec after detection for Test 11. The average water at the nozzle time was calculated to be 108 msec after detection which is approximately 17 msec slower than that of the dry mix tests. The burn times for these tests varied from a minimum time of 3.85 sec for Test 6 to a maximum time of 60.1 sec for Test 9. As can be seen in Table 8, the burn times for the wet M206 mix varied depending on the quantity of water being delivered by the deluge and also on the amount of MEK added to the mix. Tests 7 and 9 were identical tests with the only difference being the amount of water being delivered by the deluge. On Test 7, the deluge delivered 825 liter/min (218 gal/min) while on Test 9, the deluge delivered 413 liter/min (109 gal/min). The burn time for Test 7 was measured to be 22.7 seconds while the burn time for Test 9 was almost three times longer (60.1 seconds). Tests 11, 12 and 13 were tests which utilized a larger amount of MEK (35% as compared to 25% used in the other tests) and as can be seen in Table 8, the burn times for these tests are lower than the burn times for those tests using 25% MEK (Tests 7,8, and 10).

The three tests utilizing the lowered deluge manifold showed no real change or reduction in the burn time. These three tests were performed on dry mix and the difference in manifold height seemed to have no appreciable change on the burn duration.

Table 8. Test Summary of M206 Mix

Test No.	Detector No.	Charge Size	Igniter	Engine rpm	Line Press kPa (psi)	Detector Time (msec)	Flow lit/min (gpm)	Water Nozzle (msec)	Burn Time (sec)
1	4 @ 1.22 m (4 ft)	2.27 kg (5 lb) Dry	2EM 1-1/2 CC MEK	1800	303.6 (44)	100.0	840.3 (222)	238	0.88
2*	2 @ 2.44 m (8 ft) w/hoods	1.36 kg (3 lb) Dry	2EM 3CC MEK	N/A	N/A	75.0	N/A	N/A	1.82
3*	2 @ 1.52 m (5 ft) w/hoods 2 @ 3.05 m (10 ft) w/o hoods	1.36 kg (3 lb) Dry	2EM 3CC MEK	1800	303.6 (44)	87.0	828.9 (219)	N/A	0.7
4*	4 @ 1.52 M (5 ft) w/hoods	2.27 kg (5 lb) Dry	2EM 3CC MEK	N/A	N/A	100.0	N/A	N/A	1.63
5*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft)	0.59 kg (1.3 lb) Wet (25% MEK)	2 EM	1800	331.2 (48)	213.0	794.9 (210)	321	11.4
6*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	1.77 kg (3.9 lb) Wet (25% MEK)	2 EM	1800	365.7 (53)	82.4	878.1 (232)	190	3.85
7*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft)	2.95 kg (6.5 lb) Wet (25% MEK)	2 EM	1800	324.3 (47)	116.0	825.1 (218)	228	22.7
8*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	5.90 kg (13 lb) Wet (25 MEK)	3 EM	1800	331.2 (48)	101.0	825.1 (218)	231	36.2
9*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	2.95 kg (6.5 lb) Wet (25% MEK)	2 EM	1400	200.1 (29)	112.0	412.6 (109)	146	60.1
10*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft)	4.54 kg (10 lb) Wet (25% MEK)	2 EM	1800	386.4 (56)	71.0	821.3 (217)	176	19.5
11*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	2.59 kg (6.5 lb) Wet (35% MEK)	3 EM	1800	351.9 (51)	181.0	787.3 (208)	364	13.6

Table 8. (Concluded)

Test No.	Detector No.	Charge Size	Igniter	Engine rpm	Line Press kPa (psi)	Detector Time (msec)	Flow lit/min (gpm)	Water Nozzle (msec)	Burn Time (sec)
12*	2 @ 1.52 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	5.90 kg (13 lb) Wet (35% MEK)	3 EM	1800	393.3 (57)	238.0	832.7 (220)	384	7.2
13*	2 @ 1.54 m (5 ft) 2 @ 2.44 m (8 ft) w/hoods	9.08 kg (20 lb) Wet (35% MEK)	3 EM	1800	393.3 (57)	73.0	840.3 (222)	118	11.8
14**	4 @ 1.75 m (5.75 ft)	0.454 kg (1 lb) Dry	1EM & 5 gr booster	2200	545 (79)	112.0	904.6 (239)	170	
15**	4 @ 1.75 m (5.75 ft)	0.454 kg (1 lb) Dry	1EM & 5 gr booster	2200	527.7 (83)	375.0	927.3 (245)	494	
16**	4 @ 1.75 m (5.75 ft)	1.59 kg (3.5 lb) Wet	1EM & 5 gr booster	2200	524.4 (76)	99.0	881.9 (233)	149	

NOTE: All tests were performed using the 15, Full Cone Nozzles

* Blow-off cap released prematurely and wet mix with water. Test was performed with mix still wet.

** Tests were performed with a lowered manifold.

MK45 Tests

A total of 15 tests were performed using the MK45 flare mix. A table summarizing the results of these 15 tests is presented in this report as Table 9. As can be seen in Table 9, the time required by the UV detectors to sense the fire varied from a minimum of 283 msec for Test 15 to a maximum of 829 msec for Test 12. The average UV response time calculated for the 15 tests was 490 msec after ignition. Detection times for nine of these tests were within 22% of the calculated average. Water at the nozzle times were measured for 14 of the deluge tests (times were not available for Test 15) and the fastest time measured was 51 msec after detection of the fire while the slowest time measured was 149 msec after detection. An average water at the nozzle time was calculated and found to be 81 msec. Eight out of the 14 tests performed had water at the nozzle times within 23% of the average time, while 13 out of the 14 tests had times within 37% of the average time.

The maximum fireball height for the MK45 tests was found to be greatly influenced by the shape of the mix prior to ignition. As shown in Table 9, the MK45 mix was tested in two conditions, flat with the mix spread to a depth of approximately 3.8 cm (1.5 in.) and cone-shaped with the mix approximately 5.1 - 7.2 cm (2 - 3 in.) deep. Tests with the mix in a flat condition had the lower fireball heights while the cone-shaped tests generally had the higher fireball heights.

Smoke Mix Tests

A large number of tests were performed using the three smoke mixes, i.e., green, yellow, and HC smoke; however, with the exception of the HC smoke tests, the UV detectors were ineffective in detecting any fires. Since the actual combustion of the green and yellow smokes was rather mild yet produced massive quantities of smoke, detection of combustion did not occur until the combustion was practically over and the smoke no longer shielded the detector. The HC smoke, however, did burn violently and produced sufficient flame such that detection of the fire occurred early in the test. Table 10 summarizes each of the test performed using the smoke mixes and the standard UV detectors. As can be seen in Table 10, the detection times for the HC smoke are more in line with typical pyrotechnic mix detection times while the times for the green and yellow smoke mixes are too slow for practical purposes.

A total of 17 tests were performed with the smoke mixes and the dual mode smoke/UV detectors. Six different detector positions were tested in the simulated bay. Table 11 summarizes the results of these tests, and as shown in the slow detection times given in Table 11, the dual mode smoke/UV detector is not currently very practical for pyrotechnic smoke applications. As mentioned earlier in this report, the pyrotechnic smoke mixes created a large quantity of smoke that fooled the detector into thinking the optics were dirty and subsequently the detector would issue an erroneous smoke "fault" rather than an "alarm." Smoke alarms were usually not given until the very end of the test when the bay was airing out and the concentration of smoke in the air was very small.

Table 9. MK45 Flare Mix Tests

Test No. (Date)	Charge kg (lb)	Line P kPa (psi)	Flow liter/min (gal/min)	Detector Time (msec)	Water at Nozzle (msec)	Burn Time (sec)
1 Cone	0.91 (2)	426 (61.7)	729 (192.5)	416	519	1.54
2 Cone	0.91 (2)	433 (62.7)	847 (223.7)	793	942	1.5
3 Flat	1.23 (2.7)	454 (65.8)	786 (207.7)	287	387	1.12
4 Cone	1.36 (3)	471 (68.3)	806 (213)	411	510	1.17
5 Cone	2.27 (5)	460 (66.7)	806 (213)	434	521	1.59
6 Cone	2.27 (5)	466 (67.5)	825 (218)	447	527	2.0
7 Cone	2.27 (5)	460 (66.7)	806 (213)	431	483	1.66
8 Flat	2.27 (5)	483 (70.0)	825 (218)	466	531	1.67
9 Flat	2.27 (5)	449 (65)	825 (218)	339	422	2.05
10 Cone	2.27 (5)	656 (95)	988 (261)	600	675	1.55
11 Flat	4.54 (10)	662 (96)	988 (261)	721	801	2.98
12 Flat	4.54 (10)	587 (85)	924 (244)	829	882	2.77
13 Flat*	2.27 (5)	545 (79)	943 (249)	520	575	0.98
14 Cone*	2.95 (6.5)	531 (77)	882 (233)	381	432	1.18
15 Flat*	4.54 (10)	587) (85)	924 (244)	283	400	N/A

Note: Test 1 had 2 UV detectors located 1.82 m (6 ft) from center of mixer.
Tests 2-12 had 2 UV detectors located 1.82 m (6 ft) and 2 UV detectors located 2.44 m (8 ft) from center of mixer.

- All tests were performed using the 15° Full Cone nozzles
- All tests were ignited using 1 electric match and a 5 grain booster of IMR 4227 located at the bottom center of the mix.

* Manifold lowered - UV detectors located 1.75 m (5.75 ft) from center of mix.

Table 10. Summary of Smoke Mix Tests

Test No.	Smoke	Charge	Igniter	UV Detection Time
1	Green (10 lb)	4.54 kg Booster	1 EM & 5 gr	63.7 sec
2	Green (5 lb)	2.27 kg Booster	1 EM & 5 gr	118 0 sec
3	Yellow (5 lb)	2.27 kg Booster	1 EM & 5 gr	35.1 sec
4	Yellow (10 lb)	4.54 kg Booster	1 EM & 5 gr	10.7 sec
5	Yellow (5 lb)	2.27 kg Booster	1 EM & 5 gr	32.1 sec
6	HC (1 lb)	0.454 kg Booster	1 EM & 5 gr	425 0 msec
7	HC (1 lb)	0.454 kg Booster	1 EM & 5 gr	458 0 msec
8	HC (1 lb)	0.454 kg Booster	1 EM & 5 gr	423 0 msec

Table 11. Summary of Smoke Mix Tests with Dual Mode Detector

Test No.	Smoke	Charge	Igniter	Detector Position	Smoke/Flame Detection Time
1	Green	0.454 kg (1.0 lb)	EM & 5 gr Booster	Center over Mixer	No Detection
2	Green	0.908 kg (2.0 lb)	EM & 5 gr Booster	Centered over Mixer	No Detection
3	Yellow	0.454 kg (1 lb)	EM & 5 gr Booster	Centered in Bay Facing Mixer	Flame - 30 sec
4	Yellow	0.454 kg (1.0 lb)	EM & 5 gr Booster	Centered in Bay Facing Mixer	Flame - 194.5 sec
.5	Yellow	0.454 kg (1.0 lb)	EM & 5 gr Booster	Centered in Bay Facing Mixer	Flame - 11.6 sec
.6	Yellow	0.454 kg (1 lb)	EM & 5 gr Booster	Across Doorway	Smoke - 33.0 sec
.77	Yellow	0.454 kg (1.0 lb)	EM & 5 gr Booster	Across Doorway	Smoke - 129.2 sec
.8	Green	0.454 kg (1 lb)	EM & 5 gr Booster	Across Doorway	Smoke - 141.2 sec
.9	White	0.454 kg (1 lb)	EM & 5 gr Booster	Across Doorway	No Detection
10	Green	0.454 kg (1 lb)	EM & 5 gr Booster	Top Front Wall	No Detection
11	Yellow	0.454 kg (1.0 lb)	EM & 5 gr Booster	Top Front Wall	Smoke - 179 sec
12	Green	0.454 kg (1 lb)	EM & 5 gr Booster	Centered Across Mixer	Smoke - 140 sec
13	Yellow	0.454 kg (1 lb)	1 EM & 5 gr Booster	Centered Across Mixer	Smoke - 141 sec
14	White	0.454 kg (1 lb)	1 EM & 5 gr Booster	Centered Across Mixer	Smoke - 90 sec
15	Yellow	0.454 kg (1.0 lb)	1 EM & 5 gr Booster	Top Backwall	Smoke - 90 sec
16	Green	0.454 kg (1 lb)	1 EM & 5 gr Booster	Top Backwall	Smoke - 120 sec
17	White	0.454 kg (1.0 lb)	1 EM & 5 gr Booster	Top Backwall	Smoked - 82 sec

Evaluation of Protective Garment

On March 27, 1984, SwRI received one of the newly developed protective outfits designed for pyrotechnic processing. The outfit consists of the fire protection suit, headgear and gloves. This outfit was to be used in support of the current program at SwRI which involves fire suppression tests of six pyrotechnic materials. As part of the fire suppression tests a technician must weigh out a test quantity of pyrotechnic material and then place this material in a simulated mix muller. Prior to receipt of the new protective garment, SwRI personnel had been outfitted in aluminized fire-fighting proximity suits; however, all subsequent tests were performed with the new suit. The new suit was found to be much more flexible and comfortable than the aluminized proximity suit. One of the primary complaints with the proximity suit is the continuous slippage of the headgear and the limited visibility. Both of these problems have been eliminated in the new suit, and the visibility in particular is excellent. In addition to being very bulky and cumbersome, the proximity suit is also very hot and the faceshield continuously fogs up. The new fire suit is not bulky or heavy, is much cooler and the face shield does not fog up as easily. The front opening double zipper design allows the wearer (when he is in a non-hazardous area) to easily open up the front of the suit for addition ventilation. SwRI used the suit without a breathing apparatus and the fogging up of the face shield was still minimal. With a breathing apparatus, the fogging up of the face shield should be eliminated. The only drawback or complaint with the new suit involves the "feel" provided by the gloves. Even though the "feel" provided by the new gloves is far superior to that provided by the proximity suit gloves, SwRI has found that the manual dexterity of the gloves is limited and complex operations such as tightening screws and grasping thin objects are rather difficult.

The new fire protection suit appears to be very durable and relatively maintenance free. However, just how durable the suit really is cannot be determined until the suit has seen substantial prolonged use. Getting in and out of the suit is not at all difficult and an individual can do it by himself. To date we have not washed the suit, however, it has gotten slightly wet with no detrimental effects. The narrowing suit leg particularly at the lower cuff creates a problem if the wearer tries to slip the suit on over large or bulky boots or shoes.

DELUGE DESIGN CRITERIA AND EFFECTIVENESS

Generalized criteria have been developed for the design and installation of a water deluge system for pyrotechnic applications and is presented here as Table 12. Included in this table are criteria for the fire detection system, the deluge actuation valves, the deluge manifold and the nozzles. As detailed in earlier sections of this report, this deluge design was evaluated using six different pyrotechnic mixes. The effectiveness of this deluge design in combatting fires involving these six mixes is presented in Table 13, along with the maximum weights tested by SwRI. Included in Table 13 is a recommendation as to whether the current deluge design is applicable to full scale plant operations or whether additional testing of the deluge system is required.

Table 12. Deluge Design Criteria

Type and No. of Detectors	Detector Position	Detector Control System Sensitivity	Deluge Actuation Valve
UV-Minimum of 4 Detectors	Position above the piece of equipment, i.e., mixer, granulator, etc., such that field of view is as unobstructed as possible and detector views entire piece of equipment. The four detectors should be placed 90° apart for overlap coverage	Set at maximum sensitivity. Time delays should not be used.	Actuation valves (explosive or solenoid) should be positioned as close to the nozzles as possible.

Deluge Manifold	Nozzle Type	No. of Nozzles	Water Flow Rate
Manifold should be primed with water to the nozzle and not attached to any frangible structure.	15° full cone	Minimum of five nozzles	Minimum of 155 liter/min (40 gal/min) per nozzle.

Nozzles Position
Above and as close to piece of equipment, i.e., mixer, granulator, etc., as possible. 100% of the water should be directed into the mixer, granulator, etc.

Table 13. Deluge Effectiveness and Applicability

Material	Maximum Weight Tested	Deluge Effectiveness	Applicability to Plant Operations
Starter Mix	11.35 kg (25 lb)	Total Extinguishment	Recommend installation of prototype deluge in full scale operations.
M206-Wet with Solvent	9.08 kg (20 lb)	Initial fireball, controlled burn followed by total extinguishment.	Recommend installation of prototype deluge in mixing bays.
M206-Dry	2.27 kg (5 lb)	Ineffective	Recommend testing with explosive actuated valves mounted at the nozzles.
MK45-Flat Shape	4.54 kg (10 lb)	Initial fireball followed by controlled burn	Recommend testing with explosive actuated valves mounted at the nozzles.
MK45-Cone Shape	2.95 (6.5 lb)	Ineffective	Recommended testing with explosive actuated valves mounted at the nozzles.
HC Smoke	2.27 kg (5 lb)	Total extinguishment	Recommend installation of prototype deluge in plants.
Green Smoke	2.27 kg (5 lb)	UV and prototype UV/smoke detector ineffective in detecting fire.	Recommend testing with desensitized UV/smoke detector.
Yellow Smoke	2.27 kg (5 lb)	UV and prototype UV/smoke detector ineffective in detecting fire.	Recommend testing with desensitized UV/smoke detector.

CONCLUSIONS

A test program was conducted to evaluate the effectiveness of water deluge systems in controlling/extinguishing fires from various pyrotechnic materials and also to assess the detectability of pyrotechnic material fires including smoke mixes. Deluge tests were conducted on six materials in a simulated mix muller varying the quantity of pyrotechnic mix, the shape of the mix, i.e., flat or cone shaped, the condition of the mix itself, i.e., with or without solvent, the ignition point, the number of detectors, the height of the deluge system from the fire and the water application rate. Tests were conducted on the smoke mixes using standard UV detectors and using a dual mode smoke/UV detector.

Based on the findings of this test program, a number of conclusions can be drawn which are vital to the enhancement of safety in the manufacturing and processing of pyrotechnic mixes.

- The deluge system used in this program was equipped with nozzles having a tight spray pattern (15° full cone) and with a high flow rate capacity (at least 155 liter/min per nozzle), and used multiple UV detectors. The system effectively controlled and extinguished fires involving the Pine Bluff Arsenal starter mix.

- The deluge system design used in this program was effective in controlling and extinguishing fires involving the test quantities of the solvent wet M206 flare mix. The initial fireball that is produced is higher than the deluge system manifold prior to the deluge system functioning; however, once the deluge does function, the fireball is knocked down and the mix continues to burn in a controlled fashion until full extinguishment occurs. The larger quantities of unignited residue material recovered after each test further demonstrates the effectiveness of the deluge in limiting the amount of material that becomes involved.

- The tests performed using the dry (no solvent) M206 flare mix demonstrated that the mix lofts above the deluge and extinguishment efforts are ineffective. Ignition and rate of fire growth for this material is much faster than the response time of the detection/deluge system.

- Tests performed with the dry (no solvent) M206 flare mix and with the deluge system lowered closer to the mix yielded no appreciable change in the extinguishment efforts and the bulk of the mix ignited and lofted before the deluge could respond.

- The deluge system is effective in controlling and extinguishing fires involving the test quantities of the MK45 flare mix provided that the depth of the mix does not exceed 3.8 cm (1.5 in.). Tests with greater thicknesses of the mix proved the deluge to be ineffective because the majority of the mix becomes involved before the water can get to the mix. The resultant fireball is so severe that by the time the water penetrates the fireball, the bulk of the mix has been consumed.

- The combustion of green and yellow smoke mixes produces very large quantities of dense smoke very rapidly and obscures the conventional UV detectors. In addition, the actual burning of these mixes is very mild with little or no visible flame being produced which further limits the ability of conventional UV detectors to sense the combustion reliability.

- The HC smoke mix burns rather violently producing sufficient flame to allow for detection of the fire by the UV detectors. The smoke produced is also not as dense as that produced by the green and yellow smoke mixes.

- The newly developed dual mode smoke/UV detector is much too sensitive to rapidly generated large quantities of smoke and will erroneously issue "faults" indicating obscuration of the optics system. This sensitivity of the optical integrity system in the controller degrades the effectiveness of the system to the point where its usefulness at its present stage of development is very limited for this application.

RECOMMENDATIONS

Based on the results of the experimental program performed and on the subsequent data analysis, the following recommendations are made:

- Since the tight spray pattern nozzles were demonstrated to be a definite improvement over the sprinkler type nozzles in penetrating and controlling the fireballs generated in the small scale tests performed at SwRI, it is recommended that nozzles with a tight spray pattern be used to protect the mixers in lieu of sprinkler type heads. The nozzles should also be positioned as close to the pyrotechnic mix as practical in an effort to speed up delivery and concentrate the water being delivered directly into the fireball.

- Nozzles with a high flow rate capacity (at least 155 liter/min (40 gal/min)) should be used and the deluge and associated water plumbing should be sized to accomplish the high delivery rate.

- The deluge manifold and associated plumbing should not be attached to any frangible structure, i.e., blow-off roof or walls.

- Multiple UV detector coverage should be provided for hazardous operations involving pyrotechnic materials other than smoke mixes. The use of multiple detectors will result in a faster detection of a fire than will be accomplished if only a single detector is utilized.

- Time delays should not be programmed into the detection system due to the speed with which some pyrotechnic materials can be totally consumed. Any kind of a delay involving "seconds" will result in either the UV detection system missing the fire completely or the deluge responding after the bulk of the material has been consumed.

- When a Primac high speed valve is used in the deluge system, the Primac valve should be located as close to the manifold in order to minimize the water-at-the-nozzle time as much as practicable.

- Since the current deluge system response time is too slow to effectively control and extinguish dry (no solvent) magnesium-based pyrotechnic mix fires, it is recommended that tests be performed utilizing explosive actuated deluge valves mounted at each nozzle in lieu of the single Primac valve mounted prior to the manifold. The explosive actuated deluge valves will allow for pre-priming of the manifold up to the nozzles with high pressure water (same pressure as the main line) and almost instantaneous release of this water once the valves are activated by the UV detection system. These valves are also available with large flow rate capacities and should eliminate the "time delay" required by the current deluge system to build sufficient pressure to eject the blow-off caps currently being used.

- The dual mode smoke/UV detector proved to be too sensitive to large quantities of smoke produced rapidly. The Det-Tronic Corp, who is developing this detector is in the process of desensitizing the detector to large quantities of smoke. Once the detector has been revised, additional tests using the smoke producing materials should be performed.

- At the close of the experimental phase of this program, SwRI personnel were made aware of the dual UV/IR detector manufactured by Armtec Industries, Inc. (Manchester, NH) which is supposedly much faster than any UV detector currently on the market. This detector should be verified experimentally using the fast burning magnesium based mixes and the smoke mixes.

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