FIRE SUPPRESSION PERFORMANCE TESTING OF WATER MIST SYSTEMS FOR COMBUSTION TURBINE ENCLOSURES

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ABSTRACT

The use of fine water spray to replace existing halon or CO_2 systems for the fire protection of combustion turbine enclosures presents a number of unique challenges: 1) direct impingement by water sprays on all potential fire locations can not be ensured due to a large number of obstructions inside the enclosure; 2) fires that can not be extinguished by a fine water spray system may cause damage to the turbine; 3) a potential for re-ignition and sustained fires exists until all the pressurized fuel sources are isolated after the turbine comes to a complete stop; and 4) a water spray, capable of rapidly cooling the turbine casing, can cause damage as well.

Factory Mutual Research Corporation (FMRC) has developed a performance-based fire test protocol. For combustion turbine enclosure protection, the fine water spray system must:

- *be capable of extinguishing any fires greater than 1 MW in intensity even when the fire is shielded from the direct spray interaction;*
- *prevent and not cause damage to critical turbine components (either by fire or due to excessive cooling of the turbine casing by fine water system).*

Tests are conducted in an enclosure whose dimensions are specified by the system manufacturer. The FMRC test protocol calls for suppression, re-ignition and water spray heat transfer tests. The heat transfer test results are analyzed to assess the damage potential of a particular system due to excessive cooling. Another test evaluates the fire suppression ability of the water spray system when the enclosure integrity is partially compromised. This is a possible advantage of fine water sprays over halon or CO_2 protection.

Recently, a water mist system has successfully fulfilled the test protocol in an 80 m^3 enclosure. Another system is being tested in a 260 m^3 enclosure. This paper presents the FMRC test protocol and the test data obtained in the 80 m^3 enclosure.

I. INTRODUCTION

The use of Fine Water Sprays **(FWS)** as a fixed fire suppression system appears to be a promising alternative to certain halon or CO_2 applications. However, this new technology can not be applied as a general total flooding or local application fire suppression system, yet. Until such time, the approach has been to build up our understanding and confidence by developing applications for specific risk and specific occupancies. Factory Mutual Research Corporation (FMRC) Fine Spray Research Program is considering applications such as flammable liquid handling and storage rooms, telephone central offices, computer clean rooms, marine applications, light hazard occupancies and local application. Protection of combustion turbine enclosures was selected as the first potential FWS application. An earlier FMRC sponsored project focused on defining the hazards, reviewing the existing data, and compiling appropriate Approval and Standard requirements for this application.

The protection philosophy outlined below and the fire tests described in this document were developed in the course of this project.

II. BACKGROUND

Dundas[1] studied 64 fire incidents in gas turbine installations. The majority of the fires (40 incidents) were in the gas turbine compartment, eight fires occurred in the load tunnel, while the remaining sixteen fires involved accessories such as the lubrication system, fuel skid, starter skid, turning gear and A.C. generator. Out of the 64 fires, 27 were spray fires, 11 were pool fires, and 26 were other types such as electrical fires, soaked insulation fires, vapor explosions and the cases where the type of fire is unknown. Fuel oil (26 fires) and lube oil (24 fires) were the primary combustibles for the fires. Thirty-nine installations were equipped with total flooding systems. In twenty incidents the total flooding systems were successful while in nineteen cases they were not.

A halon or CO_2 total flooding system design assumes that combustion turbines are housed in relatively well-sealed enclosures, and the enclosure doors remain closed during discharge. Furthermore, the forced ventilation of the enclosure is automatically shut and the fuel delivery is stopped immediately upon fire detection. After fire detection, the doors are assumed to remain shut for an extended period until the hot surfaces cool beyond the autoignition possibility. The same assumptions are expected to be in effect for FWS protection. However, the "limited natural ventilation tests" that will be discussed below demonstrate that absolute enclosure integrity is not necessary for FWS system effectiveness. The lack of absolute enclosure integrity would be detrimental in the case of halon or CO_2 protection.

Upon detection and after the fuel supply is terminated, the rotor will coast down. All control oil and lube oil pumps and valves will be shut as soon as possible, after the rotor stops turning. This procedure, which is necessary in order not to introduce additional combustible fluids into the enclosure, is not always mandated with other protection methods. The water supply must be sufficient to provide protection during the coast-down time of the turbine. ANSI/NFPA 850 (Fire Protection for Electric Generating Plants) indicates that time from detection to isolation of all pressurized fuel sources is typically 20 minutes (but may be considerably longer depending upon the turbine design). During this period, hot surfaces can conceivably re-ignite a fuel discharge. Therefore, a fire test simulating the high surface temperatures and heat capacity of turbine components is included in the FMRC test protocol.

Fires are most easily extinguished by direct coverage (of the flame envelope for spray fires and the base for pool fires) with water sprays. Unfortunately, this condition can not be guaranteed in actual installations due to the multitude of potential fire locations, and the large number of obstructions in the gas turbine enclosures. Therefore, flames are partially shielded from direct spray impingement in the critical size fire extinguishment tests.

In order to minimize the number of tests and their cost while maintaining our confidence in the test results, several simplifications have been devised. Instead of a full simulation, only the lower portion of the gas turbine casing is simulated. Although the geometric details and the thermal mass of the obstructions are not reproduced, partial shielding of flames from direct spray coverage is simulated using sheet metal baffles. The potential for fire damage is characterized by a local maximum steel temperature. Since the fuel supply is immediately shut after fire detection, it is recognized that the casing will have minimal stress loading after fire detection. The critical temperature is thus defined as the maximum steel temperature at which no metallurgical change will occur. For carbon steel, the critical temperature is 700°C.

Previous work[2] indicated that small fires are difficult to extinguish unless the water spray directly hits the base of the fire. On the other hand, larger fires in enclosed spaces are easily extinguished. Therefore, **FMRC** testing focused on the smallest size fire that is considered a threat. Selected fires sizes also represent the smallest credible values from the leak/spill scenarios. For example, a 1 m^2 pool fire represents a spill covering only 5% of the floor area. A 1 MW diesel spray fire is supported by a 2ℓ/min diesel fuel leak. Most leaks and spills in the field are expected to create larger fires than those tested in the **FMRC** protocol.

System Fire Performance General Acceptance Criteria: In a volume to be prescribed by the manufacturer, the FWS system must: 1) be capable of extinguishing any fires of 1 MW or greater in intensity even when the fire is shielded from direct spray interaction; and **2)** prevent and not cause any damage (either by fire or by excessive cooling of the casing by FWS) to the critical turbine components.

It is important to note that these criteria are performance based rather than being prescriptive. They can be used for any particular design or any suppression system.

III. EXPERIMENTAL DETAILS

Test Enclosure: The test enclosure, schematically shown in Figure 1, is 3.6 m by 5.6 m by 3.9 m high. It is equipped with a standard door (0.81 m by 2.03 m opening), four ceiling hatches (each with

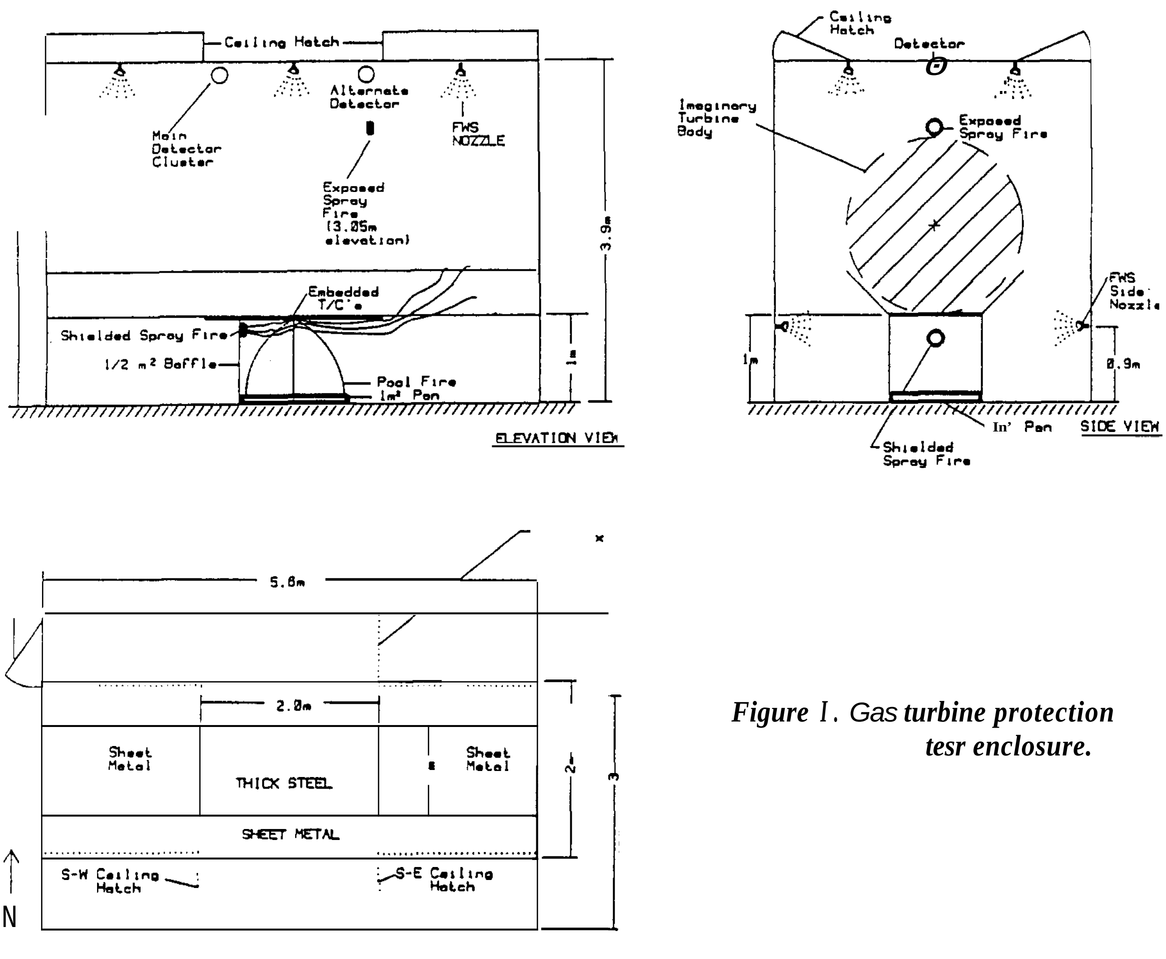


Figure 1. Gas turbine protection tesr enclosure.

0.91 m by 1.83 m opening), and four observation windows. Free volume inside the test enclosure is 79.6 m^3. The volume occupied by the gas turbine and other equipment in an actual enclosure is not accounted for in the simulation. The lower portion of a gas turbine casing is simulated with a 5 cm thick flat steel plate and 0.85 mm thick steel baffles, shown in Figure 1.

A horizontal steel plate (designated **as** "Thick Steel" in Figure 1), 1.0 m by 2.0 m by ***5*** cm thick, is placed at a 1 m elevation in the center of the room. The center of the plate is instrumented on both surfaces and across its thickness with thermocouples placed at different depths at 1.25 cm increments. The perimeter of the plate is fitted around, with 0.85 mm thick galvanized sheet metal to simulate the lower portion of the turbine casing. The sheet metal simulation extends over the entire length of the largest dimension of the enclosure. To simulate the curvature of the turbine bottom, the sheet metal is installed at a **45"** angle with respect to the horizontal to a **2** meter width, which is a typical turbine diameter corresponding to the test volume. The space below the plate where the fires for the shielded fire tests are placed is partially protected from the lateral FWS sprays using two vertical 1/2 m^2 (0.5 m wide, 1 m high) sheet metal baffles. The details and the thermal mass of the obstructions are not simulated.

FWS Suppression System: The details of the fire suppression system supplied by Securiplex, Inc can be found in reference 3. The system consists of fire detectors, control panel, skid, water and air distribution networks, and nozzles. Rate-compensated heat detectors (190°F (88"C) and 600°F (316°C)) have been installed at the ceiling of the enclosure, for fire detection. Because of the high operating temperature, heat detectors with ratings of up to 600°F (316°C) are used in gas turbine enclosures. The 190°F (88°C) detectors were used in the tests since most tests started at ambient temperature.

The control panel was programmed to activate the skid *5* seconds after detection and to cycle it to spray water for 20 seconds, shut off for **20** seconds, and spray water for another 20 seconds. The supply skid consists of a compressed air cylinder, pressure regulator, water tank and control valves. Compressed air is used to atomize the water in the nozzles and also to pressurize the water tank. Both air and water pneumatic control valves can be turned on and off to cycle the spraying sequence from the system control panel.

Water and air are distributed to the nozzles through two separate piping networks. **A** total ***of*** fourteen nozzles were used in the installation: ***6*** at the ceiling level spraying vertically down and **4** on each side spraying horizontally inward. The side nozzles were not equally spaced. **A** survey of the nozzle locations revealed that the spacing between the neighboring side nozzles ranged from 1.08 m to 1.90 m. The distance between a side nozzle and the closest end wall ranged from 0.68 m to 1.28 m.

The dual-fluid (Securiplex's 5 Ppm (nominal) 90° Jet-Mist) nozzles used in testing consume air at a rate of approximately 5-8% of the sprayed water mass, when the air and water pressures are comparable[4]. Seven exit orifices produce a non-uniform water flux distribution inside the 90" spray envelope. Mawhinney[4] measured the drop size distribution at a **1** m distance from the nozzle at three different angles from the axis. For a 565 kPa (82 psig) air pressure and a 517 kPa (75 psig) water pressure, he reports that 90% of the water volume is atomized to droplets smaller than 0.165 mm diameter on the spray axis. At **30**" from the axis, 90% of the water volume is atomized to droplets smaller than 0.201 mm diameter. In FMRC tests the water pressure was typically 85 psig, while the air pressure was 1 to 5 psig greater than the water pressure.

Instrumentation: The enclosure instrumentation includes **4** gas thermocouples, 7 thermocouples embedded in or mounted on the steel plate, and gas analysis from two different gas sampling locations. Pressure transducers were mounted on the skid to monitor the water and air supply pressures. Fire detector signals, as well as the time of ignition and the time fuel supply is terminated (in spray fire tests), are recorded as a part of the data.

Instrumentation is grouped into several areas of the test volume shown in Figure I. Referring to the elevation view, the "main detector cluster" is near the ceiling located in the center of the four western ceiling nozzles. At this location, in addition to two heat detectors, a thermocouple measures the gas temperature, and the gas sample from this location is continuously analyzed for **O,,** CO,, and CO after the steam is removed. The "alternate heat detector" is located in the center of the four eastern ceiling nozzles. At this location a thermocouple measures the gas temperature.

Another important instrument location, referred to as "flame entrained air," is selected to monitor the combustion supporting quality of the air entering the flame. At this location, referenced to where the flame is, the gas temperature and CO_2 and **O,** concentrations are measured. In spray fire tests the gas sampling port is located at the same elevation and 0.46 m behind the can combustor. In pool fire tests, the gas sampling port is at the same elevation as the lip of the pan at a 0.46 m distance from it. Another thermocouple measures the flame temperature.

IV. FIRE TESTS

Number **2** fuel oil (diesel fuel) is used in the tests. Either a pool fire or a spray fire is used to challenge the suppression system. Pool fires are established above a 1 m^2 square pan. A thin layer of heptane, gently poured over the pool surface immediately before ignition, ensures reproducible and rapid development of the pool fire. The heptane layer burns out in approximately 10 seconds. This "FMRC Standard Pool Fire" has been measured, using the FMRC Fire Products Collector, to free-bum at a rate of 1.3 MW (Total Heat Release Rate).

The spray fires are created using conventional oil burner nozzles and are stabilized using a 15 cm diameter 7.5 cm long can with an open end. The fuel nozzle is mounted at the center of the closed end of the can. This stabilizer design protects the base of the fire from direct impingement by water spray. Therefore, in the present study, spray fires were more difficult to extinguish than the pool fires. The fuel flow rates required for the design fires of 1 MW and **2** MW free-bum intensity were determined using the FMRC Fire Products Collector.

Extinguishment Tests: In all extinguishment tests, a 0.1 m^2 of ceiling vent area was maintained to prevent pressurization of the enclosure. Prior to ignition the south-west ceiling hatch and the access door are open. The access door and the south-west hatch are closed immediately after detection to simulate the shut-down of a ventilation system. Before each test, piping was purged with air to eliminate any residual water from the previous test. **A** 5 second delay was programmed into the Securiplex control panel. The system, monitoring a number of detectors, **was** programmed to activate upon detection from any of the detectors. Detection, system activation and operation were all in automatic mode. Unshielded and shielded fires were tested.

Shielded Fires: Tests are conducted with a 1 MW diesel spray fire and a 1 m^2 diesel pool fire. Fires were located between the two vertical baffles underneath the steel plate. Initially, the enclosure and its contents were at ambient temperature.

During the 1 MW diesel spray fire test, fire was first detected **24** seconds after ignition. Water spray was activated at 30 seconds after ignition and continued for 20 seconds. When the first shot terminated at 50 seconds, fire was continuing. The second shot started at 70 seconds. Fire was extinguished early in the second shot at approximately 73 seconds after ignition. Flow to fuel spray continued for another 40 seconds after suppression. No re-ignition took place. **Gas** temperatures recorded in this test are plotted in Figure **2.** Water spray is seen to decrease the gas temperatures in the flame and near the ceiling, while increasing the temperature of air being entrained by flame. This is an indication of the mixing of hot ceiling layer with the lower layer by water sprays.

During the 1 m^2 pool fire test, fire was first detected 40 seconds after ignition. Water spray came on at 46 seconds and continued for 20 seconds. Fire was extinguished towards the end of the first shot at approximately 63 seconds after ignition. There was no need for the second shot which activated automatically at 87 seconds. No re-ignition took place.

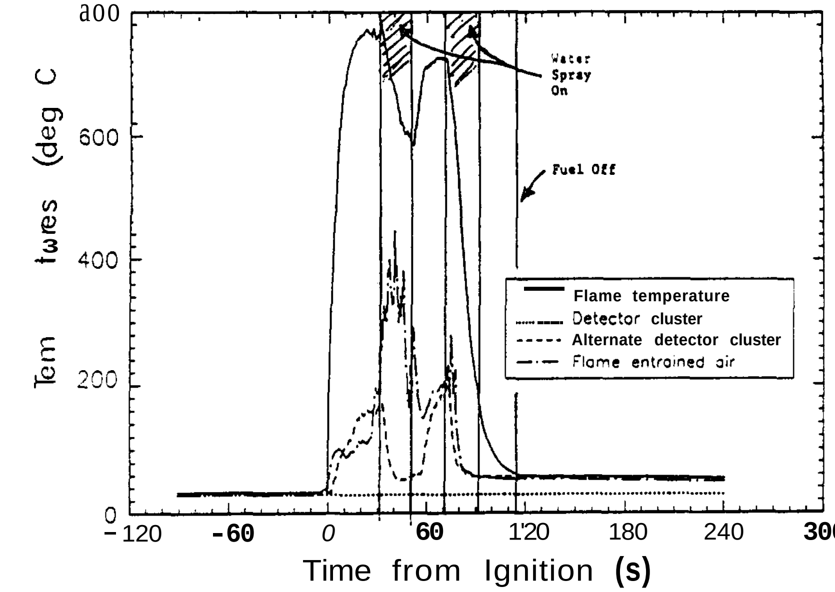


Figure 2. Gas temperatures recorded in the shielded sprayfire test.

Unshielded Fire: The test protocol calls for a 1 *MW* diesel spray fire at a location to be selected by **FMRC**. The fire was located at 3.05 m elevation (0.9 m below the ceiling) directly below the alternate heat detector located at the center of the four eastern ceiling nozzles. The enclosure and its contents were initially at ambient temperature. Detection was instantaneous, so the water spray actuated 6 seconds after ignition. The first 20 seconds of water discharge did not extinguish the fire. During the following **20** second period without spray, measured flame temperature displayed a significant drop, possibly due to oxygen vitiation. The fire was extinguished during the second 20 seconds of water discharge. In order to prove that extinguishment is not a result of oxygen vitiation near the ceiling, and that it is accomplished by the FWS system, this test was repeated without protection. Without protection, flames lasted for **92** seconds thus proving the suppression in the protected test. Video records clearly showed a ceiling layer development in the unprotected exposed fire test. The upper layer **was** marked by dense smoke. During the bum, flame seeking oxygen leaned downward towards the lower layer and away from the flame temperature thermocouple. This was the reason for the reduction in the recorded temperature.

System Performance under Limited Natural Ventilation: This test was identical to the 1 MW shielded spray fire test above, except: 1) The access door (1.6 m^2 opening) was left open throughout the test, **2)** the fire intensity was increased to 2 *MW*. Fire was first detected 12 seconds after ignition. Water spray was activated at 18 seconds and continued for 21 seconds. When the first shot terminated at 39 seconds, the fire was continuing. The second shot started at 60 seconds. Fire was extinguished early in the second shot. Flow to the fuel spray continued until 100 seconds, i.e., approximately for another 40 seconds after suppression. No re-ignition took place.

Re-ignition Test: This is a repeat of the 1 MW shielded fire test at elevated initial temperature. The 5 cm thick steel plate was heated to approximately 400°C using the 1 MW shielded spray fire. (The auto-ignition temperature of diesel fuel is reported[5] to be 257°C.) The access door and the southwest hatch were open to ventilate the fire during the heat-up period. Recognizing that the existing detectors will prematurely activate the system, the FWS system control panel was not powered. When the steel plate reached the desired temperature, the detectors were already in detection. After data acquisition was started, the control panel was powered and the pre-programmed 2-shot water discharge sequence was activated. The flame was extinguished during the first shot (as opposed to the second shot in the cold plate test). The fuel spray continued for another 15 seconds after the second shot. No re-ignition occurred either between or after the water spray shots. The plate internal thermocouples did not show any rapid temperature drop due to water spray impingement.

V. POTENTIAL FOR DAMAGE DUE TO SPRAY COOLING

Water droplets can rapidly cool the turbine casing and can conceivably cause damage due to stress cracking or excessive deformation. An earlier FMRC study has indicated that, because of the tight clearances between the blades and the casing, damage due to blade rubbing is more critical than damage due to stress cracking. Using a beam model, simplified methods for calculating the casing deformation for the simplified spray coverage configurations (shown in Figure 3) were developed in that work. Casing deformation occurs due to shrinkage and the hoop moments created by non-uniform cooling. Larger casing deformations are predicted for more nonuniform circumferential spray coverage scenarios. A manufacturer's system is classified as in one of these spray coverage configurations according to their nozzle placement design. The system tested has been classified as in the four- spray category (recognizing the two ceiling and the two side nozzle rows).

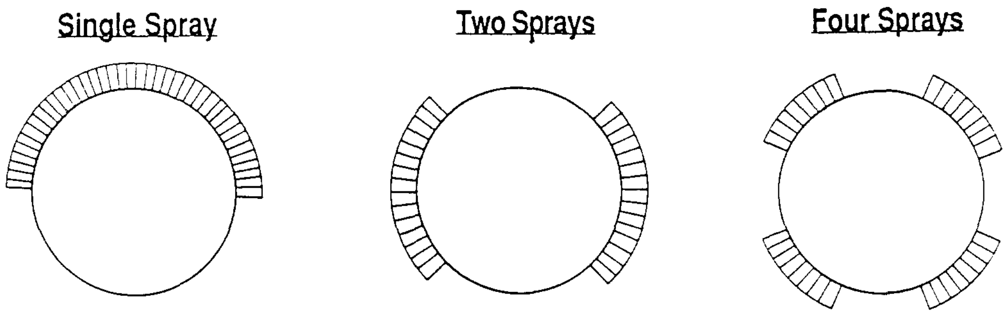
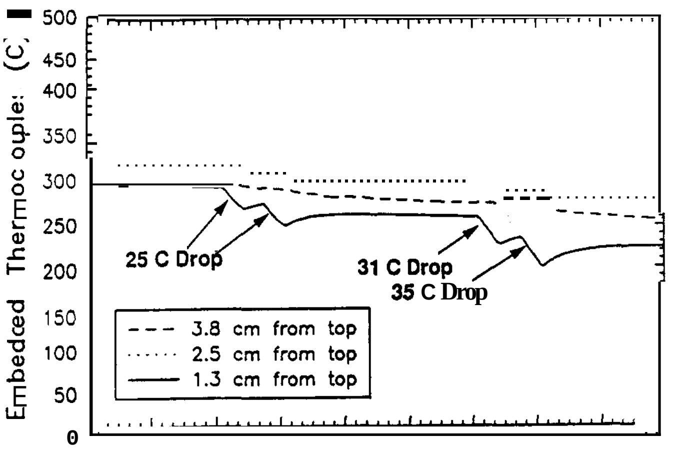


Figure 3. Simplified spray coverage conjigurations.

The FMRC test protocol requires the measurement of the cooling heat flux imparted by a nozzle installed at the minimum stand-off distance; this distance is specified by the manufacturer's design/installation manual. This is accomplished by the spray cooling test described below. The spray cooling heat flux is used to predict the maximum casing deflection. No damage is assumed so long as the predicted casing deflection is smaller than the radial clearance between the rotor blades and the casing. In practice, the predicted maximum casing deflection must be less than 0.1% of the turbine diameter, which is taken as 2 m in this study.

employed in previous tests. The effect of any residues that may have deposited on the plate during the heat-up period is ignored. The water spraying sequence was as follows: 20 sec. on, 20 sec. off, 20 sec. on, 3 minutes off, 20 sec. on, 20 sec. off, 20 sec. on. One of the upper surface thermocouples registered a 25°C drop during each one of the 20 second discharges. The thermocouple embedded 1/2 in. beneath the top surface registered



Analysis: The formulae to predict casing deflection require the temperature profile across the casing. These formulae are integrated into a software so that once the initial and the boundary conditions are specified, maximum casing deflection is calculated as a function of time. The FMRC software also solves the transient one-dimensional heat conduction equation across the thickness of the casing for specified initial and time dependent boundary conditions. The spray cooling heat flux is inferred by matching the code predictions to measured steel temperatures. Steel surface and embedded thermocouple data are analyzed to infer the corresponding spray cooling heat flux. Due to the nonuniform nature of the spray pattern, different heat flux values are inferred for different thermocouples (since they are at different lateral locations).

FMRC analysis used the data from the thermocouple embedded 1.25 cm beneath the sprayed surface, since it represented the highest spray heat flux. The 25°C temperature drop over 20 seconds is consistent with a spray heat flux of approximately 170 kW/m^2. This heat flux value has been used to predict the casing temperature and deflection history for the 10 shot sequence proposed by Securiplex to cover the 20 minute protection requirement (additional shots will only occur if a heat detector indicates the continued presence of a fire.) The maximum casing deflection after the first two shots is predicted to be less than 1 mm. Turbine radial tip clearance is known to increase during the coast-down after fire detection. The largest casing deflection, during the 20 minute protected period, occurs at the end of the 10th shot, and is calculated to be 2 mm.

VI. DISCUSSION

Fires can occur when the turbine is at operating temperature as well as when it is cold (during start-up). The massive quantities of steam that are generated when the sprays interact with hot objects, in the former case, aid suppression. Although the thermal mass is not simulated in the FMRC setup, a comparison of the "re-ignition test" with the "shielded spray fire test" described above proves this effect. In order to cover the probability of a fire occurring during turbine start-up, all suppression tests have been performed when the plate is initially at room temperature. Following the same logic, detection and actuation delays have been minimized by employing 190°F (88°C) detectors and a 5 second water activation delay (time from detection to water application) in suppression tests. In using this method, heating of the plate by the fire is minimized. Suppression performance of a system is expected to improve as the initial temperature and the detection delays are increased.

An important component needed to assess damage to the turbine due to unextinguished fires is the magnitude of the flame heat flux. Data from steel plate thermocouples were analyzed. The maximum heat flux from the 2 MW spray fire to the steel plate is 150 kW/m^2. The maximum heat flux from the 1 MW spray fire to the steel plate is calculated to be less than 100 kW/m^2. Radiative heat flux emitted from an optically thick flame at the measured flame temperature of 1075°C is 187 kW/m^2. Therefore, as expected, radiation is the dominant heating mechanism in buoyancy-controlled flames. Higher heat fluxes are possible due to convective heating in momentum-controlled flames.

A property that makes fine water spray an attractive alternative to halon or to CO, is its ability to perform when the enclosure seal is not perfect, for example, when a door is open. This was proven in the "limited natural ventilation test" described above. In that test a shielded 2 MW spray fire was extinguished when the 1.6 m^2 access door was deliberately left open. The maximum amount of air that can be supplied by a door of this size is estimated to be 1.2 Kg/sec, using the correlations for post flash-over fire. The minimum amount of air needed (at 100% combustion efficiency) to support a 2 MW fire is 0.67 Kg/s. Based on these numbers the fire appears to be close to transition but definitely in the fuel-controlled (i.e., fully ventilated) regime.

Key gas concentration data are reported in Table I. The minimum O, concentrations given in parentheses are calculated from peak CO, CO, concentrations using a simple chemistry model. Agreement between measured and calculated values is a measure of the gas concentration data integrity. In unprotected tests, fire goes out due to oxygen depletion. A simplified theory (based upon reducing the adiabatic flame temperature to 1600°K) predicts that at least 12.9% (dry, mole basis) oxygen is required to support combustion. Indeed, the minimum oxygen concentrations recorded near the base of the flame (fire entrained air) in the un-protected tests are in line with this prediction. Significantly higher minimum oxygen concentrations (15 to 18%) observed in protected tests is proof that extinguishment does not occur simply through oxygen depletion. This also indicates, however, that the suppression system benefits from the presence of the enclosure. Larger FWS application rates would ensure suppression at even higher oxygen concentrations, but may cause damage to turbine casing.

TABLE I

Key Gas Concentration Data. All values are volume percent dry basis, i.e., after steam is removed from the gas sample. Oxygen concentration values reported in parentheses are deduced from CO and CO_2 data.

TEST	FIRE ENTRAINED AIR Min. O_2 (%)	FIRE ENTRAINED AIR Max. CO_2 (%)	CEILING Min. O_2 (%)	CEILING Max. CO_2 (%)	CEILING Max. CO (%)
Unprotected 1 MW **Shielded Spray**[1]	10.9 (13.51)	5.3	13.0 (10.90)	7.1	0.20
Protected 1 **MW Shielded Spray**	16.0 (16.58)	3.1	15.4 (16.46)	3.1	0.22
Unprotected 1 m^2 **Shielded Pool**[2]	10.6 (13.23)	5.5	13.0 (13.33)	5.3	0.28
Protected 1 m^2 **Shielded Pool**	16.0 (16.99)	2.8	15.7 (16.94)	2.8	0.15
Unprotected 1 MW **Exposed Spray** (10 **ft elevation)**	9.5 (Pegged?) (9.32)	8.3	3.7 (5.73)	9.8	1.60
Protected 1 MW **Exposed Spray** (10 **ft elevation)**	16.6 (15.32)	4.0	4.5 (6.39)	9.4	1.50
Re-Ignition Test[3]	18 (16.02)	3.5	-	-	0.1
Protected 2 MW **Shielded Spray with Limited Natural Ventilation**	15.0 (15.60)	3.8	9.1 (8.26)	8.7	0.60

[1] Empty enclosure (no obstructions)

[2] Horizontal (not at 45°) side baffles result in compartmentalization and double peaks in fire entrained gas composition.

[3] Gas analyzer data is not reliable.

VII. SUMMARY AND CONCLUSIONS

A simple performance-based fire test protocol for combustion turbine enclosure protection is presented. The test protocol ensures that a fine water spray system is capable of putting out shielded and exposed spray fires of intensity greater than 1 MW, and shielded pool fires larger than 1 m^2. It is shown that suppression can be achieved even when the enclosure has a small opening, as long as the fire intensity is greater than 2 MW. Potential for damage to hot turbine casing because of excessive cooling is also evaluated.

The fine water spray system employing 5 ℓpm (nominal) dual fluid nozzles operated by air and water was tested in an 80 m^3 enclosure. Six nozzles were installed on the ceiling, and eight were mounted on the sidewalls parallel to the turbine axis. Water is sprayed in a cyclical fashion: 20 seconds on, 20 seconds off, 20 seconds on. The fine water spray system extinguished the test fires and successfully fulfilled the requirements of the FMRC fire performance test protocol.

ACKNOWLEDGEMENTS

The test protocol described and utilized in this report was developed by an FMRC team which, in addition to the authors, includes Messrs. Paul H. Dobson and Robert E. Dundas of the FMRC Standards Division, and Messrs. Richard Ferron and Robert Kasiski of FMRC Approvals Division. Experimental work, including fabrication and instrumentation of the test enclosure, was capably executed by FMRC Test Center personnel. Methodology used to assess the damage potential due to spray cooling utilizes the formulae developed by Drs. Mary M. Delichatsios and John de Ris, in an internally sponsored project.

Experimental work was sponsored by Securiplex, Inc. Detection and suppression systems including the nozzles, piping and water/air supply equipment was provided, installed, and operated by the sponsor. The Securiplex team included Messrs. Pierre Girard, Francois Demers, Peter Stathopoulos and Victor Gameiro.

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