

**PERFORMANCE EVALUATION  
OF A  
LOW PRESSURE WATER MIST SYSTEM  
IN A  
MARINE MACHINERY SPACE  
WITH OPEN DOORWAY**

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### Introduction

Grinnell has completed a second series of large scale fire tests involving the evaluation of the *AquaMist*, low pressure (12 bar), impinging jet nozzle, water mist deluge system in a 500m<sup>4</sup> simulated machinery space with a 4m<sup>2</sup> open doorway. The first series of tests are described in Reference 1. Both series of evaluations were based on the fire test protocols recommended by the International Maritime Organization (**IMO**) in their "Interim Test Method for Fire Testing Evaluating Water-Based Fire-Extinguishing Systems for Machinery Spaces of Category A and Cargo Pump-Rooms", which existed at the time.

The first series of tests were conducted in April of 1994 with the bottom of the 2m x 2m doorway located at the building floor level. The second series of tests were conducted in August of 1994 with the bottom of the 2m x 2m doorway located 0.5m above the building floor level. The bottom of the doorway was raised to more closely simulate a marine installation in which the air inlet draft through the open doorway could not occur in the bilge area beneath the machinery space floor plates. Details of the second test series are given in Reference 2.

During the 39th meeting of the **IMO** Fire Protection Sub-Committee last July, certain tests were added to the **IMO** machinery space protocol. These included 0.5m<sup>2</sup> heptane and lubrication oil pan fires concealed within the bilge area under the engine block as well as a 0.1m<sup>2</sup> heptane pan fire shielded underneath a 1m wide overhang at the side of the engine block. The low pressure system consisting of overhead mounted *AquaMist* AM10 nozzles was not able to extinguish these fires. The reasons, which are primarily related to the general principles of fire extinguishment by water mist, are presented in the Discussion section.

Nonetheless, presented in this paper are the results of 21 tests which have successfully demonstrated the capability of an overhead, low pressure water mist system to extinguish a wide variety of hydrocarbon pool, spray, cascading pool as well as combination Class A and B fires representative of those which might occur in a machinery space.

## Description of AquaMist Nozzles

The AM10 *AquaMist* Nozzle utilized in the marine machinery space fire tests being reported on is illustrated in Figure 1. The nozzle K-factor is nominally 3.5 (lpm/bar), the smallest diameter within the nozzle is nominally 2.3 mm and the strainer perforation diameter is specified at nominally 1.5 mm. In an actual installation, corrosion resistant piping and a suitable mainline strainer would be required for use with the *AquaMist* nozzles. The frame material of the nozzles is cast from ASTM A-743 alloy CF-8M, which is considered to be the cast equivalent of wrought Type 316 stainless steel. The inlet strainer, orifice insert and diffuser are fabricated from Type 316 stainless steel. At the nominal flowing pressure of 11.7 bar utilized throughout the test series, the flow rate per nozzle is about 12 lpm. Figures 2 and 3 show representative data on number of droplets and cumulative volume versus drop diameter, at 12 bar, one meter below the spherical nozzle diffuser (patents pending).

Approximately 10% of the AM10's droplets, which comprise about 50% of the volume flow, consists of droplets greater than 300 microns. These relatively large, high momentum droplets are used to help entrain the finer droplets and carry them into the combustion zone. They also provide surface cooling and extinguishment of Class A combustibles by direct wetting. At 1m below the nozzle, the pattern is filled to about 1.4m in diameter, when sprayed in the open. When sprayed in an array, the pattern expands and the water droplets are distributed around the space according to the size of the droplets (e.g., smallest being the most mobile).

## Description of Test Set-Up

Figure 4 illustrates plan and front wall elevation views of the 10m x 10m x 5m high enclosure used for this test series, which was conducted in the 18m wide x 22m long (6000m<sup>3</sup>) main fire test hall at the Swedish National Testing and Research Institute (SP), in Borås, Sweden. Figure 4 also provides an overlay of the AM10 nozzle locations.

The diesel engine mock-up along with the locations of the fuel spray jets and pool trays are illustrated in Figures 5 and 6. The engine mock-up was 1m x 3m x 2.5m high, and it was constructed of sheet steel with a nominal thickness of 5mm. When this test series was performed, in August of last year, the mock-up was in accordance with the International Maritime Organization (IMO) machinery space qualification test requirements which existed at that time. However, in December of 1994, the height of the mock-up was changed from 2.5m to 3m. The mock-up ~~was~~ fitted with: two steel tubes (2mm wall thickness) having an outside diameter of 0.3m and a length of 3m that simulate exhaust manifolds; along with, an adjacent 0.7m wide by 3.5m long solid steel plate. The floor plates surrounding the engine block were 5mm thick sheet steel, and they were spaced approximately 0.1m away from the sides of the block. The mock-up is considered to simulate a small diesel engine or part of a large diesel engine.

A three square meter fuel tray was located on top of the engine mock-up and a 4 square meter tray was located at the bottom of the simulated 0.75m high bilge area, beneath the engine mock-up. When oil pool fires were set-up in the top tray, they were pre-filled with water to establish a free-board height of about 50mm. Figure 6 schematically illustrates horizontally orientated fuel jets on the top and at the side of the engine mock-up. An exposed 45° upward directed fuel jet, on top of the engine mock-up, was also evaluated.

The 15mm diameter by 1m high steel pipe (Obstruction Rod), located on top of the engine mock-up, provided a hot spot re-ignition point for the adjacent pressurized fuel jet, as did the top tube and the tray area. The solid plate at the right side with its angle supports, and the lower tube along the side of the engine mock-up provided multiple re-ignition points for the right side fuel jet, in addition to shielding of the fuel spray. The top tube also tended to provide some shielding of the pool tray at the top of the engine mock-up.

The piping arrangement consisted of a dual feed gridded piping system, which was established to minimize the differences between the flow rates of individual nozzles and to allow water flow from all nozzles at about the same time. Two supply hoses were connected near the centers of the 50mm mains located on opposite sides of the grid, 10m apart. Five 40 mm cross connections spaced 2m apart were made between the mains to serve as the feed lines to the individual nozzles. At a 2m spacing along the cross connections, a 25mm arm-over was installed with about a 0.5m drop to just above the ceiling. At that point, the drops were reduced to 15mm diameter down to the nozzles. The nozzles were located at either a 0.2m or 0.9m diffuser to ceiling distance, and flat escutcheon plates were installed around the drop nipples to seal off the penetration through the ceiling. A 15mm drop was made from the front 40mm cross connection down to the two nozzles which were positioned 0.3m inside of the doorway, 0.3m in from the left and right edges and 0.5m above the top of the opening.

The two nozzles over the doorway were used to minimize the intake of fresh air into the enclosure. A similar effect could be obtained by installing the ceiling nozzles at a closer spacing and eliminating the nozzles over the doorway. However, the above described system was considered to be the more energy efficient.

The pipework was fitted with a pressure tap located near the center of the array and connected back to a gauge at the pump location so that the operator could immediately adjust the pump output in response to any pressure changes. The above described piping was not sized at the minimum required for an actual system. Rather, it was sized on the basis of maintaining essentially the same residual (flowing) pressure for all nozzles.

Both of the thermocouples were fabricated from 0.25mm chromel-alumel thermocouple wire that was welded together at the sensing points. The ceiling gas thermocouple was located about 25mm below the ceiling, while the gas thermocouple at the right side of the engine mock-up was located about 0.55m below the 0.7m wide solid plate.

The thermocouple wire, from the ceiling down to the 0.7m wide plate, at right side of the engine mock-up, was contained within 25mm steel pipe for protection.

### **Total Heat Release Rates**

During the test series described in the following section, a variety of pool and spray fire tests were conducted. Arrangements could not be made for calorimeter measurement of the Total Heat Release Rates (Total HRR). Consequently, it was necessary to estimate the Total HRR values utilizing a heat of combustion of 39MJ/kg for the diesel oil and 44.6MJ/kg for the heptane. The mass flow rates of the pool fires were calculated using Reference 3 and, the burning efficiency was assumed to be **85%**. For the spray fires, the mass flow rates given in Table 2 were used.

### **Fire Scenarios**

The fire scenarios were chosen by the IMO to represent possible fires in an enclosure with a hydrocarbon fueled engine. Fires might occur, for example, if oil from a pipe break contacts a hot surface in the exhaust system or, if a leak forms a spill that ignites. A combination of these two scenarios is also possible which was reflected in the tests. To simulate a combination of a spill fire and a fire involving Class **A** material, a test was conducted with a small wood crib placed in a tray with heptane. To simulate hot surfaces, such as exhaust ducts or manifolds, one of the selected fire scenarios involved a steel plate, situated on the top of the simulated engine, that was heated with a propane gas burner to at least 350°C prior to the start of the test. The steel plate then acted as a potential source of re-ignition for a heptane spray. Table 1 summarizes the various fire scenarios.

The freeboard used for the pool fires on the top of the engine block was 50mm. The freeboard for the 0.1m<sup>2</sup> tray fire positioned 1.4m in from the front end of the engine and, at the inside edge of the floor plates, was 150mm. The tray used for the combination wood crib and heptane pool fire was 2.2m<sup>2</sup> in area. The tray was circular with a diameter of 1.67m and the free board was approximately 100mm. A square 4m<sup>2</sup> tray was positioned centric, underneath the engine mock-up, to collect the fuel flowing down the side of the engine block in the flowing fire scenario (scenario J). The tray had a rim height of 150mm.

The wood crib used in fire scenario K was dimensioned 0.3m x 0.3m x 0.3m and consisted of eight alternate layers of four trade size 38mm x 38mm kiln dried spruce, 0.3m long. The alternative layers of the individual members in each layer were evenly spaced along the length of the previous layer of wood members and stapled together.

After the wood crib was assembled, it was conditioned at a temperature of 50±5°C for at least 16 hours in order to ensure that the moisture content did not exceed 5% prior to the fire test.

The spray fires were achieved with a hydraulic pump and different nozzles for creating the oil or heptane sprays. The nozzles used, their characteristics and the pressures and flow rates are specified in Table 2.

### **Test Procedures**

The spray fires were ignited using a torch and allowed to burn for **15** seconds or less before the extinguishing system **was** activated. The reason for this was that experience has shown that spray fires tend to be more difficult to extinguish by water mist with shorter pre-burn times. In the case of combination fires, the spray fire was ignited by the pool fire after the pool fire was allowed to burn for two minutes.

From the thermocouple reading during the test and from visual observations, both from the doorway opening and via windows at the sides of the test room, it **was** possible to judge when the fire(s) were extinguished. When the fire(s) were extinguished rapidly, the water was left on for a couple of minutes afterwards. In the cases that the time to extinction was prolonged, the water was left on for longer times, however, not more than 15 minutes from start of flow.

When spray fires were used, the fuel flow was left on for at least one minute after the fire was extinguished, to make sure that no reignition occurred. The level of fuel in the trays was observed after the end of the applicable tests to make sure that no fuel limitation occurred during the test. This was ordinarily done by reigniting the fuel.

### **Discussion of Test Results**

The tests presented in this report were conducted in a simulated machinery space having a volume of 500m<sup>3</sup> and a ceiling height of 5m, using different hydrocarbon fuel fire scenarios. The enclosure was provided with one natural ventilation doorway opening, located centric in the front wall, measuring 2m x 2m, with its bottom located 0.5m above floor level, in order to simulate a marine application with a bilge area.

The fire scenarios were chosen to represent possible fires in an enclosure with a hydrocarbon fueled engine. **Fires** might occur, for example, if an oil pipe breaks and the oil contacts a hot surface of the exhaust system or if a leak forms a spill that ignites. A combination of these two scenarios is **also** possible and was reflected in the tests. To simulate a combination of a spill fire and a fire involving Class A material, a small wood crib was placed in a tray with heptane. Hot surfaces, such **as** exhaust ducts, were simulated with heated steel plate situated on the top of the simulated engine. The pre-burn times were short, **as** experience has showed it to be the most difficult scenario to extinguish.

The low pressure fire extinguishing system tested was designed as a fixed deluge system having twenty-five *AquaMist* AM10 nozzles installed uniformly on a 2m x 2m spacing throughout the ceiling, at both 0.2m and 0.9m below the ceiling. In addition to the ceiling nozzles, two nozzles were positioned over the 2m x 2m doorway opening in the front wall. A nominal flowing pressure of 11.7 bar was utilized throughout the tests which provided for a flow rate per nozzle of about 12 lpm and an average water density of approximately 3mm/min (i.e. 3 lpm/m<sup>2</sup>).

The two nozzles over the doorway were used to minimize the intake of fresh air into the enclosure. A similar effect could be obtained by installing the ceiling nozzles at a closer spacing and eliminating the nozzles over the doorway. However, the above described system was considered to be the more energy efficient.

The temperature inside the test enclosure was measured both near the fire to determine the time to extinguishment and at the ceiling to determine the impact from the fire on the enclosure construction. The O<sub>2</sub>, CO and CO<sub>2</sub> concentrations were measured at a point judged to be at approximately the same level as the average position of the fires. This location was set at 2.5m above the floor.

Table 3 summarizes the salient test results for a nozzle diffuser to ceiling height of 0.2m while the comparable data for a 0.9m height are given in Table 4. Only seven tests were performed at the 0.9m ceiling to nozzle diffuser height, in order to spot check performance at worst case combinations of conditions; and, no further tests were deemed necessary at this position. Sample temperature versus time data is provided in Figures 7 through 12 for three different fire scenarios and the two different ceiling to nozzle diffuser heights. These graphs are typical for extinguishment of hydrocarbon fuel fires by the *AquaMist* low pressure water mist system [1, 2] and, I believe, water mist systems of the various types.

A general observation is that the larger sized (Low Pressure) spray fires were extinguished much faster than the smaller (Low Pressure/Low Flow) fires. The time of extinguishment ranged from 23 to 80 seconds for the large spray fires and from 5:24 to 7:30 for the smaller spray fires. The fact that larger fires tend to be easier to extinguish with water mist compared with smaller sized fires have been reported for numerous other tests, for example [4] and [5]. These two oil spray fire scenarios were arranged both on the top of the engine block and along the side of the engine block, below the solid steel side plate. Although the steel side plate provided a substantial obstruction to direct impingement by the water spray, no significant difference in the time to extinguishment was observed for the same fire scenario, whether or not it was obstructed. However, no strict comparison was made with the Low Flow/Low Pressure oil sprays, as only heptane was used on the top and only diesel oil at the side of the engine block. Further, there seems to be no significant effect regarding the extinguishing time versus the nozzle distance below the ceiling.

Another visual observation was related to the change in temperature and, therefore, pressure inside the enclosure during the fire extinguishment process. This was observed on the flow in and out of the doorway opening, especially during the tests where the time to extinguishment was longer. The flow periodically changed from an outflow of smoke and water vapor over the complete cross section of the opening to an inflow of air at the bottom half of the opening. The outward flow of smoke corresponded to an over pressure within the compartment and vice versa. Rapid extinguishment resulted in a major inward draft with the water spray from the nozzles over the doorway being drawn into the enclosure over a meter, at floor level, followed by a return of the smoke and water spray to an almost neutral state.

The minimum  $O_2$  concentration at the measurement point ranged from approximately **15%** to **19.3%**, the CO concentration from below **0.01%** to approximately **0.26%** and the  $CO_2$  concentration from approximately **1.4%** to **3.4%**. The large fire scenarios show a very rapid initial reduction in the  $O_2$  concentration. This was due to the activation of the nozzles, which drove the smoke trapped at the ceiling level down, towards the measurement point. The reduction in the average  $O_2$  concentration for the enclosure, to the **15** to **19%** range, clearly made it easier for the water mist system to extinguish the various fires. However, the levels were well above the **9%** value for Class A fires and the **13%** value for Class B fires which are generally associated with extinguishment by oxygen starvation.

Regarding the ceiling temperatures, the fire scenarios on the top of the engine mock-up caused the highest temperatures. The fire scenarios with a Low Pressure oil spray angled **45°** up rapidly resulted in ceiling gas temperatures in excess of **900°C**; however, the fires in the two tests were extinguished in an average of about one minute. When the time to extinguishment was prolonged, for example in the Low Pressure/Low Flow and pool/flowing fire scenarios, the temperatures at the ceiling were controlled to moderate levels.

In tests **1.14** and **1.18**, a constant leakage flow of heptane was arranged on top of the engine block. The fuel was allowed to form a **3 m<sup>2</sup>** pool on the top, flow down one side of the engine block and into a **4 m<sup>2</sup>** tray underneath the floor plates. In both cases, the system extinguished the fire in the top tray first. The leakage flow was not turned off, after extinguishment of the top tray fire, which resulted in the fuel forming a pool fire underneath that burned up the side of the engine block. This pool fire was extinguished, in both cases, after approximately four minutes.

Test 1.22 was performed as a reference test without the activation of the extinguishing system. The fire scenario chosen was the Low Pressure/Low Flow diesel spray. It was observed that the conditions in the test enclosure reached a steady state after around eight minutes, with an O<sub>2</sub> concentration of approximately 16.5%. The O<sub>2</sub> concentration would, of course, vary with the sampling position inside the enclosure. However, by visual observation, it was determined that the sampling position was in the smoke gas layer. The thermocouple data acquisition system was not in operation during the reference test.

Figure 13 illustrates the observed general stages in the extinguishment of the diesel oil spray fires. Portrayal of the extinguishment of the heptane fires would be similar except that the separated flames would tend to be more purplish. Starting from what has been termed Stage 1 (Free Burn), the initial effect of the water mist becoming entrained within the air-fuel mixture is described as Stage 2 (Initial Mist Effect). In Stage 2, the combustion zone moves away from the nozzle, expanding the clear space, and the intense white hot spot fluctuates in size although diminishing in size over-all. Also, the apparent intensity of the flames, at the outer extremities, begins to decrease and dull in color towards a dark or reddish orange. At Stage 3 (Initial Separation of Flame), the intense white spot further diminishes in size or totally disappears. Also, the yellowish orange portion of the flame moves further away from the spray nozzle. During this stage, there may be a backward flicker of the yellowish orange portion of the flame which, because of flame turbulence, can jump back to the air-fuel mixture and return the flame development to Stage 2. Surrounding hot spots may also re-ignite the air-fuel mixture closer to the nozzle tip.

At Stage 4 (Separated Remnant of Flame), there are no intense hot spots in the flame and, only a last remnant of yellowish orange to dark orange flame remains, separated from the nozzle by several meters. Again, however, as in the case of Stage 3, backward flickers of flame can cause the flame development to jump back from Stage 4 to Stage 3 or even Stage 2. Ultimately, through continuous cooling of the surrounding hot spots and dilution of the air-fuel mixture, Stage 5 Extinguishment is achieved. For example, the sequence of stages for extinguishment of a typical shielded diesel oil spray fire by the low pressure AM10 AquaMist nozzles is 1-2-3-2-3-4-3-4 and -5.

## Conclusion and Observations

Firstly, with regard to the subject of low pressure, impinging jet water mists systems:

1. Two series of evaluations consisting of almost 50 individual tests have clearly demonstrated the ability of an overhead, low pressure, impinging jet water mist deluge system to extinguish a wide variety of exposed and shielded, pool and pressurized, hydrocarbon fuel fires in an open doorway compartment with a 5m high ceiling.

2. At this point in technology development, comparative tests in large compartments indicate that internal scroll water mist systems operating at pressures greater than 100 bar will provide somewhat faster extinguishment times than the low pressure, impinging jet nozzles. However, the low pressure approach offers a viable alternative when considering simplicity, reliability, filtration requirements, installed cost and maintenance.

With regard to the general subject of water mist systems, the following viewpoints are offered:

- A. The effectiveness of gases such as Halon is not affected by shielding or obstructions whereas, they are clearly a consideration in the case of water mist.
- B. The design of a gas distribution system primarily involves compartment volume and delivery rate considerations while the design of a water mist system involves nozzle spacing, application density, compartment height as well as concealment considerations.
- C. Gases such as Halon simply become non-effective with ventilation while a definable degree of ventilation can be tolerated with water mist.

For these reasons, I believe that the implications of the term “Halon Options” or “Alternatives to Halon” are much more preferable with regard to describing deluge type water mist systems than the phrase “Halon Alternative”.

Lastly, with regard to the general fire extinguishment attributes of water mist systems, I would like to offer the following observations:

- a. It will be an extremely difficult task to reliably predict the complexities of extinguishment of Class B fires by water mist systems through the use of first principles.

Factors such as the interactive effects between nozzles operating in an array, the effects of combustion products being drawn down from the ceiling, shielding, mist momentum and trajectory as well as localized cooling and oxygen depletion phenomena will make this a very formidable task.

- b. Low flash point pool fires, such as those typified by heptane, are primarily extinguished by driving the mist to the burning surface and separating the flammable vapors from it through expansion of the resulting water vapor. Once separated, the resulting residual vapors are dispersed and diluted to the point of extinguishment.

Simply surrounding a horizontally and vertically shielded low flash point liquid pool fire, in a ventilated enclosure, with low momentum droplets, will not result in extinguishment by localized cooling or oxygen depletion. The flame front simply overpowers the mist and essentially drives it away. Because of this, it will be highly improbable that any type of ceiling mounted, overhead water mist system will be able to extinguish the 0.5m<sup>2</sup> pan fires positioned underneath the engine block, in the IMO machinery space test procedures.

- c. Trying to extinguish a flammable liquid fire with water mist by overpowering it from all directions is ineffective.

Light areas need to be intentionally left within the nozzle spray patterns which will allow the flames to escape from the burning area. In the case of the low pressure *AquaMist* system, this is accomplished by leaving light density areas between the conical spray patterns while the areas between the individual sprayers of multi-orifice nozzles accomplishes the same effect.

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## REFERENCES

1. Pepi, Jerome S., *Fire Test Status Report on the Evaluation of the AquaMist Fixed WaterMist Deluge System in Ventilated Marine Machinery Spaces*, SFPE Technical Symposium on Halon Alternatives, Knoxville, TN, 28 June 1994.
2. Arvidson, Magnus, "MachinerySpace Fire Tests for Grinnell Fire Protection Using AquaMist AM10 Nozzles", SP Test Report R30494b, February 1995.
3. SFPE, *Fire Protection Handbook*, National Fire Protection Association, Quincy, MA, USA, 17th edition.
4. Wighus, Ragnar, et al, *Full Scale WaterMist Experiments*, International Conference on Water Mist Fire Suppression Systems, Boras Sweden, November 4-5, 1993.
5. Mawhinney, Jack R., *Design of WaterMist Fire Suppression Systems for Shipboard use*, International Conference on Water Mist Fire Suppression Systems, Boras, Sweden, November 4-5, 1993.
6. *Standard for the Installation of WaterMist Fire Suppression Systems*, NFPA 750, National Fire Protection Association, Batterymarch Park, Quincy, MA USA, (Draft, to be published in 1996).

TABLE 1

## DESCRIPTIONS OF FIRE SCENARIOS

FIRE SCENARIO	DESCRIPTION	FUEL	ESTIMATED HRR [MW]
A	Low pressure horizontal spray on top of the simulated engine, under one AMIO nozzle.	Light diesel oil	6.6 MW
B	Low pressure horizontal spray on top of the simulated engine. between two AMIO nozzles.	Light diesel oil	6.6 MW
C	Low pressure horizontal spray on top of the simulated engine, between four AMIO nozzles.	Light diesel oil	6.6 MW
D	Low pressure spray on top of the simulated engine centered with nozzle angled upward at a 45° angle to strike a 13mm diameter rod 1 m away.	Light diesel oil	6.6 MW
E	Low pressure concealed horizontal spray on side of the simulated engine with oil spray nozzle positioned 0.1m in from the end of engine side.	Light diesel oil	6.6 MW
F	Low pressure concealed horizontal spray on side of the simulated engine with the oil spray nozzle positioned 1.2m in from the front end of engine side.	Light diesel oil	6.6 MW
G	High pressure horizontal oil spray on top of the simulated engine.	Light diesel oil	2.0 MW
H	Low pressure, low flow, concealed horizontal oil spray on side of the simulated engine with oil spray nozzle positioned 1.2m in from the front end of engine and 0.1m <sup>2</sup> tray positioned 1.4m in from the engine front end at the inside edge of floor grating.	Light diesel oil	1.1 MW
I	3m <sup>2</sup> pool fire on top of engine.	Heptane	10.1 MW
J	Flowing fire 0.25 kg/s from top of the simulated engine.	Heptane	10.1 MW+ 14.0MW*
K	Class A fire, a small wood crib, in 2.2m <sup>2</sup> pool fire with 30 sec preburn. The test tray was positioned 0.75m above the floor.	Heptane	7.1 MW
L	A steel plate (30cm x 60cm x 5 cm) offset 20' to the spray was heated to over 350°C with a gasburner. The steel plate was thereafter heated by the top low pressure/low flow spray nozzle positioned horizontally 0.5m (1.0m in test 1.9) from the front surface of the plate.	Heptane	1.2 MW
M	Identical with fire scenario H, except that no oil tray was used.	Light diesel oil	1.1 MW

\* Theoretical value, the pool fire under the floor plate was likely affected by restricted ventilation.

TABLE 2

CHARACTERISTICS OF THE FUEL SPRAY FIRES

FUEL SPRAY SPECIFICATIONS			
FIRE TYPE	LOW PRESSURE	LOW PRESSURE, LOW FLOW	HIGH PRESSURE
FUEL	COMMERCIAL FUEL OIL OR LIGHT DIESEL OIL	HEPTANE	COMMERCIAL FUEL OIL OR LIGHT DIESEL OIL
SPRAY ANGLE	WIDE SPRAY ANGLE (120° TO 125°) FULL CONE TYPE	WIDE SPRAY ANGLE (80°) FULL CONE TYPE	STANDARD ANGLE (70°) FULL CONE TYPE
NOMINAL FUEL PRESSURE	8 BAR	8.5 BAR	150 BAR
FUEL FLOW [KG/S]	0.16±0.01 KG/S	0.03±0.005 KG/S	0.05±0.002 KG/S
FUEL FLOW [KG/MIN]	9.6±0.6 KG/MIN	1.8±0.3 KG/MIN	3.0±0.12 KG/MIN
FUEL TEMPERATURE	20±5° C	20±5° C	20±5° C
SPRAY NOZZLE SPECIFICATIONS			
NOZZLE TYPE	LECHLER 460.728	LECHLER 460.446	LECHLER 460.406
ACTUAL MEASURED FLOW RATE [KG/MIN] AT PRESSURE [BAR]	10.2 KG/MIN AT 8 BAR	1.6 KG/MIN AT 8.5 BAR	3.2 KG/MIN AT 200 BAR
			SPRAYING SYSTEMS TG 0.7

TABLE 3  
 SUMMARY OF FIRE TEST RESULTS FOR AM10 AQUAMIST NOZZLE DELUGE SYSTEM  
 PROTECTING A SIMULATED MARINE DIESEL ENGINE IN A 10 M X 10 M X 5 M HIGH ENCLOSURE  
 WITH A 2 M X 2 M HIGH OPEN DOORWAY AND  
 A CEILING TO NOZZLE DIFFUSER HEIGHT OF 0.2 M [ 1 ]

TEST NO.	FIRE SCENARIO, [ 2 ]	SPRAY TYPE, [ 3 ]	IGNITION OF POOL FIRE, min:sec	IGNITION OF SPRAY FIRE, min:sec	INITIATION OF WATER FLOW [ 4 ] min:sec	MAXIMUM GAS TEMP. AT CEILING		MAXIMUM GAS TEMP. AT SIDE [ 7 ]		ELAPSED TIME [ 8 ] TO EXTINGUISH, min:sec	MAXIMUM CO <sub>2</sub> , Percent	MAXIMUM CO, Percent	MINIMUM O <sub>2</sub> , Percent
						TEMP., DEG. C	TIME, min:sec	TEMP., DEG. C	TIME, min:sec				
1.1	A	LP	-	1:00	1:15	575	1:20	-	-	0:52	2.2	0.007	17.5
1.2	B	LP	-	1:00	1:15	805	1:25	-	-	0:24	2.1	0.058	17.7
1.3	C	LP	-	1:00	1:15	875	1:25	-	-	0:23	1.7	[ 11 ]	18.5
1.4	E	LP	-	1:00	1:15	520	1:25	955	1:05	0:46	2.6	[ 11 ]	17.5
1.5	F	LP	-	1:00	1:15	450	1:20	805	1:10	0:48	2.8	[ 11 ]	16.6
1.6	G	HP	-	1:03	1:15	120	1:20	-	-	0:54	1.2	[ 11 ]	19.0
1.7	G	HP	-	1:00	1:15	120	1:15	-	-	0:53	1.2	[ 11 ]	19.3
1.8	M	LP/LF	-	1:00	1:15	115	5:05	255	1:10	5:45	2.6	[ 11 ]	17.1
1.9	L	LP/LF	-	1:00	1:15 [ 5 ]	390	1:18	-	-	6:30	2.6	0.059	17.0
1.10	L	LP/LF	-	1:00	1:15 [ 6 ]	330	3:30	-	-	7:30 [ 6 ]	2.5	0.033	17.0
1.11	D	LP	-	1:00	1:14	1100	1:10	-	-	0:46	2.3	0.145	17.5
1.12	K	-	1:00	-	1:30	220	1:25	-	-	3:22	2.5	0.10	17.2
1.13	I	-	1:00	-	1:14	600	1:15	-	-	2:05	2.3	0.092	17.3
1.14	J	-	1:35	-	1:55	880	2:02	-	-	[ 9 ]	2.8	0.26	15.0
1.15	H	LP/LF	1:00	3:00	3:15	120	6:45	970	4:20	1:10.1	2.5	0.098	17.2

NOTES:

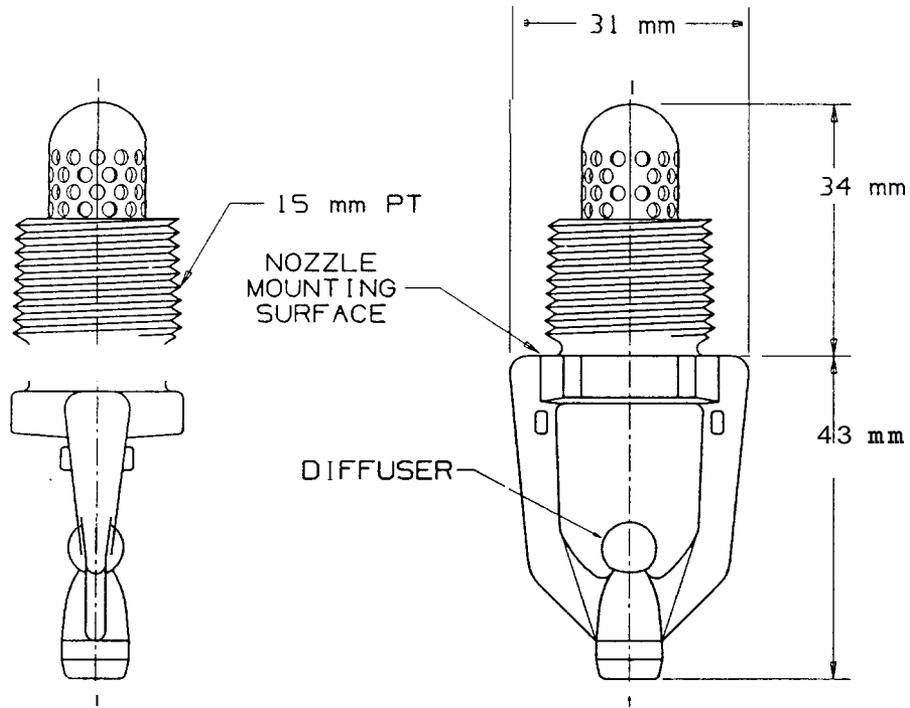
- [ 1 ] Ceiling nozzles located on 2 m x 2 m spacing, 1 m off of the walls, flowing at nominally 11.7 bar ( 12 lpm/nozzle ). Two additional nozzles were located 0.5 m inside of the doorway, 0.3 m in from the left and right edges, and 0.5 m above the top of the doorway.
- [ 2 ] See Table 1 for a description of the fire scenarios.
- [ 3 ] See Table 2 for a description of the fuel spray fire characteristics.
- [ 4 ] Time at which water began to flow out of the nozzles.
- [ 5 ] The temperature of the steel plate measured 390 Deg. C when water from the nozzles was initiated.
- [ 6 ] The temperature of the steel plate measured 385 Deg. C when water from the nozzles was initiated and 227 Deg. C when the test was terminated.
- [ 7 ] The thermocouples located at the center-right side of the mock-up beneath the 0.7 m wide steel plate.
- [ 8 ] Time after initiation of water flow.
- [ 9 ] The fire in the top tray was extinguished in 2:45 and the fire under the floor plates was extinguished in 4:21.
- [ 10 ] The tray fire was extinguished in 5:19 and the spray fire was extinguished in 5:24.
- [ 11 ] Data acquisition not functional.

**TABLE 4**  
**SUMMARY OF FIRE TEST RESULTS FOR AM10 NOZZLE AQUAMIST NOZZLE DELUGE SYSTEM**  
**PROTECTING A SIMULATED MARINE DIESEL ENGINE IN A 10 M X 10 M X 5 M HIGH ENCLOSURE**  
**WITH A 2 M X 2 M HIGH OPEN DOORWAY AND**  
**A CEILING TO NOZZLE DIFFUSER HEIGHT OF 0.9 M [1]**

TEST NO.	FIRE SCENARIO, [2]	SPRAY TYPE, [3]	IGNITION OF POOL OF FIRE, min:sec	IGNITION OF SPRAY OF FIRE, min:sec	INITIATION OF WATER FLOW [4] min:sec	MAXIMUM GAS TEMP. AT CEILING		MAXIMUM GAS TEMP. AT SIDE [8]		ELAPSED TIME [9] TO EXTINGUISH., min:sec	MAXIMUM CO <sub>2</sub> , Percent	MAXIMUM CO, Percent	MINIMUM O <sub>2</sub> , Percent
						TEMP., DEG. C	TIME, min:sec	TEMP., DEG. C	TIME, min:sec				
1.16	D	LP	-	1:00	1:10	915	1:25	-	-	1:20	2.3	0.25	17.3
1.17	L	LP/LF	-	1:00	1:12 [5]	305	1:10	-	-	6:32 [5]	2.5	0.086	17.2
1.18	J	-	1:00	-	1:30	825	2:15	650	4:30	[10]	3.4	0.25	15.8
1.19	H	LP/LF	1:00	3:00	3:15	115	5:00	950	3:45	[11]	3.3	0.26	15.9
1.20	C	LP	-	1:00	1:12	825	1:20	-	-	0:29	1.7	0.097	18.2
1.21	G	HP	-	1:00	1:14	120	2:20	-	-	1:14	1.4	0.063	18.8
1.22	H	LP/LF	-	1:00	[6]	[7]	[7]	[7]	[7]	[12]	3.0	0.074	16.3

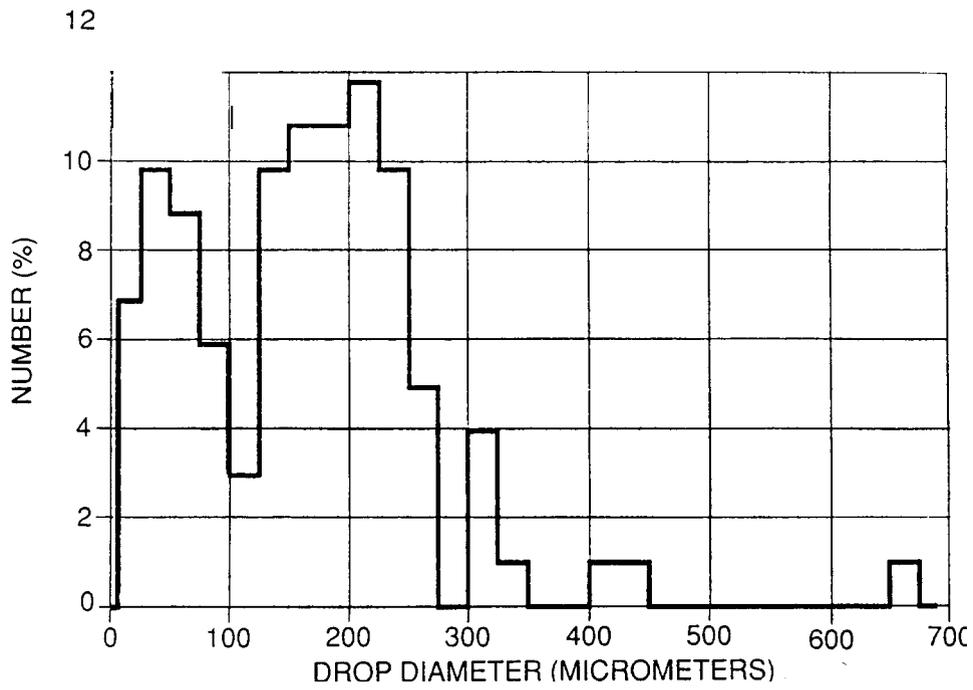
**NOTES:**

- [ 1 ] Ceiling nozzles located on 2 m x 2 m spacing, 1 m off of the walls, flowing at nominally 11.7 bar ( 12 lpm/nozzle ). Two additional nozzles were located 0.5 m inside of the doorway, 0.3 m in from the left and right edges, and 0.5 m above the top of the doorway.
- [ 2 ] See Table 1 for a description of the fire scenarios.
- [ 3 ] See Table 2 for a description of the fuel spray fire characteristics.
- [ 4 ] Time at which water began to flow out of the nozzles.
- [ 5 ] The temperature of the steel plate measured 380 Deg. C and 218 Deg. C when the test was terminated.
- [ 6 ] Reference test without activation of the system.
- [ 7 ] Data acquisition not functional.
- [ 8 ] The thermocouple was located at the center-right side of the mock-up, beneath the 0.7 m wide steel plate.
- [ 9 ] Time after initiation of water flow.
- [ 10 ] The fire in the top tray was extinguished in 0:50 and the fire under the floor plates was extinguished in 4:12.
- [ 11 ] The tray fire was extinguished in 6:45 and the spray fire was extinguished in 7:00.
- [ 12 ] The test was conducted for 15 minutes before the fuel flow was shut off.

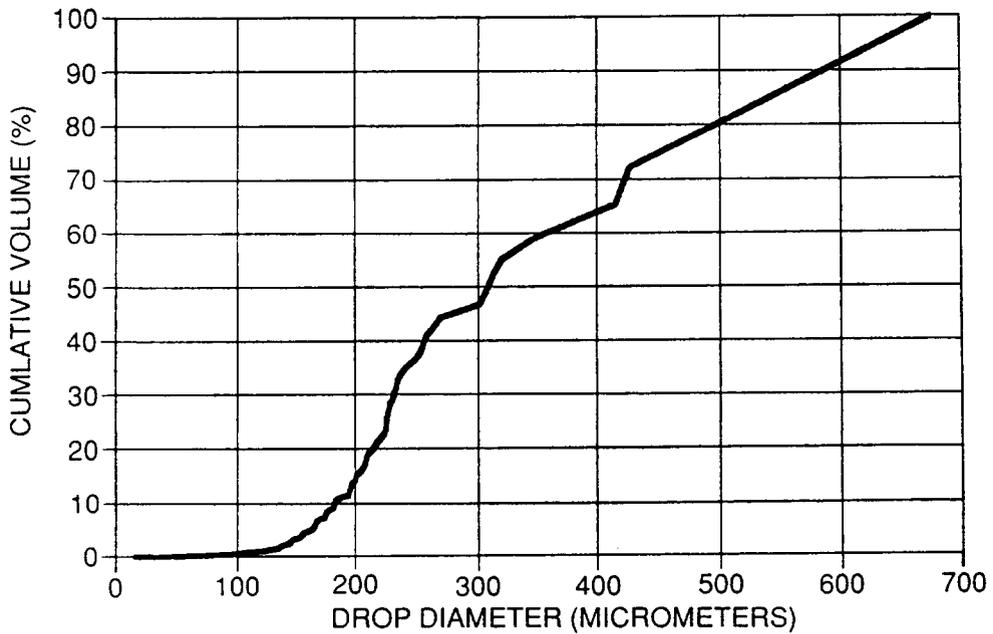


- Patented and Patents Pending

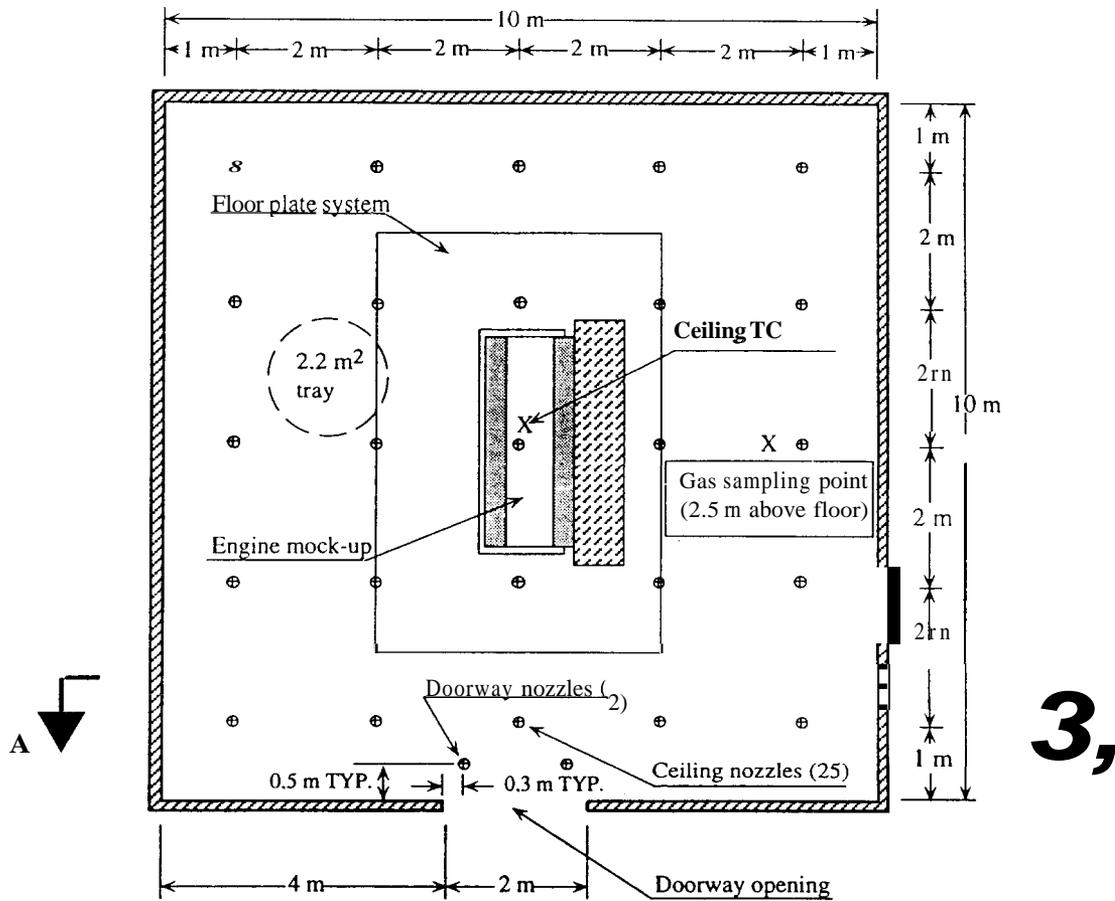
**Figure 1**  
**Illustration Of**  
***AquaMist* AM10 Nozzle •**



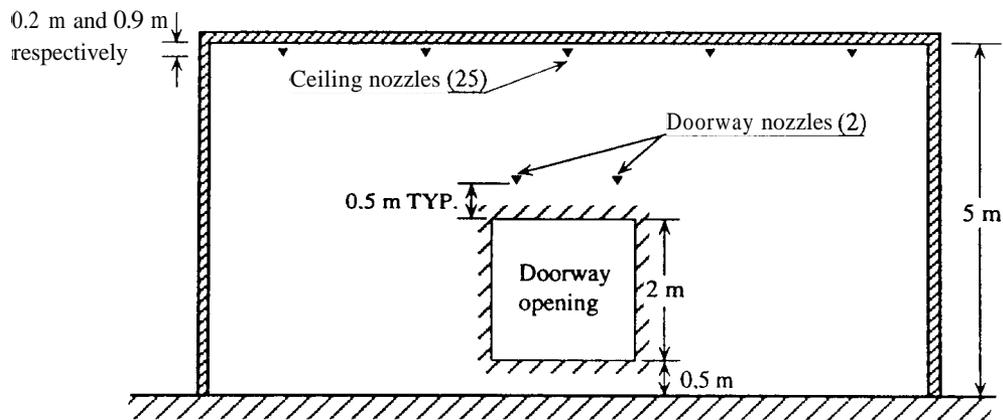
**Figure 2**  
**Number Of Droplets Versus Drop Diameter**  
**For AM10 Nozzle At 12 Bar**  
**One Meter Below Diffuser**



**Figure 3**  
**Cumulative Volume Versus Drop Diameter**  
**For AM10 Nozzle At 12 Bar**  
**One Meter Below Diffuser**

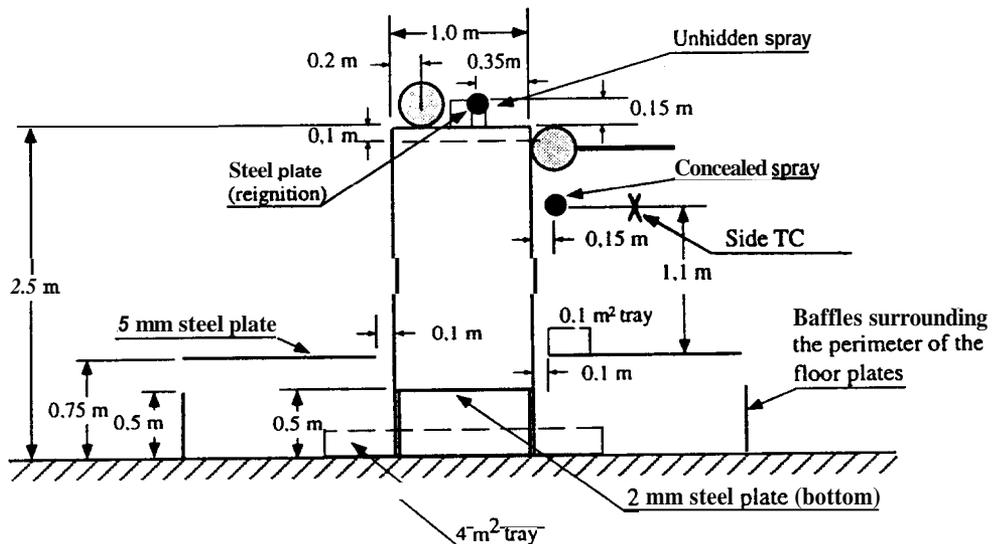
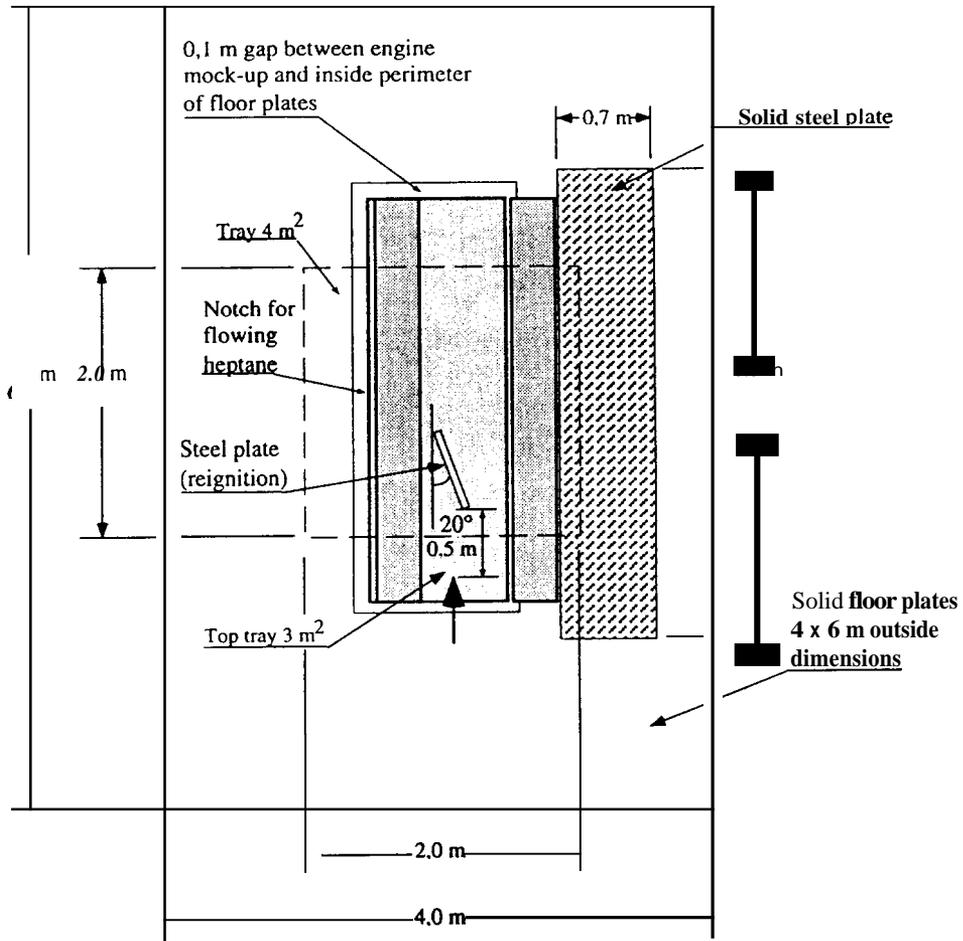


ToR view

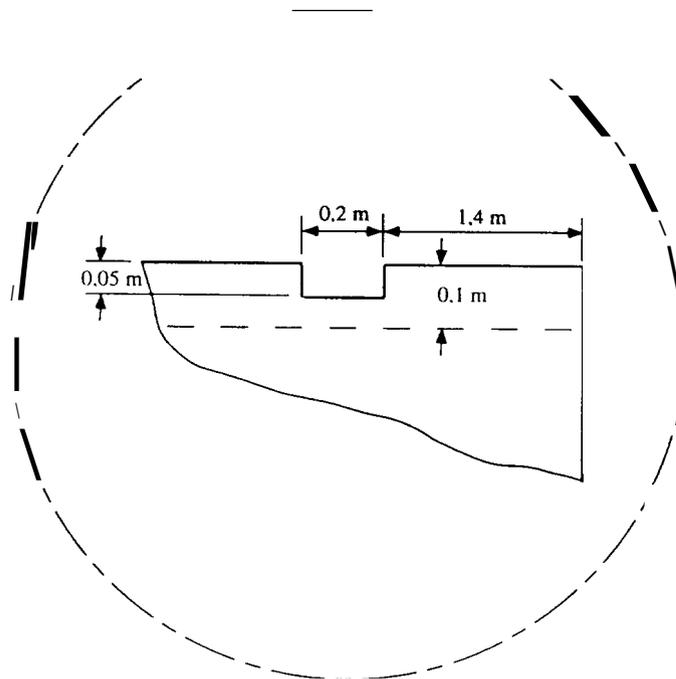
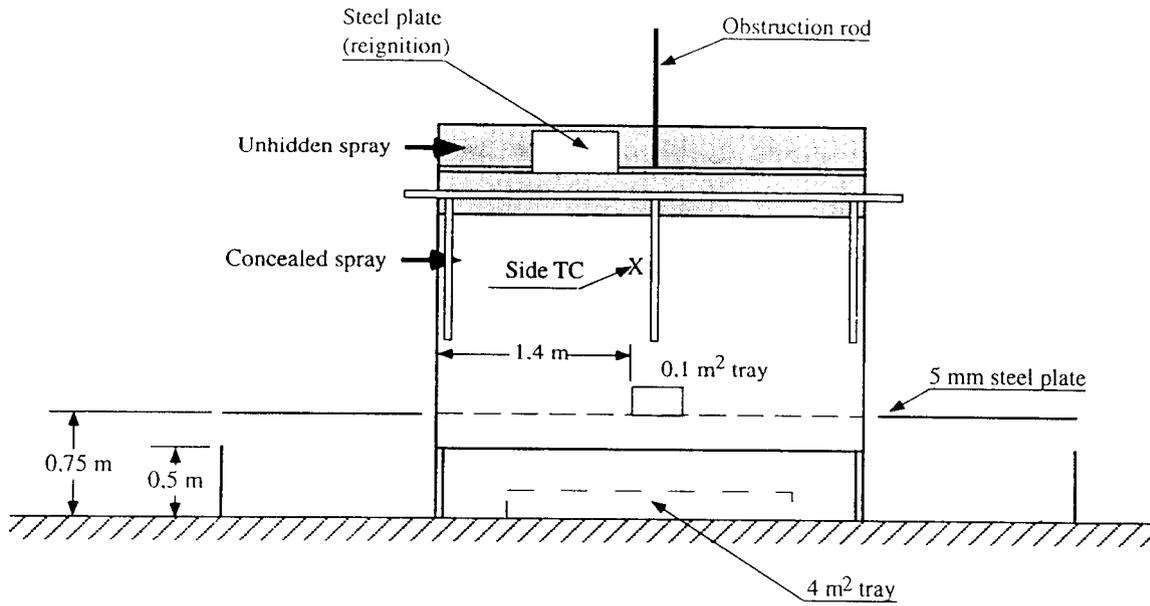


Section view A-A

**Figure 4**  
**Illustration Of Enclosure**  
**And Nozzle Locations**

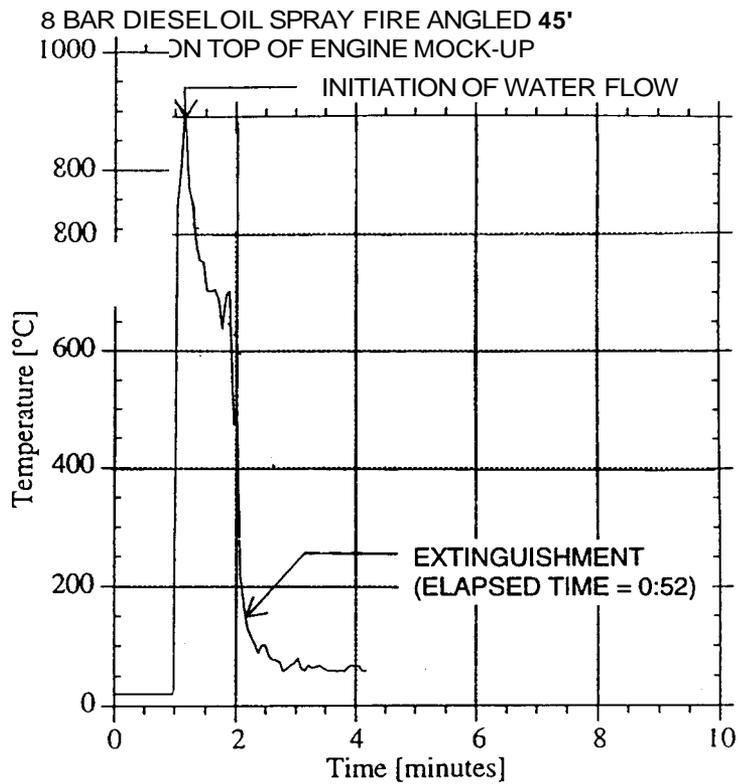


**Figure 5**  
**Plan And End Elevation Views**  
**Of Engine Mock-up**

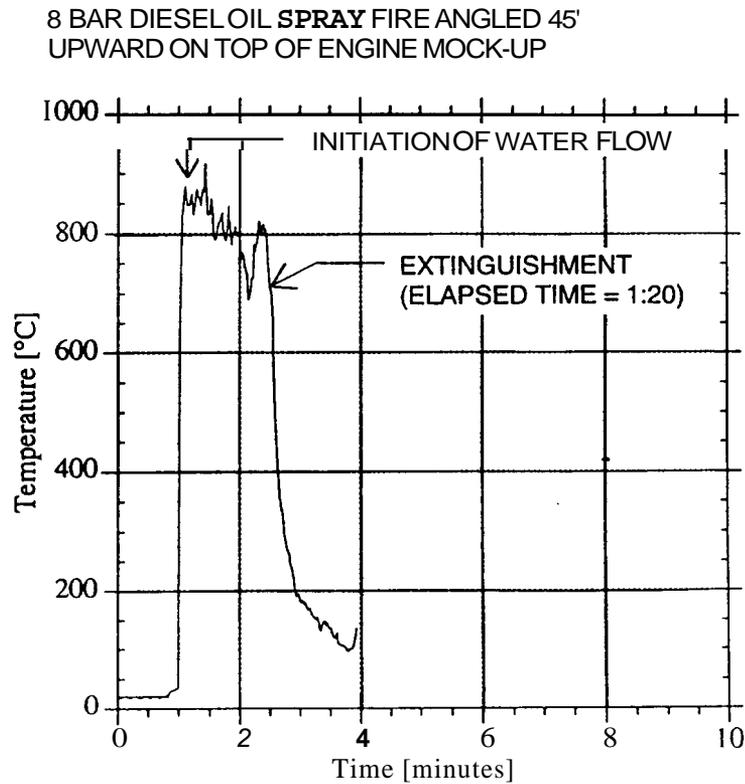


Detail of notch for **flowing** fire scenario

**Figure 6**  
**Side Elevation View Of**  
**Engine Mock-up And**  
**Detail Of Top Tray Notch**

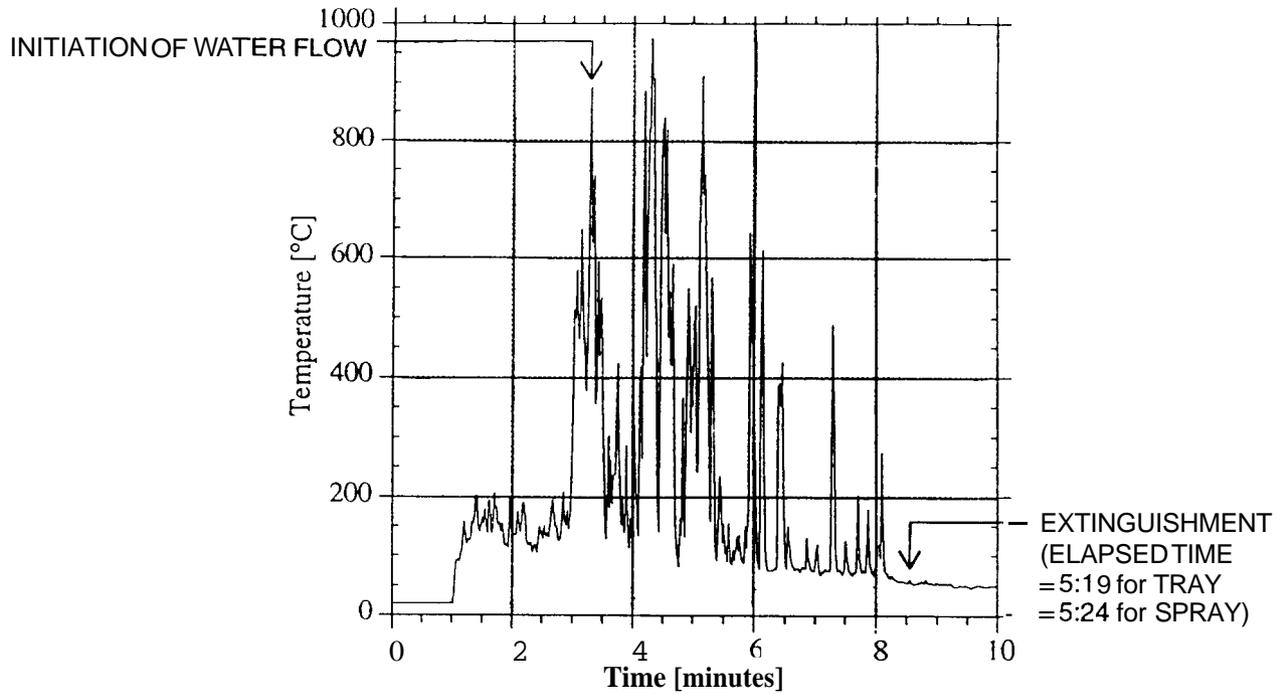


**Figure 7**  
**Test 1.11 Ceiling Gas Temperature**  
**Over Center Of Diesel Engine Mock-up**  
**(Ceiling To AM10 Nozzle Diffuser Height Of 0.2 m)**



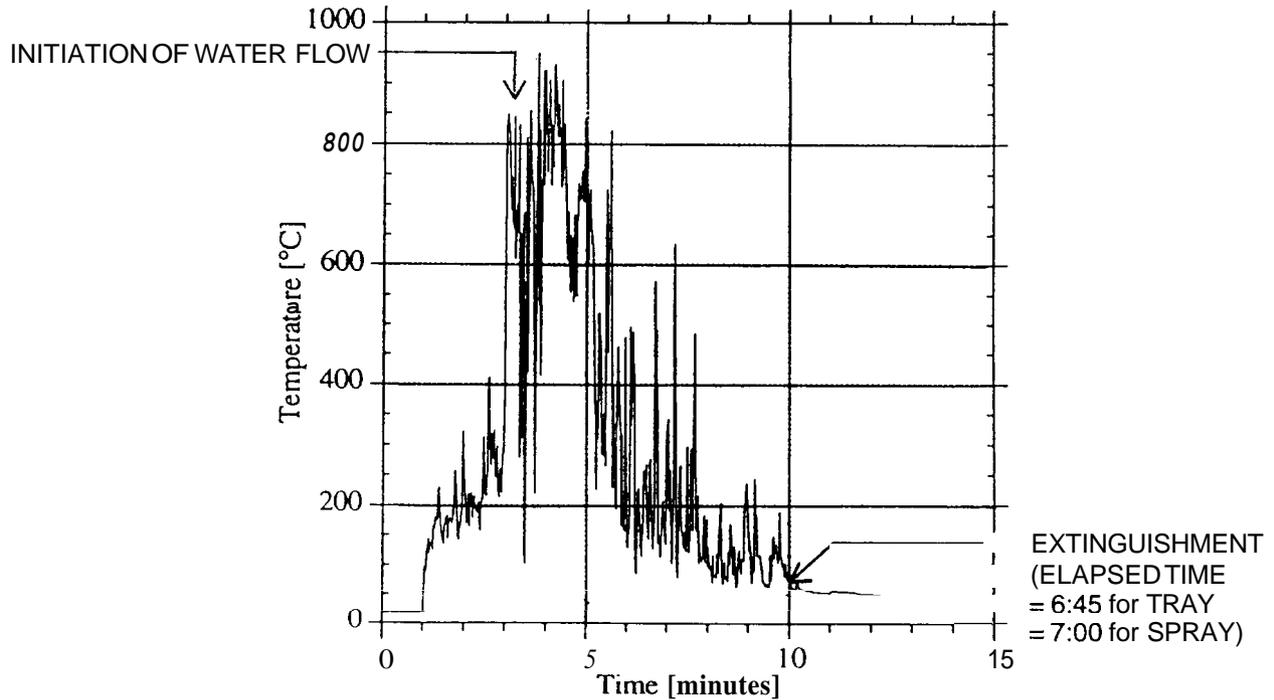
**Figure 8**  
**Test 1.16 Ceiling Gas Temperature**  
**Over Center Of Diesel Engine Mock-up**  
**(Ceiling To AM10 Nozzle Diffuser Height Of 0.9 m)**

8.5 BAR HORIZONTAL DIESEL OIL SPRAY FIRE  
AT RIGHT SIDE OF ENGINE MOCK-UP



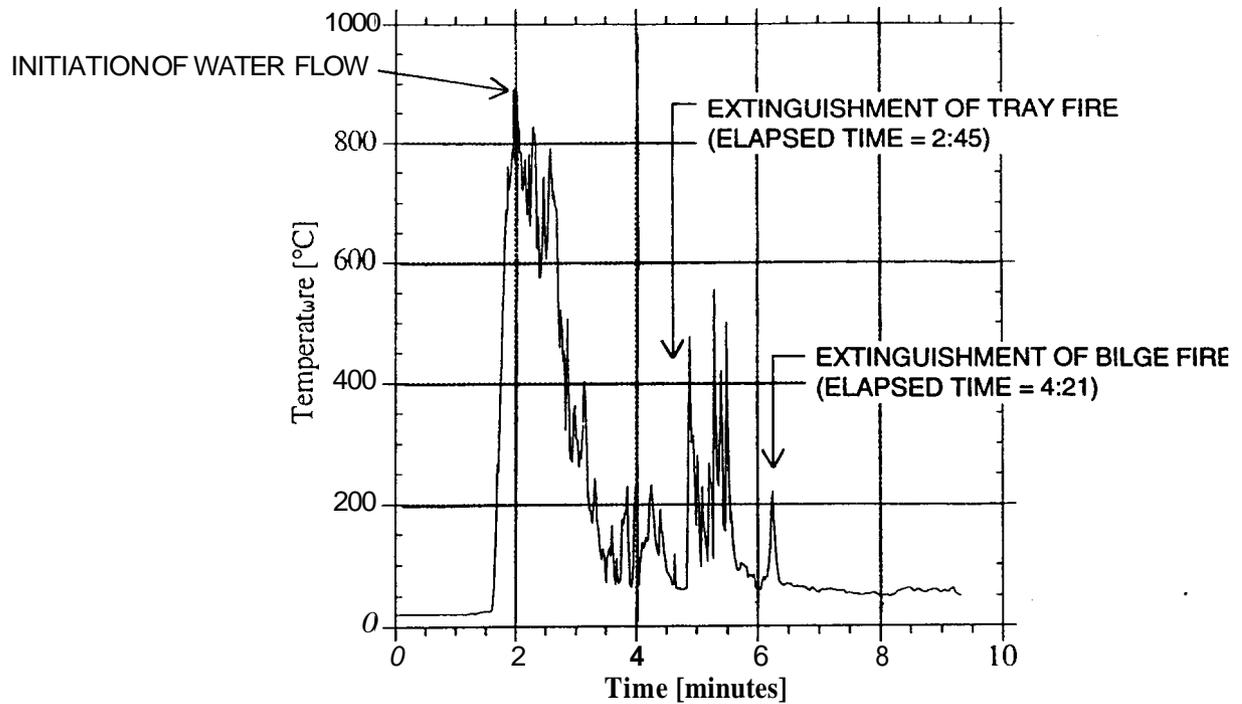
**Figure 9**  
**Test 1.15 Gas Temperature Beneath 0.7 m**  
**Wide Plate At Right Side Of Diesel Engine Mock-Up**  
**(Ceiling To AMIO Nozzle Diffuser Height Of 0.2 m)**

8.5 BAR HORIZONTAL DIESEL OIL SPRAY FIRE  
AT RIGHT SIDE OF ENGINE MOCK-UP



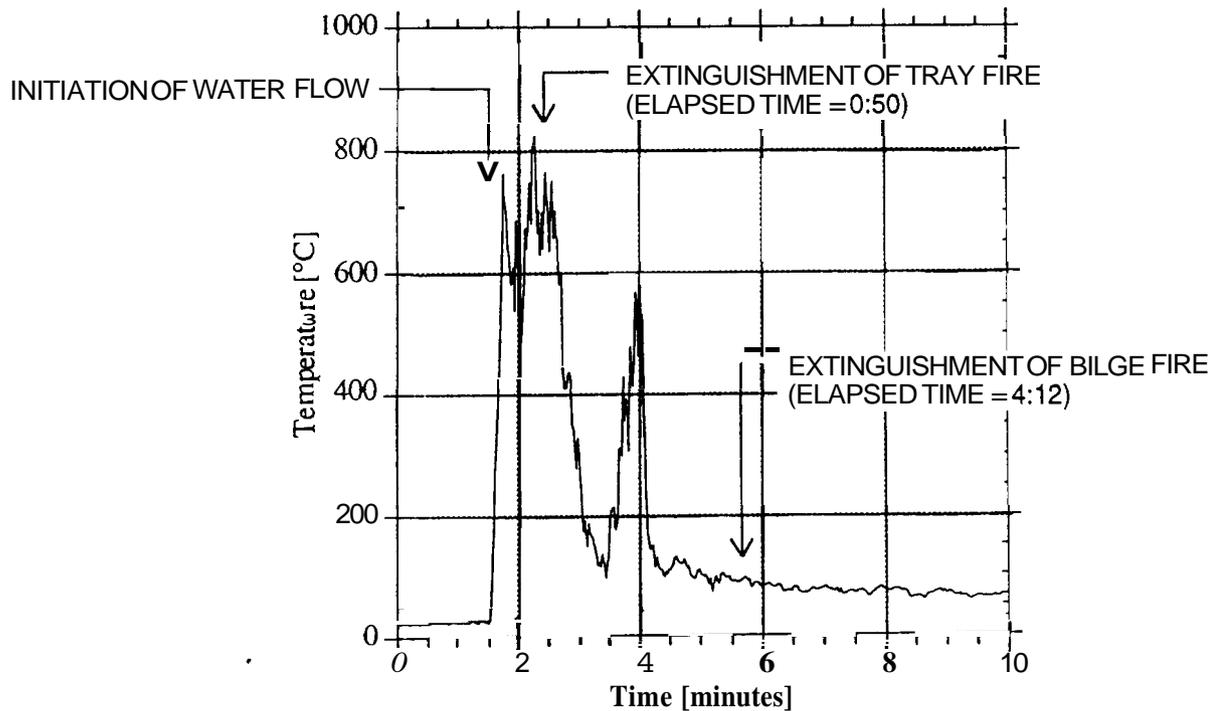
**Figure 10**  
**Test 1.19 Gas Temperature Beneath 0.7 m**  
**Wide Plate At Right Side Of Diesel Engine Mock-up**  
**(Ceiling To AMIO Nozzle Diffuser Height Of 0.9 m)**

FLOWING HEPTANE FIRE

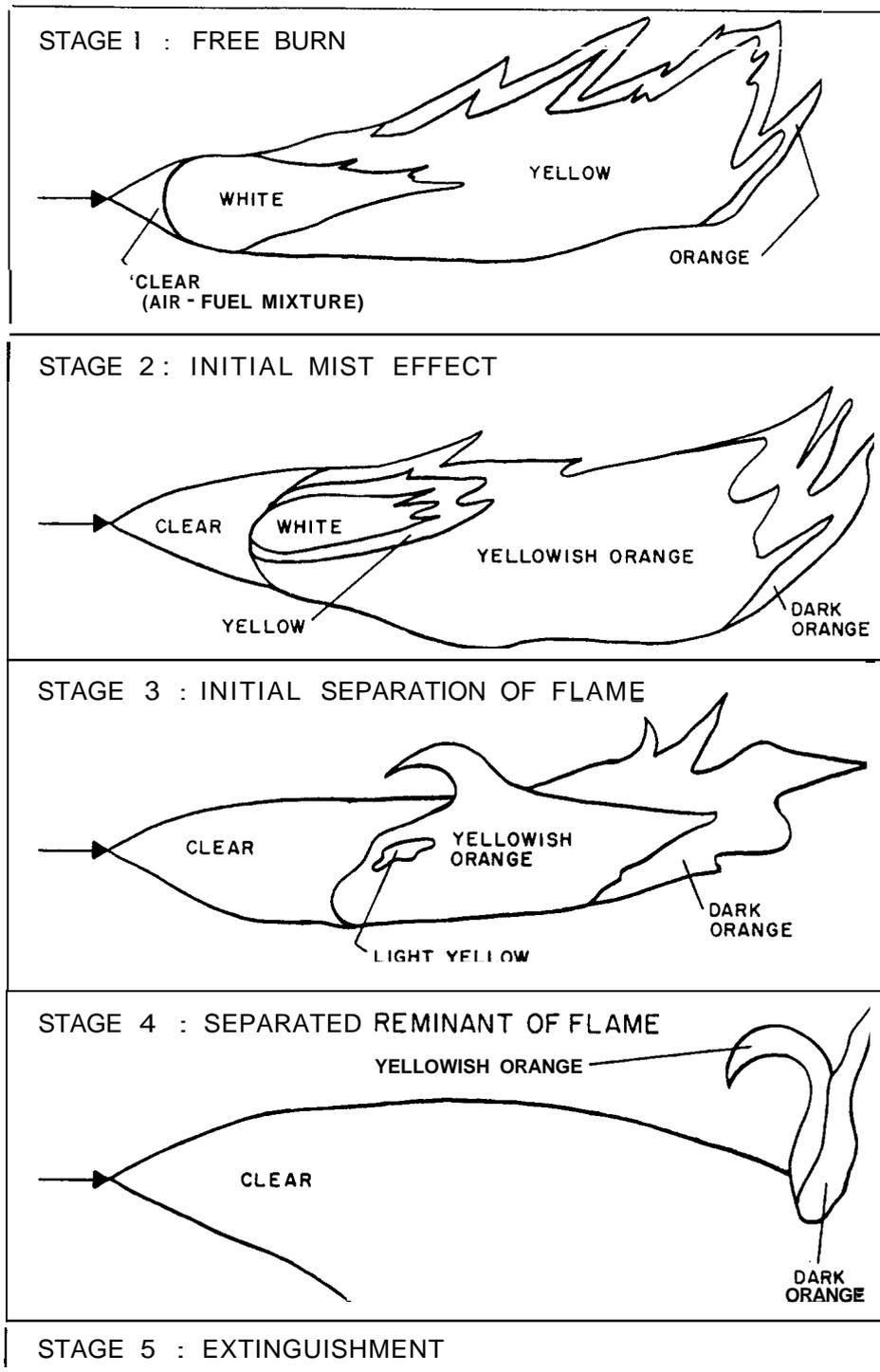


**Figure 11**  
**Test 1.14 Ceiling Gas Temperature**  
**Over Center Of Diesel Engine Mock-up**  
**(Ceiling To AM10 Nozzle Diffuser Height Of 0.2 m)**

FLOWING HEPTANE FIRE



**Figure 12**  
**Test 1.18 Ceiling Gas Temperature**  
**Over Center Of Diesel Engine Mock-up**  
**(Ceiling To AM10 Nozzle Diffuser Height Of 0.9 m)**



**Figure 13**  
**General Stages In The**  
**Extinguishment Of A Diesel Oil Spray Fire By**  
**The AM10 AquaMist Nozzles**