FMRC J.I. 0D3R7.PR

TECHNICAL REPORT

FIRE PERFORMANCE TESTING OF THE FIKE FINE WATER SPRAY SYSTEMS FOR PROTECTION OF COMBUSTION TURBINE ENCLOSURES, MACHINERY SPACES AND SPECIAL HAZARD MACHINERY SPACES 260 m^3 IN VOLUME

By:
Tak-Sang Chan

Prepared for:
Fike Protection Systems
704 South 10th Street
P. O. Box 610
Blue Springs, MO 64013

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FACTORY MUTUAL | Factory Mutual System

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DISCLAIMER

ABSTRACT

Fine water spray systems developed by Fike have been evaluated using Factory Mutual Research Corporation Approval Standards (Class 5560) for gas turbine enclosures, machinery spaces and special hazard machinery spaces in volumes up to 260 m^3. All fire performance requirements for these occupancies were successfully met.

The fire tests were conducted in an enclosure of dimensions 7.3 m x 7.3 m x 4.9 m high. The tests are conducted under the assumption that the protected spaces will be equipped with automatic interlocks for automatic door closure, ventilation shutdown, and fuel and lubrication supply shutoffs (only fuel shutoffs in the case of gas turbine enclosures).

The Fike fine spray system for gas turbine enclosures is a single fluid system, which consists of six eight-orifice nozzles installed on the end walls of the enclosure, discharging water horizontally. Atomization is achieved by an impact disk installed near the orifices. The system extinguished all the required diesel spray and pool fires.

The fine spray system for machinery spaces and special hazards consists of nine nozzles, which also have eight orifices in each nozzle but with a larger clearance between the impact disk and the orifices. The nozzles were installed at 2.44 m spacing below the ceiling, with the impact disk 23 cm down from the ceiling. The system extinguished all the required diesel and heptane test fires.

ACKNOWLEDGMENTS

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I

INTRODUCTION

The phaseout of halons due to their impact on the environment has led to an intense search for halon replacements for fire protection.[1] However, in the case of protection for gas turbine enclosures and associated machinery spaces, carbon dioxide remains a traditional alternative in that it is an environmentally acceptable agent. Carbon dioxide is similar to halon in the sense that installation requirements are based upon the need to provide a design concentration, which will result in fire extinction in the enclosed volume to be protected. Because carbon dioxide is lethal at the required concentration, restrictions involving alarms and delays are necessary if carbon dioxide is to be used in normally occupied areas.[2] Recently, Dundas[3] in a study of fire protection of gas turbine installation, reported a forty-nine percent failure rate for total flooding halon or carbon dioxide systems. Of these failures, thirty-seven percent were attributed to the extinguishment agent leaking from the protected compartment through open doors or vents. This failure rate would also be expected to occur for the new gaseous alternatives to halon since a design concentration would also have to be maintained. For these reasons, Factory Mutual Research Corporation (FMRC) began in 1993 to investigate the use of fine water spray as a replacement to halon and as an alternative to other total flooding gaseous systems,[4] resulting in the development of the FMRC Approval Standards (Class 5560)[5,6] for fine spray systems for the protection of gas turbine enclosures and machinery spaces. A report detailed the development of the test protocol can be found in Reference 7. Fire testing has been conducted using the standards to evaluate the Fike Micro Mist fine water spray systems. This report describes the testing and presents the test results.

The standards for gas turbine enclosures and machinery spaces are discussed below. The primary objective of the gas turbine standard is to assure that the approved product extinguishes spray and pool fires that may occur, for example, due to breaks in lubrication, hydraulic, or diesel fuel lines. An analysis of test data reported by the Norwegian Fire Research Laboratory[8] indicates that propane or natural gas fires will also be extinguished by fine spray systems which extinguish the test fires of the FMRC Approval Standard (Class 5560). The Approval Standard assumes that upon fire detection, fuel supplies are terminated automatically; however, lubrication supply must continue until the rotor coasts down. The water supply of the fine spray system is to be sized to be sufficient to provide protection during the coast-down time of the turbine.

Fire testing for the gas turbine enclosure is designed to assure that the fine spray system would be able to extinguish fires greater than 1 MW in intensity even when the fire is shielded from direct spray interaction. Fires smaller than 1 MW are unlikely to occur in practice and are not expected to cause severe damage to the turbine casing.[7]

The fire performance protocol is also designed to assure that damage caused by cooling of the turbine casing does not result in excessive deformation and blade rubbing. In the case of Fike, the system is designed so that no direct impingement of the spray occurs and testing indicates that blade rubbing will not result from discharge of the system. Fire scenarios in the standard include exposed and shielded diesel oil spray fires and shielded diesel oil pool fires. Shielded diesel spray fire scenarios with an open door were conducted to demonstrate the system's ability to extinguish fires if limited ventilation inadvertently occurs. This is included as a safety factor in the event that required automatic interlocks fail for automatic door closure. Another protection concern is the re-ignition of fires due to hot surfaces. The possibility of re-ignition is covered by requiring a water supply sufficient to protect the turbine during the rotor coast-down period, as specified by turbine manufacturers.

Fire testing was also conducted to demonstrate the ability of the fine spray system to protect against fire caused by insulation mats soaked with diesel oil. One test showed that small mat fires would not maintain a spray fire, while a second fire test demonstrated that an insulation mat fire would be controlled in the absence of a spray fire.

The machinery space fire tests are designed to protect spaces such as auxiliary turbine rooms and other machinery spaces where the hazards are typical of diesel oil spray and pool fires. Examples of such hazards are: oil pumps, oil tanks, fuel filters, gearboxes, drive shafts, or lubrication skids. Shielded and exposed diesel oil spray fires and shielded diesel oil pool fires are used as the fire sources in the performance testing. The fire tests are based on the assumption that the fine spray system will be installed with automatic interlocks for automatic door closure, ventilation shutdown, and fuel and lubrication supply shutdown. Because it is assumed that fuel and lubrication supplies will be shutdown, the water supply is only required to supply protection for ten minutes. The same turbine mock-up is used for the machinery spaces tests as in the gas turbine fire testing. This test configuration provides a highly shielded fire, which is appropriate given the wide variation in machinery configurations in which the fine spray systems may be installed. The major differences between the testing for the machinery spaces and the gas turbine enclosures are: no testing is required related to the cooling of a hot turbine casing by the fine spray system, and fine spray nozzles are only allowed to be installed on the ceiling. The restriction to ceiling installed nozzles has been made because the configuration of the machinery in the room to be protected is unknown a priori. Moreover, hazard related installation rules (local application) are not allowed because the system is tested as a deluge-like system. Another reason that systems with hazard specific placement are not allowed in a generalized machinery space standard is that the complex configuration of machinery in many installations is likely to result in highly shielded fires, and therefore, direct impingement of the fine water spray on the fire cannot be assured. In contrast, fine spray nozzles are allowed to be installed at specific locations with respect to the turbine because the geometry of the gas turbine is well defined and special nozzle placement may be developed in part to cause cooling to be uniform, thus reducing turbine casing deflections compared to non-uniform cooling.

Special hazard machinery space testing is designed to assure extinguishment of spray and pool fires where the hazard is no greater than that of heptane. Engine test cells are an example of such a hazard. The fine spray system must extinguish those fires required for machinery space testing plus a similar set of fires using heptane (shielded and exposed heptane spray fires and shielded heptane pool fires).

II

TEST FACILITIES AND INSTRUMENTATION

Fire testing was conducted at the FMRC Building 18 test facility located in Norwood, MA. The building has two primary test sites. One test site has a building height of 10 m. The other has a building height of 4.7 m. An enclosure for the fire tests required by the FMRC Class 5560 Approval Standards was constructed in the 10-m test site. The enclosure, shown in Figure 1, was 7.3 m x 7.3 m x 4.9 m high (260 m^3 in volume). The dimensions of the enclosure were selected to be representative of an intermediate size of gas turbine enclosures. The test enclosure was constructed using wood studs and 12.7 mm thick wallboards. A door, 0.8 m wide x 2.0 m high, was installed along one wall to provide natural draft in some tests.

A horizontal A36 steel plate, 1.0 m x 2.0 m x 0.05 m thick, formed the top of a "table" placed in the center of the room. The top of the steel plate was one meter above the floor. The plate formed a portion of a mock-up, simulating the underside of a gas turbine. The simulated turbine is shown in the end view of Figure 1. Galvanized sheet metal, attached to the steel plate, formed the remaining portion of the mock-up. A horizontal sheet metal plate extended longitudinally the full length of the enclosure, forming a 1.65 m wide x 7.3 m long horizontal surface. The curvature of the underside of the turbine was simulated by galvanized sheet metal directed upward at an angle of 45^0 on either side of the horizontal sheet metal surface. These side pieces also extended longitudinally the entire length of the enclosure, extending to a height of 1.2 m above the horizontal sheet metal and steel plate surface. The width of the mock-up was 4 m.

The purpose of the steel plate was to provide a means of determining the cooling heat flux caused by the discharge of the fine spray system onto a hot turbine casing. Near the center of the plate, thermocouples were embedded into the plate at three depths: 12.7 mm, 25.4 mm and 38.1 mm below the plate surface. Inconel sheathed thermocouples were embedded in the plate by removing cylindrical plugs from the plate. The thermocouples were inserted, allowing the thermocouple wire to follow a horizontal path sixteen thermocouple diameters in length, thus reducing errors due to the vertical temperature gradient in the plate. The steel cylindrical plugs were replaced, using a heat conductive and electrically insulating sealant and welding around the top of the plugs.

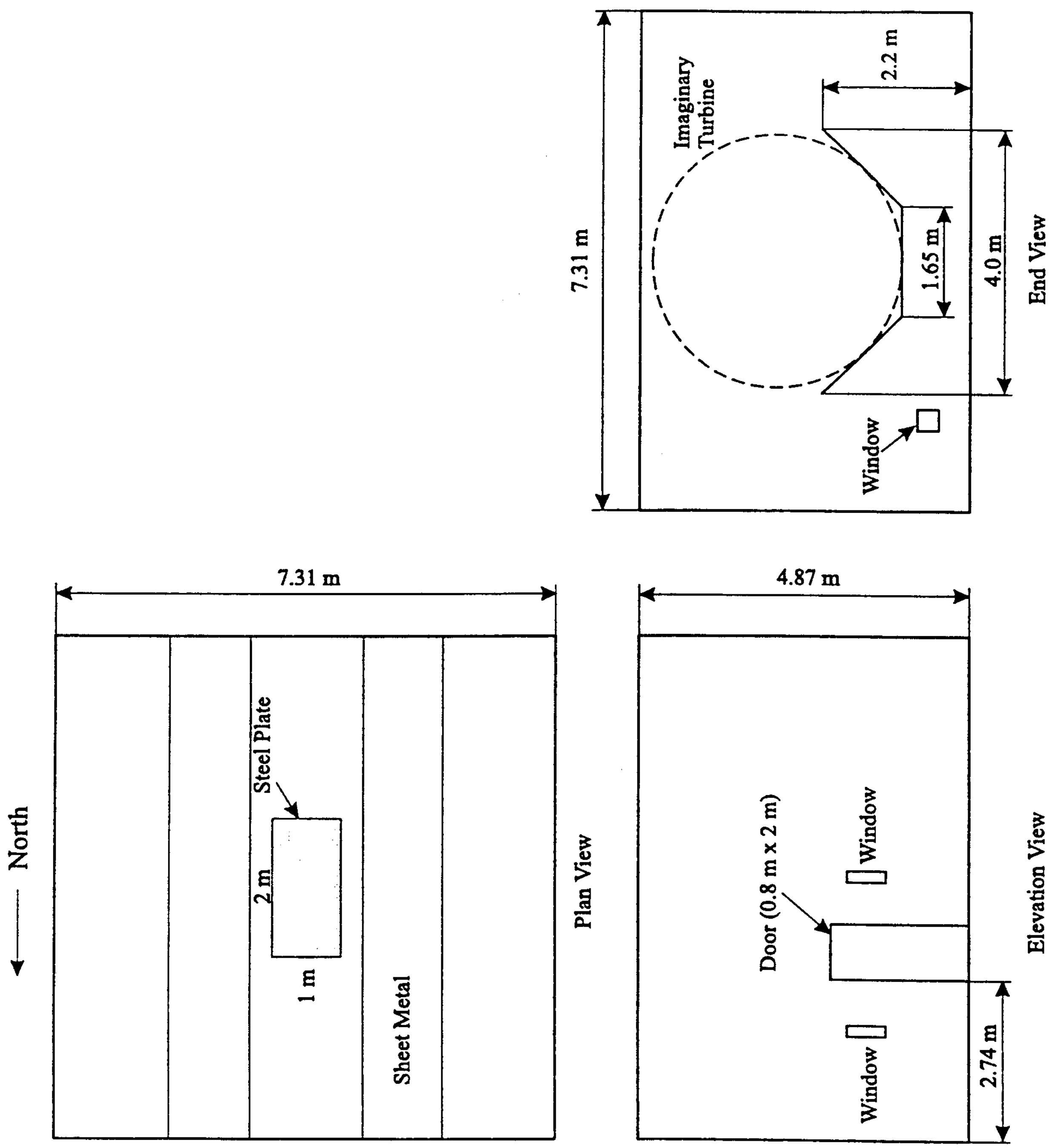


Figure 1. Schematic of the Test Enclosure.

Bare bead thermocouples were used to measure gas temperature at two locations: in the flame and in the entrained air flow. The bare bead thermocouples were welded from 28 gauge chromel-alumel wire.

Concentrations of oxygen were measured using gas sampling near the location of the entrained air thermocouple. Oxygen concentrations were measured to determine if sufficient oxygen was available to sustain combustion. Carbon dioxide concentrations were also measured as a check to see if the oxygen measuring equipment was functioning properly. Oxygen concentrations were obtained with a paramagnetic analyzer and the carbon dioxide concentration was obtained with an infrared analyzer. The analyzers were calibrated at the beginning of each test day using span and zero gases. The gases were filtered and dried prior to entering the analyzers.

Water supply tank pressure and nozzle discharge pressure was monitored using pressure transducers. All data from the various instrumentation channels were acquired at a rate of one scan per second using a computerized data acquisition system.

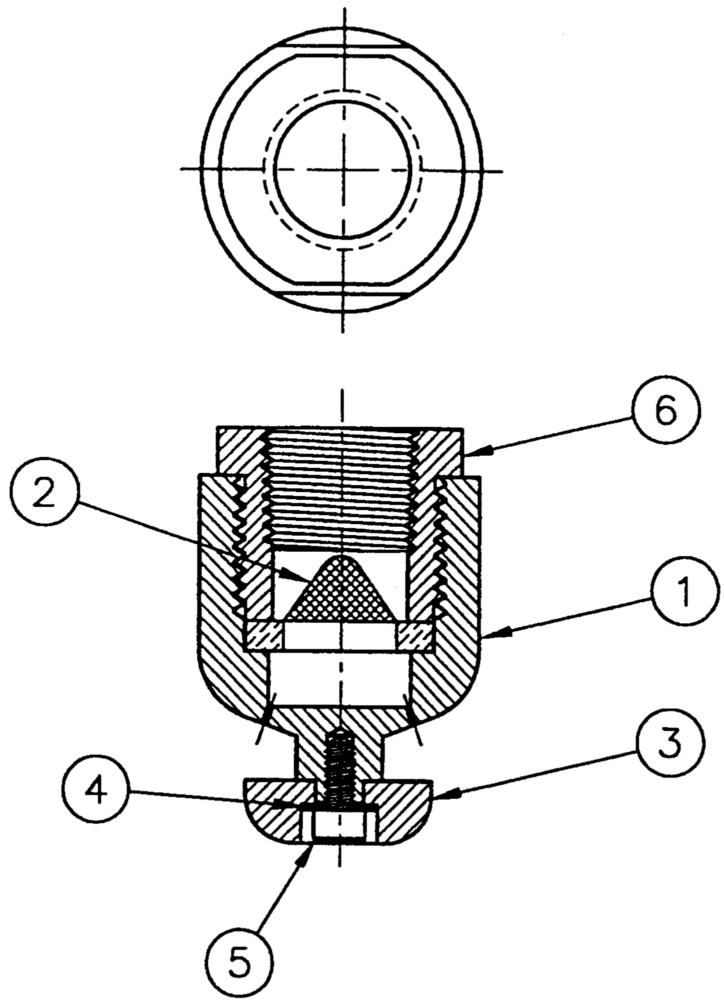
III

FIKE FINE WATER SPRAY SYSTEMS

The Fike fine spray systems tested consisted of a 405 *l* water tank and three commercial nitrogen cylinders pressurized when full to 155 bar. Upon actuation of the system, nitrogen was flowed through a pressure regulator, which reduced the pressure to 22 bar, to pressurize the water tank. Water under pressure entered a dip tube near the tank bottom and flowed to the open fine spray nozzles. The water was discharged in an on/off sequence by opening and closing a water valve at the exit of the dip tube. The gas turbine fine spray system is designed to spray water for 30 seconds and then pause for 40 seconds. This is repeated for eight spraying cycles followed by a 160-second delay, after which the system can start another eight cycles. The machinery spaces system is designed for 40 second discharge and 40 second pause for four spraying cycles. After a one-minute delay, the system may be activated for another four cycles.

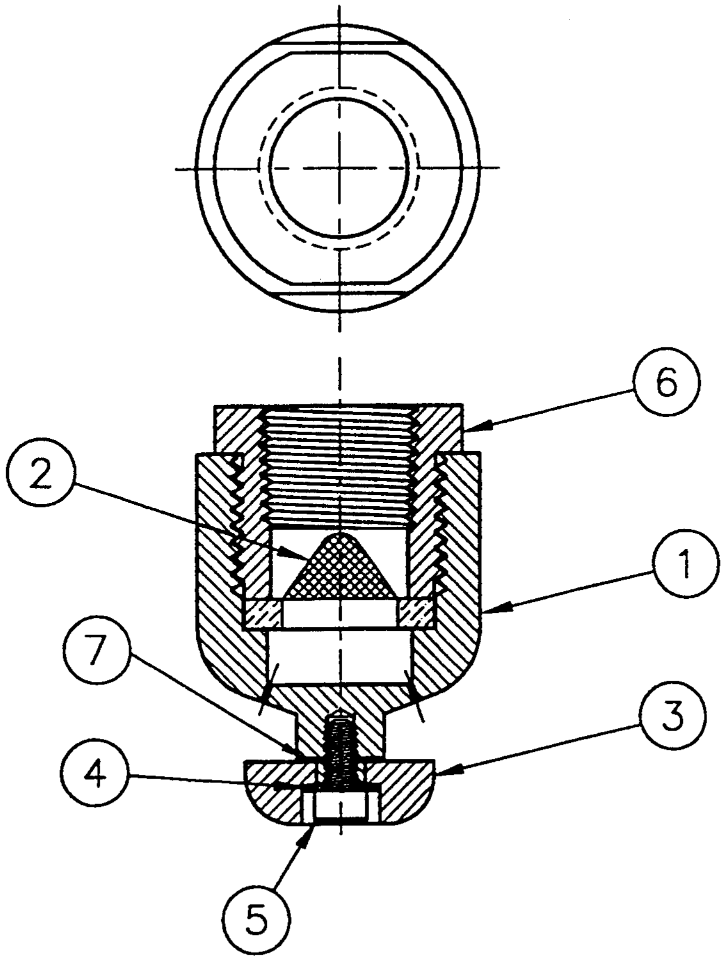
The nozzle used for the gas turbine testing consisted of eight orifices. Figure 2 shows a drawing of the nozzle. Atomization was achieved by impinging water from the orifices onto the edge of an impact disk mounted below the orifices. The axes of the orifices made a 20° angle with the axis of the nozzle body and intercepted with the edge of the disk. The nozzle used for the machinery space was almost identical to the nozzle used for the gas turbine enclosure. The only difference is an addition of a metal shim between the impact disk and the nozzle body, as shown in Figure 3.

The fine spray nozzle placements and piping is shown in Figure 4 for the gas turbine testing. The Fike gas turbine protection system consisted of six nozzles which were installed on the end walls of the turbine enclosure, discharging along the longitudinal turbine aisles. Two nozzles were installed 1.27 m below the ceiling on both the north wall and south wall of the enclosure. The distance between the nozzles to the corresponding enclosure corners was also 1.27 m. The other two nozzles were mounted 1.27 m above the floor directly below one of the upper nozzles. These two nozzles were installed diagonally to each other in the southeast and northwest corners of the enclosure. In addition to the water tank pressure, discharge pressure of the nozzle at the lower southeast corner (see Figure 4) was also monitored. Points A and B in the figure correspond to the fire locations for the exposed spray fire tests, which is described in Section IV.



Item	Description
1	Nozzle Body
2	Strainer
3	Impact Disk
4	#8 Flat Washer SS
5	#8-32 x 3/8" LG. SOC. HD. CAP SCREW SS
6	Water Mist Nozzle Adapter

Figure 2. Schematic of the Fine Spray Nozzle for Gas Turbine Enclosure.



Item	Description
1	Nozzle Body
2	Strainer
3	Impact Disk
4	#8 Flat Washer SS
5	#8-32 x 3/8" LG. SOC. HD. CAP SCREW SS
6	Water Mist Nozzle Adapter
7	Shim, 0.016 Thick

Figure 3. Schematic of the Fine Spray Nozzle for Machinery Spaces.

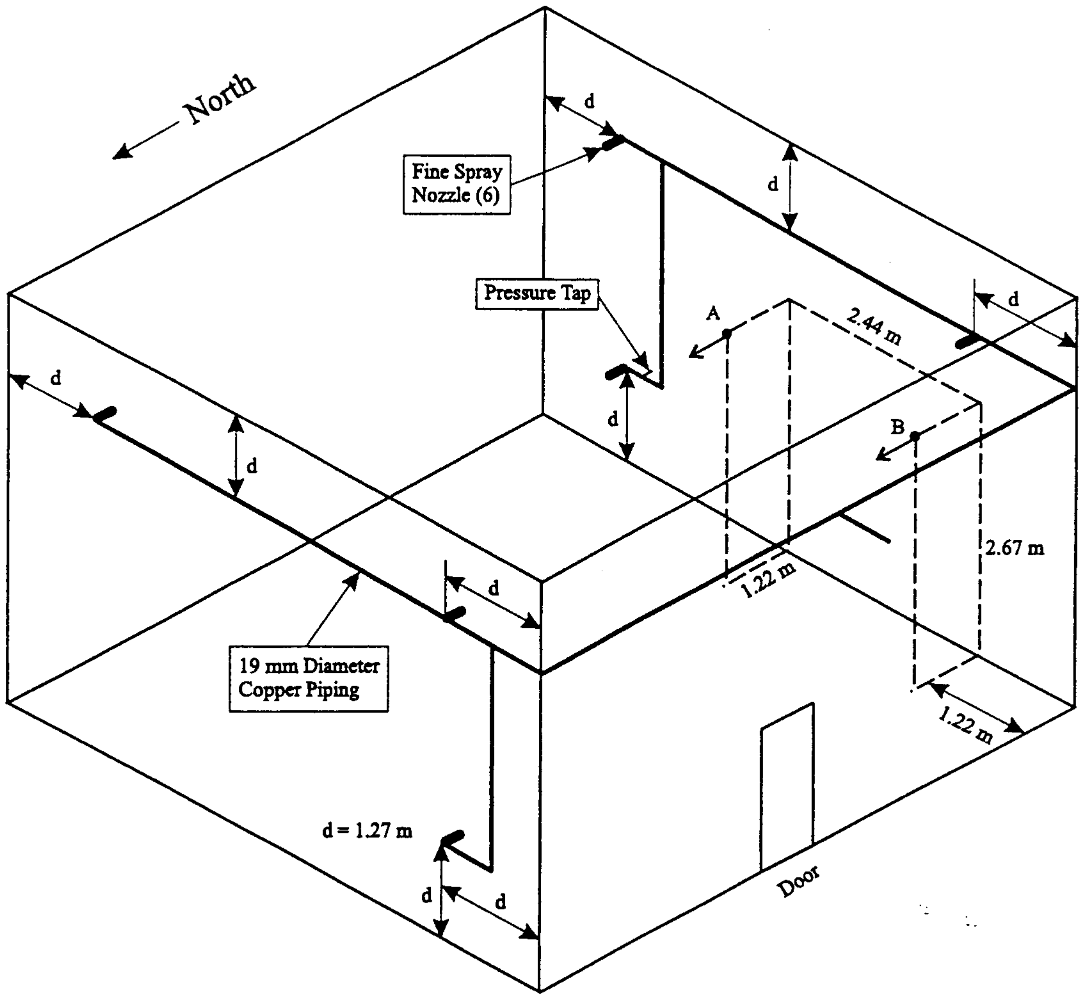


Figure 4. Installation of Fike Fine Spray System for Gas Turbine Enclosure. A and B Indicate the Fire Location in Exposed Spray Fire Testing.

The system configuration used for the machinery spaces is shown in Figure 5. Nine nozzles were installed below the ceiling at 2.44 m x 2.44 m spacing; the top of the impact disk was 23 cm down from the ceiling. A pressure tap was provided at the downstream end of the east pipe to monitor the water discharge pressure. Point B corresponds to the same location as that in Figure 4, whereas point C is the other exposed fire location used in the machinery spaces testing. These locations are noted in Section IV. The same nozzle and piping configuration was used for the special hazard space fire testing.

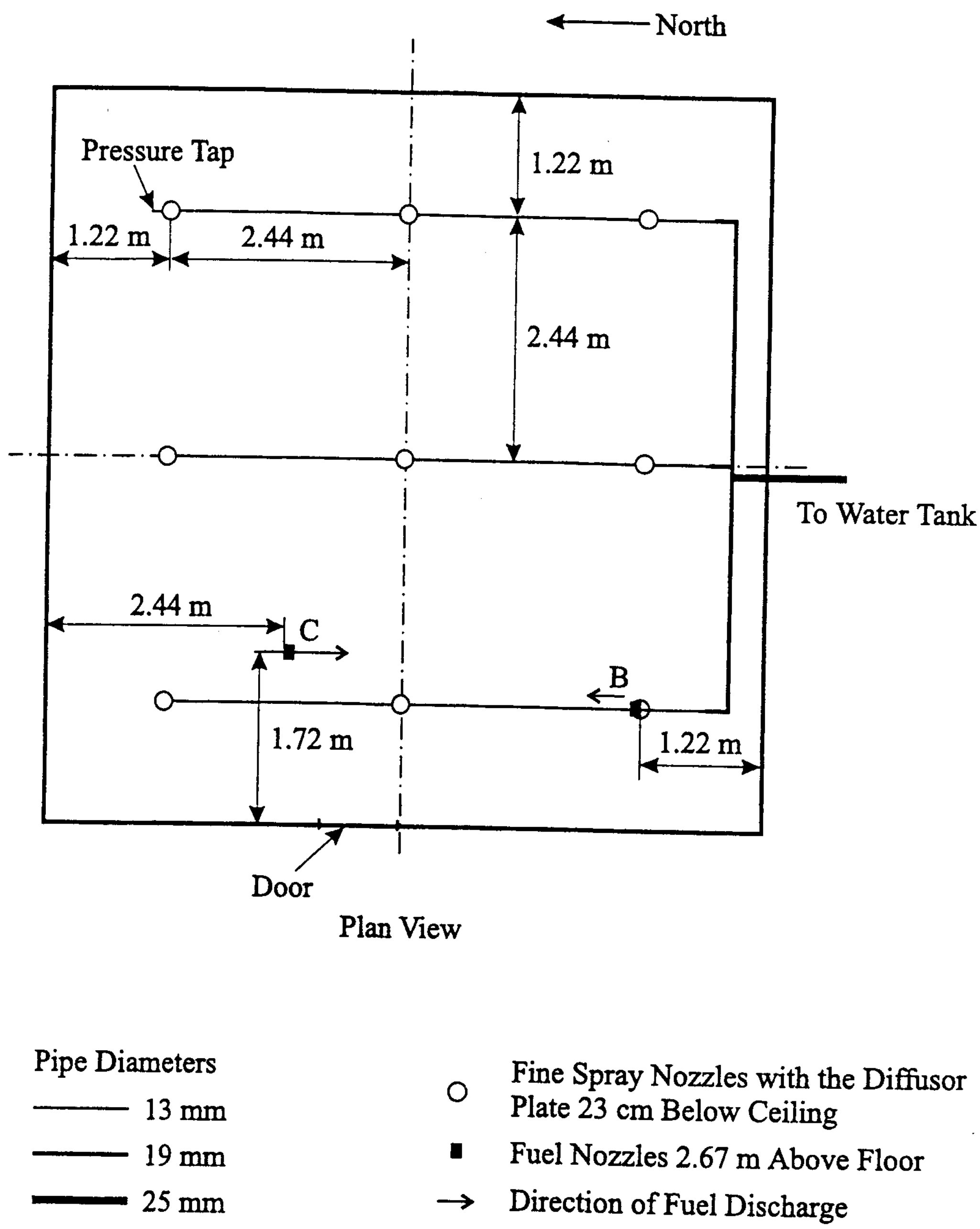


Figure 5. Installation of Fike Fine Spray System for Machinery Spaces and Special Hazard Spaces. B and C Indicate the Fire Location in Exposed Spray Fire Testing.

IV
DESCRIPTION OF FIRE TESTS

4.1 Fire Sources

Fire sources are prescribed in the FMRC Approval Standard (Class 5560) to simulate fires which could result from fractured fuel, hydraulic, or lubrication lines. These fires could take the form of spray and pool fires. Because of the geometric complexity of machinery spaces and gas turbine enclosures, it is likely that fires resulting from fractured lines will be highly shielded and will not be covered directly by fine spray. It is important to demonstrate that the fine spray can be entrained into the fires. For this reason, most of the fire sources prescribed in the standard are highly shielded. For gas turbine enclosures and machinery spaces, the fuel prescribed for the fire sources is diesel fuel (#2 fuel oil). Extinguishment of the diesel oil fires covers protection for fires from hydraulic oils, lubrications oils, propane, natural gas, or other fuels with similar combustion characteristics. In the case of special hazard machinery spaces, the fuel is heptane, thus protection for liquid fuels with combustion characteristics no more severe than heptane are covered.

Diesel and heptane spray fires were generated using conventional oil burner nozzles. The fires were stabilized using a 150 mm diameter, 75 mm long can, open at one end. The fuel nozzle was mounted at the center of the closed end of the can. This stabilizer design protected the base of the fire from direct impingement by water spray. Two fire sizes were used in the diesel spray fire tests: 1 MW and 2 MW. Two different fuel nozzles were used. The operating pressure and flow rates required for the two fire sizes were established using the FMRC Fire Product Collector. Similarly, two heptane spray fires were generated using the same fuel nozzles and operating pressures. Based on the operating pressures, the heat release rates for the two heptane fires were estimated to be 0.8 MW and 1.7 MW. The diesel and heptane spray fires were ignited using a propane torch.

Shielded diesel and heptane pool fires were established above a 1 m^2 square pan. The pan was filled with 5 cm of water and 2 cm of fuel. The heat release rate of the 1 m^2 diesel pool fire was measured to be 1.3 MW using the FMRC Fire Products Collector. The heptane pool fire is estimated to have a heat release rate of 1.9 MW. Both the diesel and heptane pool fires were ignited using a propane torch.

4.2 Test Configurations

Table I lists the test configurations as required by the fire test protocol. For the spray fire source, both shielded and exposed fire configurations were used. Exposed spray fires were located above the turbine mock-up. Two locations were selected for each of the gas turbine, machinery space, and special hazard space testing. These locations were chosen as a potential weak coverage area after a visual examination of the spray pattern and a study of the nozzle layout. For the gas turbine testing, the two locations are indicated in Figure 4 as A and B. Location A was 2.67 m above the floor, 1.22 m from the south wall, and centered between the east and west wall of the enclosure. The fuel was sprayed from south to north as indicated by the arrow. Location B was obtained by moving location A horizontally toward the west wall to a distance of 1.22 m from the wall. Both A and B were 0.5 m above the top edge of the turbine mock-up.

The exposed fire locations for the machinery space and special hazard testing are indicated in Figure 5. In addition to location B as described above, fire tests were also conducted with the fire at location C, shown in Figure 5. The fuel nozzle was oriented so that the fuel was discharged from north to south.

The shielded spray fires were directed along the longitudinal centerline of the gas turbine mock-up under the steel plate, as shown in Figure 6. The fuel spray nozzle was 0.5 m above the floor. Additional shielding was provided by two 0.5 m wide x 1 m high sheet metal baffles attached to the east and west sides of the steel plate as shown in the figure. The locations for the flame temperature and gas concentration measurements were also indicated in the figure. The flame temperature was obtained about 0.25 m beyond the opening edge of the can stabilizer at the can radius. The gas sampling port for entrained air temperature and concentration measurement was located 0.5 m behind the can stabilizer at the same level as the fuel nozzle. When tests were conducted with the 1 MW diesel spray fires and 0.8 MW heptane spray fires, the door to the enclosure was closed. When the 2 MW diesel spray fires and 1.7 MW heptane spray fires were used the door to the enclosure was open.

TABLE I

TEST CONFIGURATIONS USED IN EACH OF THE GAS TURBINE ENCLOSURE, MACHINERY SPACE, AND SPECIAL HAZARD SPACE TESTING

Test Fire Configuration	Gas Turbine Enclosure Testing (Diesel Fuel)	Machinery Space Testing (Diesel Fuel)	Special Hazard Space Testing (Heptane Fuel)
Shielded spray fire	√	√	√
Shielded spray fire with door open	√	√	√
1 m^2 shielded pool fire	√	√	√
Exposed spray fire at location A	√	-	-
Exposed spray fire at location B	√	√	√
Exposed spray fire at location C	-	√	√
Shielded spray fire with 0.09 m^2 insulation mat	√	-	-
1 m^2 shielded pool fire with insulation mat	√	-	-
Cooling Test	√	-	-
Re-ignition Test	√	-	-

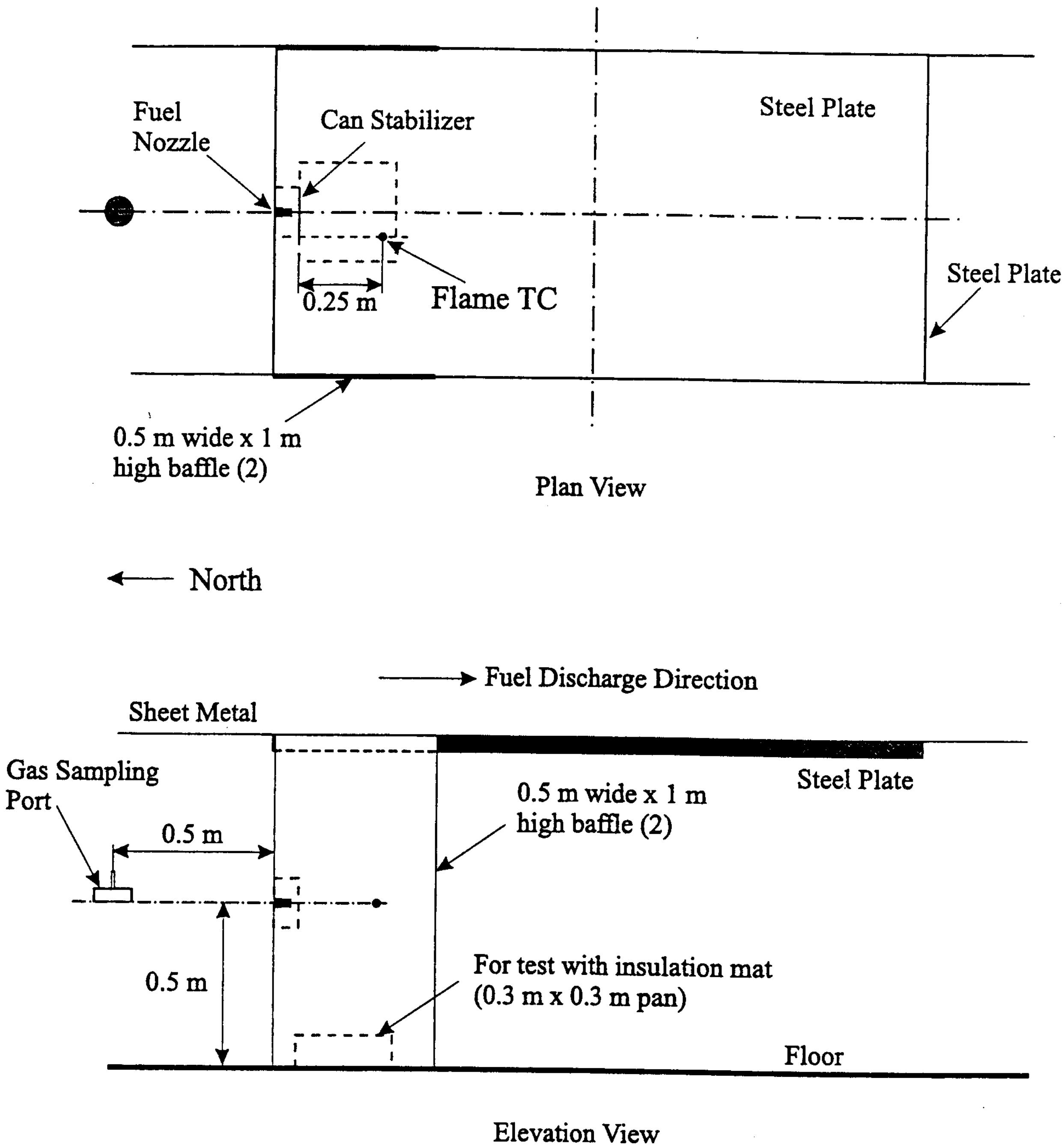


Figure 6. Fire Source Configuration and Instrumentation for Shielded Spray Fire Testing.

The 1 m^2 diesel and heptane shielded pool fire tests were conducted with the pan placed on the floor centered under the steel plate. The 0.5 m^2 baffles were moved close to the center of the plate, as shown in Figure 7, so that half of the pan was shielded. The flame temperature was obtained at 0.25 m from the rim of the pan, 25 mm above the pool surface. The gas sampling port was located about 0.46 m from the outside rim of pan, at the same elevation as the flame thermocouple.

Fire testing was also conducted as part of the gas turbine enclosure testing to determine if diesel oil soaked insulation mat fires would prevent extinguishment of diesel spray fires. Fiberglass insulation mat was placed in a 0.3 x 0.3 m pan and soaked with 2 *l* of diesel oil. The pan was placed on the floor aligned with the edge of the can stabilizer installed as in the 1 MW shielded spray fire. The location of the insulation mat is shown in Figure 6. A small amount of heptane (0.05 *l*) was poured onto the insulation mat to facilitate ignition of the mat. Both the insulation mat and the spray fire were ignited with a propane torch.

Another fire test was conducted to test the ability of the gas turbine enclosure fine spray system to control mat fires. In this test, the 1 m^2 pan was filled with fiberglass insulation material. The pan was filled with about 10 *l* of diesel fuel and a small amount of heptane (0.5 *l*) was poured onto the top of the mat. The test was otherwise the same as that for the 1 m^2 shielded diesel pool fire.

Detection systems were not used to actuate the fine spray systems in any of the fire tests. Instead, the systems were manually actuated after a 15 seconds pre-burn in the case of spray fires or 30 seconds in the case of pool fires. The performance of the fine spray systems in the fire testing would be expected to be enhanced by any further delay due to detection. This is because the mock-up would be heated by the fire, creating hot surfaces which would vaporize water droplets. Fire testing when the mock-up is at ambient conditions, in effect, simulates fire performance during the startup of gas turbine or other equipment.

4.3 CONSIDERATION OF SPRAY COOLING AND RE-IGNITION

An important FMRC Approval objective is to assure that turbine damage will not occur due to excessive cooling of the gas turbine casing by the fine spray system. A test, described in the fire test protocol was conducted to determine the effect of cooling on deformation of the casing.

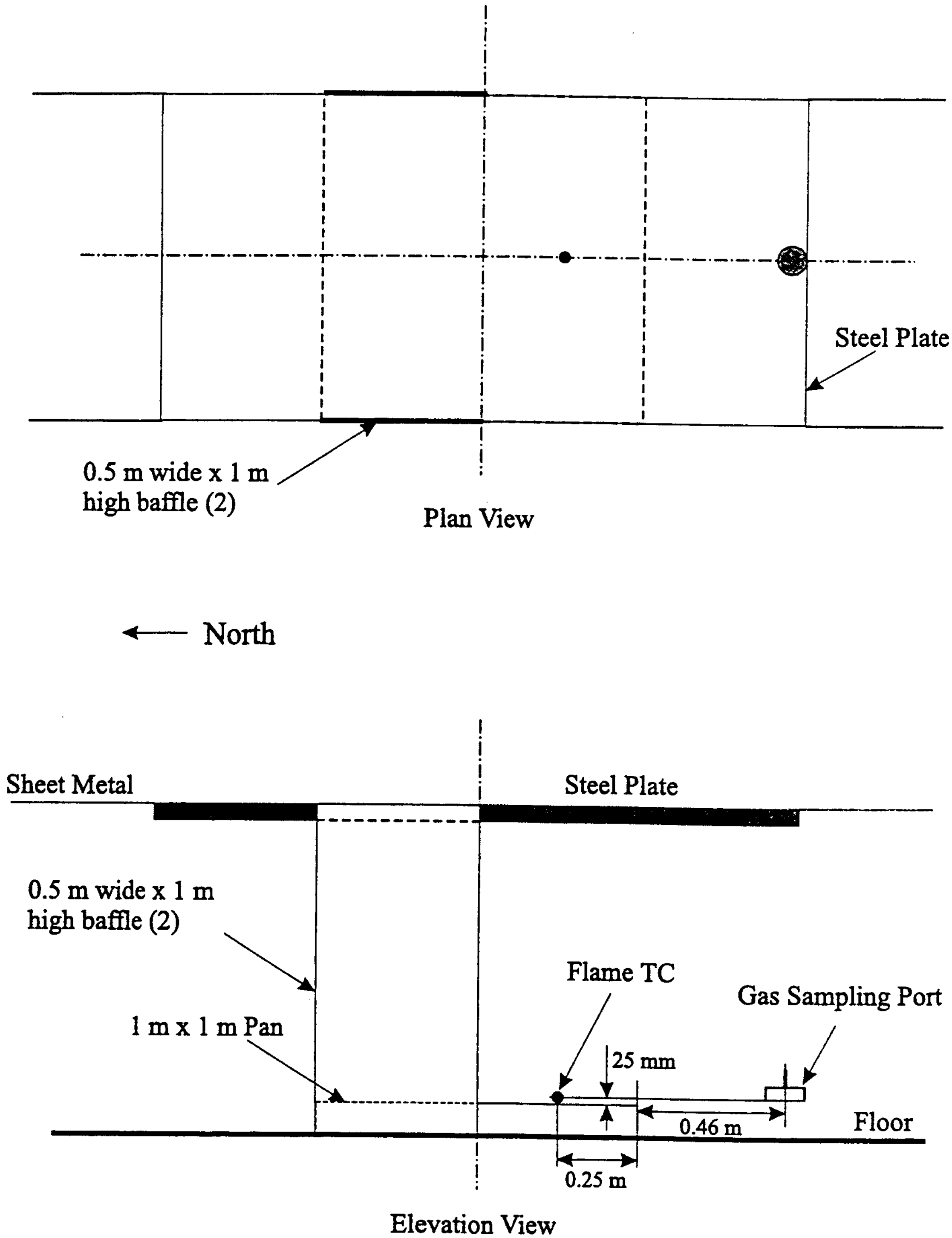


Figure 7. Fire Source Configuration and Instrumentation for Shielded Pool Fire Testing.

In this test, a spray nozzle is installed above the steel plate at the minimum distance specified in the manufacturer's design manual. The steel plate, representing a surface of the turbine casing, is heated to 300 °C, after which the fine spray head discharges water under normal operating conditions. From the temperature record of the embedded thermocouples, the deformation of the turbine casing can be calculated using a model developed by FMRC. In the case of Fike system, however, direct spray impingement on the casing is not expected because the fine spray nozzles are placed on the turbine enclosure walls. The cooling effect was, therefore, investigated in a test using all six nozzles as installed in Figure 2. The steel plate was heated to 300 °C and all the nozzles were discharged.

Re-ignition of diesel spray fires due to hot surfaces is also an issue for gas turbine enclosures. The FMRC Approval Standard prescribes a method for investigation the ability of the fine spray system to cool hot surfaces below the auto ignition temperature for a diesel spray. The steel plate is to be heated to 300 °C, a representative surface temperature for a gas turbine casing, and the fine spray system is then to extinguish the 1 MW shielded diesel spray fire. After extinguishment, the fine water spray discharge is to be continued and re-ignition is not to occur during a 15 seconds continuation of the diesel spray.

V

RESULTS

Results of all fire tests conducted as part of the FMRC approval of the Fike fine spray system for protection of gas turbine enclosure are listed in Table II, along with the water tank pressures, the nozzle discharge pressures, oxygen concentrations and the discharge times required for extinguishment (excluding the 15 s and 30 s pre-burn time). The extinguishment times were based on the flame temperature thermocouple decreasing below 100 °C. Extinguishment was also checked by visual observation. The water discharge pressure measurements are within 5% less than the water tank pressure.

The Fike fine spray system for gas turbine enclosures extinguished all test fires except the shielded insulation mat fire. In this test, the fire was controlled. It was observed that flamelets about only 0.2 m height covered less than half of the mat. It was considered that the fire could be manually extinguished and would not cause significant damage to the turbine.

The oxygen concentrations at the time of extinguishment were at or above 15%. The relatively high oxygen concentration at extinguishment indicates the ability of the fine spray system to extinguish the fires before self-extinguishment would occur due to oxygen depletion.

Figure 8 shows the temperature of the steel plate in the spray cooling tests. Recall that the plate was heated to a temperature of 300 °C. No sudden change after the fine spray system discharged (at time zero) is observable; a thermal stress model indicates that deformation of the turbine casing would be negligible.

Tables III and IV show results from fire testing for the machinery spaces and special hazard spaces, respectively. As indicated in the Tables, the Fike machinery space fine spray system extinguished all test fires required in the FMRC Approval Standards (Class 5560) for machinery spaces and special hazards. The oxygen concentrations at the time of extinguishment were all above 15%.

TABLE II

FIRE TEST RESULTS FOR GAS TURBINE ENCLOSURES

Test Fire Configuration	Water Tank Pressure (bar)	Min. Oxygen Concentration (%)	Extinguishment Time (min:sec)*
Shielded spray fire	22.75	15.9	4:28
Shielded spray fire with door open	22.68	15	3:29
1 m^2 shielded pool fire	22.75	x	4:37
Exposed spray fire at location A	22.61	17.1	4:21
Exposed spray fire at location B	22.54	17.2	4:27
Shielded spray fire with 0.09 m^2 insulation mat	22.75	x	3:18
1 m^2 shielded pool fire with insulation mat	22.58	-	Control
Re-ignition Test	22.39	15	2:44

* Time from actuation of the fine spray system.
x Oxygen data not reliable due to flame exposure to gas sampling port.

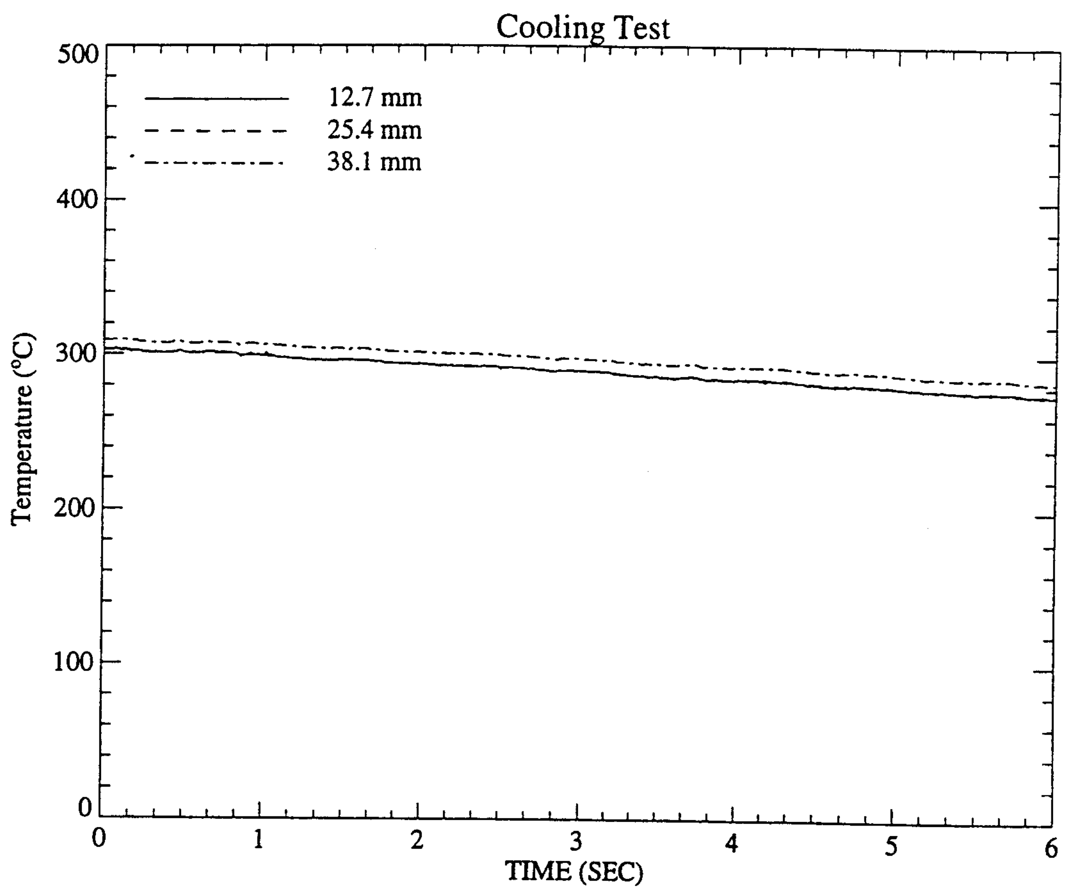


Figure 8. Temperature at Three Depths within Steel Plate during Discharge of Fine Spray System for Gas Turbine Enclosure.

TABLE III

FIRE TEST RESULTS FOR MACHINERY SPACE TESTING

Test Fire Configuration	Water Tank Pressure (bar)	Min. Oxygen Concentration (%)	Extinguishment Time (sec) *
Shielded spray fire	22.26	15.8	4:50
Shielded spray fire with door open	22.40	15.3	2:09
1 m^2 shielded pool fire	22.12	16.1	4:00
Exposed spray fire at location B	22.40	17.1	4:35
Exposed spray fire at location C	22.06	17.9	3:17

* Time from actuation of the fine spray system.

TABLE IV

FIRE TEST RESULTS FOR SPECIAL HAZARD SPACE TESTING

Test Fire Configuration	Water Tank Pressure (bar)	Min. Oxygen Concentration (%)	Extinguishment Time (sec) *
Shielded spray fire	22.26	16.1	3:07
Shielded spray fire with door open	21.85	15.1	2:15
1 m^2 shielded pool fire	22.13	15.7	2:05
Exposed spray fire at location B	22.19	16.9	4:16
Exposed spray fire at location C	22.40	17.8	3:13

* Time from actuation of the fine spray system.

VI

CONCLUSIONS

1. The Fike fine spray system for gas turbine enclosure up to 260 m^3, consisting of six eight-orifice nozzles installed on the enclosure walls, extinguished all shielded diesel spray and pool fires as required in the FMRC Approval Standards (Class 5560) for gas turbine enclosures. The fine spray system also extinguished a combination of diesel spray and diesel oil soaked insulation mat fire and controlled a diesel oil soaked insulation mat fire. Deformation of a simulated hot turbine casing due to spray cooling of has been shown negligible.

2. The Fike fine spray system for machinery spaces up to 260 m^3, consisting of nine eight-orifice nozzles installed at 2.44 m spacing, extinguished all shielded diesel spray and pool fires as required in the FMRC Approval Standards (Class 5560) for machinery spaces.

3. The Fike machinery space fine spray system also extinguished all shielded heptane spray and pool fires as required in the FMRC Approval Standards (Class 5560) for special hazard spaces up to 260 m^3.

REFERENCES

1. Grant, C. C., "Halon and Beyond: Developing New Alternative," NFPA J., p. 40-54, November/December 1994.

2. Williamson, H. V., "Carbon Dioxide and Application Systems," in Fire Protection Handbook, 16th Edition, NFPA, Quincy, MA, 1986.

3. Dundas, R. E., "Experience with External Fires in Gas Turbine Installations and Implications for Fire Protection," ASME Paper No. 90-GT-375, Gas Turbine and Aeroengine Congress and Exposition, Brussels, Belgium, June 11-14, 1990.

4. Bill, R. G., Jr. and Groce, P. A., "Perspective on Fine Spray (Water Mist) Technology at Factory Mutual Research Corporation," Proc. Int. Conf. on Water Mist Fire Suppression Systems, Swedish National Testing and Research Inst., Boras, Sweden, November 4-5, 1993.

5. "Draft Performance Requirements for Fine Water Spray Systems for the Protection of Gas Turbines in Enclosures," Class 5560, Factory Mutual Research Corporation, Norwood, MA, 1996.

6. "Draft Performance Requirements for Fine Water Spray Systems for the Protection of Machinery Spaces," Class 5560, Factory Mutual Research Corporation, Norwood, MA, 1996.

7. Bill, R. G, Jr. and Ural, E. A., "A Fire Test Methodology to Evaluate Fine Water Spray Protection of Combustion Turbine Enclosures and Machinery Spaces," FMRC Technical Report, J. I. 0B0J2.RA, to be issued.

8. Wighus, R., Arne, P., Drangshalt, G., and Stensaas, J. P., "Full Scale Water Mist Experiments," Proc. Int. Conf. on Water Mist Fire Suppression Systems, Swedish National Testing and Research Institute, Boras, Sweden, November 4-5, 1993.