A COMPARISON OF FPETOOL PREDICTIONS TO EXPERIMENTAL RESULTS: COMPARISON OF CLEAN AGENT AND SPRINKLER SYSTEM PERFORMANCE ON IN-CABINET FIRES

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ABSTRACT

Model predictions are widely employed in the assessment of fire hazards, and there is an ongoing need to expand the existing comparisons between fire test data and model predictions to additional fire scenarios. This paper presents a comparison of fire model predictions with experimental results from pre-flashover fire tests conducted in a mockup of typical electronic data processing (EDP) or telecommunications facilities.

The zone model FPETool: Fire Simulator was used to predict the results of single room pre-flashover fire tests. The tests involved the suppression of an in-cabinet fire by a clean agent (e.g., FM-200®) system, and by a standard water sprinkler system. With the exception of heat release rates, all inputs were selected without knowledge of the experimental results. Predictions made by FPETool: Fire Simulator are discussed, and the model predictions compared to the experimental data.

INTRODUCTION

Data processing and telecommunication facilities are commonly protected in the event of a fire with gaseous clean agents, automatic sprinklers, or both clean agent and sprinkler systems.

The primary purpose of a sprinkler system, whether of the pre-action or wet pipe variety, is to *contain the fire* to the room of origin and to manage the temperatures at the ceiling to prevent structural damage and/or collapse. It is important to note that this differs significantly from the primary purpose of a gaseous clean agent system, which is to *extinguish the fire* quickly, limiting fire damage to the object(s) involved in the origin of the fire.

Sprinkler system activation typically occurs when the temperature at the sprinkler head exceeds that required either to melt a fusible link in the head, or to break a liquid filled glass bulb which comprises part of the sprinkler head construction. Typical sprinkler heads will activate when the temperature of the link or glass bulb reaches approximately 135 ^{o}F or higher. The attainment of such temperatures at the sprinkler head requires a relatively large fire.

A smoke detection system is typically utilized to actuate a gaseous agent system; in this case the fires are detected in their incipient stage, and hence the fire size at system actuation is much less than the fire size at actuation for sprinkler systems.

Hughes Associates, Inc. was commissioned by Great Lakes Chemical Corporation to perform a set of full-scale tests to illustrate the differences between sprinkler and gaseous agent suppression systems when applied to in-cabinet fires, such as may occur in electronic data processing or telecommunication facilities. In designing these tests, it was desired to predict fire conditions prior to performing the actual tests, in order to ensure both proper test design and safe execution of the tests. For example, it was desired to avoid employing a test fire which would fail to produce enough heat to activate the sprinkler heads. FPETool: Fire Simulator was employed in anticipation of providing a prediction of the fire events, in particular estimates of the time to smoke detector and sprinkler head activation, the heat release rate at system activation, and ceiling jet temperatures.

EXPERIMENTAL SECTION

ENCLOSURE

A schematic diagram of the test enclosure is given in Figure 1. The 10 m x 10 m x 3.2 m (32.8 ft x 32.8 ft x 12 ft) enclosure was equipped with a 0.45 m (1.5 ft) deep subfloor and a suspended ceiling extending 1.2 m (4 ft) below the drywall ceiling. The enclosure is constructed from 12.7 mm (0.5 in) gypsum wallboard over a metal stud frame. Access to the room is accomplished via two 0.88 m x 2 m (2.9 ft x 6.6 ft) doors, one at the southern end of the east wall and the other at the northern end of the west wall. Both doors open at the level of the raised subfloor. The enclosure has five 1.2 m x 1.8 m (46 in x 70 in) windows made of 5 mm (3/16 in) polycarbonate, reinforced with two sets of horizontal braces made from 1.6 cm (5/8 in.) plywood. Three smaller windows, nominal 0.3 m x 0.3 m (1 ft x 1 ft), are located along the southern and western walls. A set of 0.51 m x 0.51 m (20 in x 20 in) motorized dampers in the ceiling along the southern wall connects to an 85 m^3/min (3000 cfm) fan which was utilized for post-test exhaust. A 0.61 m x 1.22 m (2 ft x 4 ft) metal grate below these dampers allows for flow through the suspended ceiling. Four sets of 25.4 cm x 25.4 cm (10 in x 10 in.) motorized dampers in the subfloor allow for inflow of make up air through the subfloor. Standard floor tiles were placed in an area 6.1m x 7.9 m (20 ft x 26 ft) as shown in Figure 1, and the cabinet containing the fuel array was placed on these tiles.

In addition to the cabinet containing the fuel array, three other data processing equipment cabinets were arranged on the partial layer of floor tiles. These cabinets had been gutted prior to placement in the chamber and were not operational. Three file cabinets, two tables and chairs, and a non-operating PC were also arranged in this area.

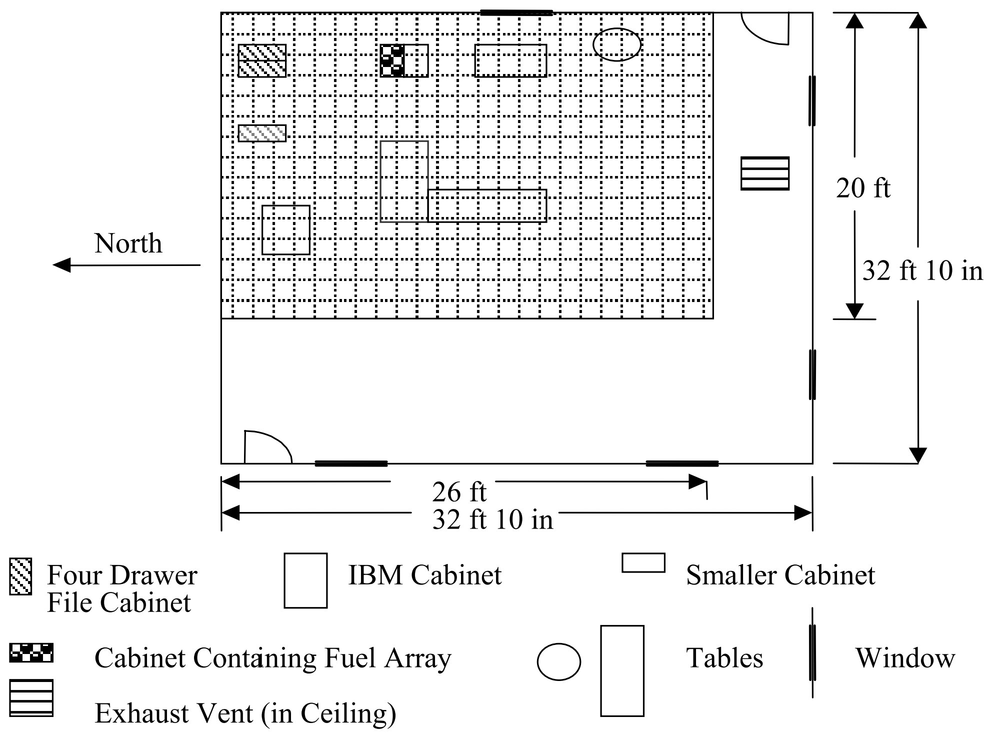

Figure 1. Enclosure Schematic

FIRE TEST OBJECT

The fire test object consisted of eight sheets of ABS (Acrylonitrile-Butadiene-Styrene) plastic, 20.3 cm x 40.6 cm x 0.95 cm (8 in x 16 in x 0.375 in), arranged vertically in two rows of four sheets each, with a 1.27 cm (0.5 in.) gap between the bottom and top rows, placed inside an electronics cabinet. The four sheets in each row are arranged with 1.27 cm (0.5 in.) gaps between the outer sheets and a larger center gap of 3.2 cm (1.25 in.). The plastic sheets are mounted on 0.6 cm (0.25 in) "all-thread" rods on a stand constructed of 2.5 cm x 2.5 cm (1 in x 1 in) Unistrut® beams. The array was placed inside an electronics cabinet equipped with metal mesh doors, with the sheets oriented parallel to the solid metal walls of the cabinet. The ABS fuel array was ignited by 3 ml of n-heptane in a 5 cm (2 in) square pan located 1.27 cm (0.5 in) below the array. This fuel array is similar to that adopted by Underwriters Laboratories, Inc in their standard on Halocarbon Clean Agent Extinguishing System Units, UL 2166 [1], and is shown schematically in Figure 2.

The heat release rate of the fire test object (ABS array in electronic cabinet) was determined by locating the test object under a 3 m x 3 m (10 ft x 10 ft) hood equipped and instrumented to determine heat release rate based upon oxygen consumption. The experimentally determined heat release rate for the fire test object is given in Figure 3.

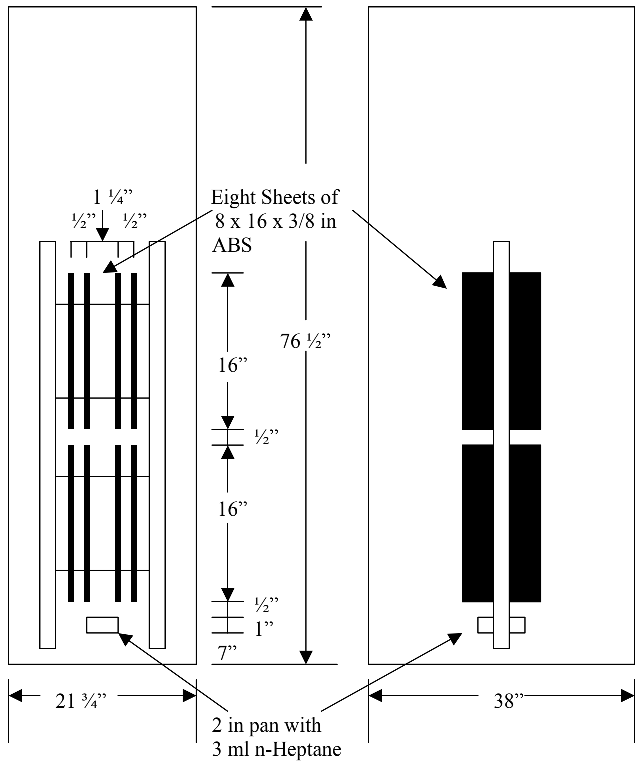

Figure 2. Fuel Array Schematic

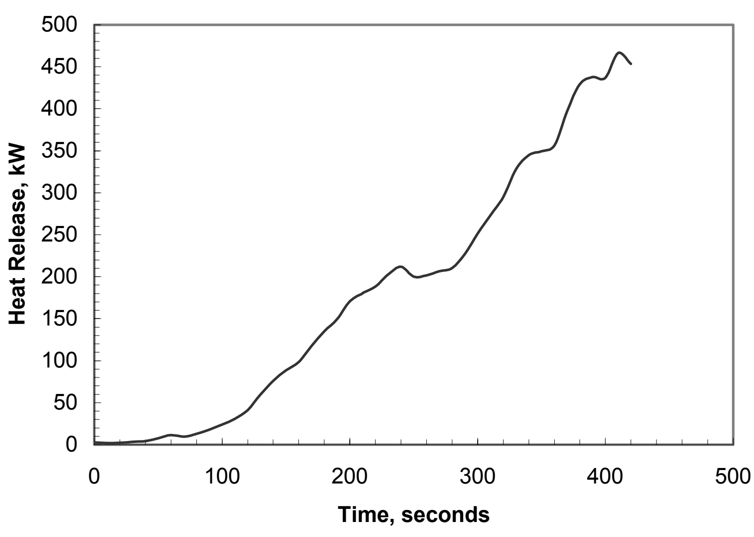

Figure 3. Heat Release Rate for In-Cabinet Test Fire

SMOKE DETECTION SYSTEMS

For the FM-200® tests two smoke detection systems were employed. The first of these systems was a Fenwal AnaLASER II air sampling detection system. This system was designed and installed by a local Fenwal distributor and employed a 0.061 % obscuration per foot alarm threshold, a mid-range value for an AnaLASER II.

The second detection system consisted of Simplex 4098 series True Alarm ionization and photoelectric smoke detectors. Six detectors, three ionization detectors (Part number 4098-9717) and three photoelectric detectors (Part number 4098-9714) were monitored during these tests. An ionization detector and a photoelectric detector were located at the three air sampling locations nearest the fire location. These detectors were placed side by side during these tests as opposed to the alternating photoelectric and ionization detector at half the maximum spacing that would typically have been employed. The alarm thresholds for these detectors were 1.3 % obscuration per foot for the ionization detectors and 2.5% obscuration per foot for the photoelectric detectors.

FM-200® SYSTEM

The FM-200® system was designed to discharge 134.5 kg (297 lb) of FM-200® into the main area of the enclosure in 9.5 seconds to result in a 7 % by volume concentration inside the enclosure to satisfy the requirements of NFPA 2001. The agent was discharged from a 180 L (6.36 ft^3) Hygood Ltd cylinder (part number 9240). The agent was discharged through a Hygood Ltd flex hose (part number 6540), and a short piping system constructed from 5 cm (2 in) NPT schedule 40 threaded steel pipe terminating in a Hygood Ltd eight port aluminum nozzle with an orifice area of 10.13 cm^2 (1.57 in^2; part number 3441) located in the center of the room with the nozzle orifices 6.4cm (2.5 in) below the suspended ceiling.

The FM-200® system incorporated a 30 second delay from detection to cylinder actuation. This delay is the maximum delay time under the recommendations of FM Global Property loss prevention sheet 5-14 on Telecommunications Facilities [2].

AUTOMATIC SPRINKLER SYSTEM

The automatic sprinkler system was designed and installed in accordance with NFPA 13 and was based upon an Ordinary Hazard Class I classification for this enclosure. The application density for Ordinary Hazard Class I rooms less than 139.4 m^2 (1500 ft^2) is 6.11 lpm/m^2 (0.15 gpm/ft^2) [3]. Data processing spaces can be classified as Light Hazards if the space can be kept clear of combustible materials outside of the data processing equipment cabinets. Nine sprinkler heads were employed in the main space and an additional nine above the suspended ceiling. The sprinkler heads were arranged with a symmetrical 3.35 m (11 ft) spacing for a coverage area of 11.24 m^2 (121 ft^2) which is in compliance with the NFPA 13 maximum spacing requirement for ordinary hazards of 4.6 m (15 ft) and coverage area of 12.1 m^2 (130 ft^2) [3]. The sprinkler heads utilized were commercially available standard response glass bulb sprinklers with a temperature rating of 68 ^oC (155 ^oF) and a Response Time Index (RTI) of approximately144 $(ft\ s)^{1/2}$ (80 $(m\ s)^{1/2}$).

NFPA 13 would require that the water supply employed be adequate to supply all of the sprinklers within the design area for a minimum duration of 60 minutes [3]. However, the storage of this large an amount of water would be impractical, and in any event since we know the location of the fire, it is expected that only the two sprinklers nearest the fire will be activated. Hence, the water supply for this system was designed to supply the two sprinklers nearest the fire location for a period of 29 minutes at the design flow rate of 68.7 lpm (18.2 gpm) from each sprinkler.

ENCLOSURE INSTRUMENTATION

The chamber was instrumented to monitor temperatures, smoke densities, species concentrations and the operation of the FM-200® and sprinkler systems. Four thermocouple trees were installed in the enclosure. Each tree consisted of three type K thermocouples, one at the level of the raised floor, one mid-way between the raised floor and the suspended ceiling and the last at the height of the suspended ceiling. These trees were located at the center of the eastern wall, the center of the southern wall, in the northeast corner, and at the center of the northern wall. Type K thermocouples were also located at the position of each sprinkler head.

The smoke optical density was measured with a white light meter with a 1.52 m (5 ft) path length located 1.83 m (6 ft) above the raised floor at the center of the southern wall.

Oxygen, carbon monoxide and carbon dioxide concentrations were monitored by separate analyzers from a common sampling point located at mid-height at the center of the southern wall. A Servomex 540A paramagnetic oxygen analyzer equipped with a zero suppression module to obtain a measurement range of 16 to 21 % by volume oxygen was utilized to monitor the oxygen concentration. Horiba VIR 510 analyzers were utilized to monitor the carbon monoxide concentration with a range 0 to 1000 ppm and carbon dioxide concentration with a range of 0 to 2 % by volume. Note that FM-200® interferes with the carbon monoxide and carbon dioxide measurements.

A KVB Analect Diamond 20 Fourier Transform Infrared Spectrometer, FTIR, was utilized to monitor the FM-200® and thermal decomposition product (HF) concentrations. The FTIR was located at the center of the northern wall, 43.2 cm (17 in.) above the raised floor, and configured to have an active path length of 45.7 cm (18 in.).

An Omega Engineering PX653-05BD5V pressure transducer with a range of -1,244 to 1,244 Pa (-5 to 5 iwc) was utilized to monitor the pressure in the test chamber.

Two Omega Engineering PX603-1KG5V and one PX613-1KG5V pressure transducers with a range of 0-6.89 MPa, gauge (0-1000 psig) were utilized to monitor the pressure of the FM-200® as it discharged into the test chamber. Three type K stainless steel sheathed exposed bead thermocouples, Omega Engineering KMQSS-062E-12, were utilized to monitor the temperature of the flowing FM-200®. The locations of these transducers and thermocouples were in the cylinder, at the discharge hose connection at the cylinder outlet, and before the nozzle.

TEST PROCEDURE

Data acquisition was commenced with the ignition of the n-heptane pan below the ABS plastic array. During the FM-200® test, the FM-200® system was actuated 30 seconds after the AnaLASER II smoke detection system went into alarm. The enclosure remained sealed with the doors and vents closed and the exhaust blower shut down until 20 minutes after FM-200® system actuation.

During the sprinkler system test, the water supply pump was started prior to the start of data acquisition. After ignition of the n-heptane pan, the room remained sealed for 17.7 minutes. At that time, the vents were opened and the exhaust blower started. At 22 minutes after ignition, the water supply pump was shut down and the fire extinguished with a portable extinguisher.

INPUT FOR FPETOOL SIMULATIONS

Table 1 shows the input data for the FPETool simulations. The minimum oxygen levels and heat transfer factors employed were the default values for FPETool Fire Simulator. Heat release rate input data are shown in Table 2.

DISCUSSION

HEAT RELEASE RATE REQUIRED FOR SPRINKLER ACTIVATION

In designing this series of tests, the question arose as to whether or not the proposed test fire would release sufficient heat to activate the sprinkler heads prior to the exhaustion of the fuel. The tests were to be conducted in an existing enclosure and the first step in this analysis was to design the proper, i.e. code compliant, detection systems for both an FM-200® and a sprinkler system. The FM-200® and sprinkler systems were designed in accordance with NFPA 2001 and NFPA 13, respectively. Inputting the experimental heat release data for the test fire, the location of the fire, the enclosure dimensions, and the location and properties of the detection systems, FPETool predicted that activation of the closest (NE) sprinkler head would occur at 249 seconds, at which time the heat release rate would be approximately 210 kW.

SMOKE DETECTOR ACTIVATION TIME

FPETool predicted activation of the ionization detector at 95 seconds; the measured value was 112 seconds. FPETool assumes smoke detector activation occurs when the ceiling jet temperature at the radial location of the smoke detector attains the activation temperature; by default, an activation temperature of 13 ^{o}C (23 ^{o}F) above the initial detector temperature is employed by FPETool. In this case, activation is predicted to occur at a ceiling jet temperature of 93 ^{o}F (34 ^{o}C).

SPRINKLER ACTIVATION TIME

The calculated and observed sprinkler activation times are compared in Table 3.

FPETool predicted an activation time of 249 seconds for the northeast sprinkler; this compares to a measured value of 278 seconds. Hence the measured value was within approximately 10% of the predicted value. The activation time for the north detector was measured to be 352 seconds, compared to a predicted value of 253 seconds. This result is not surprising, as the FPETool

Table 1. FPETool Input

Input Parameter	
Minimum Oxygen Level 21 °C 600 °C	 10.0 2.0
Heat Transfer Factor Radiant fraction Max energy loss internal	 0.35 0.90
Sprinkler, NE location Distance from center of fire (ft) RTI $(ft\ s)^{1/2}$ Activation temperature, °F	 10.6 144 155
Sprinkler, N location Distance from center of fire (ft) RTI $(ft\ s)^{1/2}$ Activation temperature, °F	 11.3 144 155
Room dimensions Ceiling height (ft) Length (ft) Width (ft)	 8.0 32.8 32.8
Ceiling Material Thickness (in) Thermal conductivity (kW/mK) Density (kg/m^3) Specific heat (KJ/kg K)	Glass fiber 0.5 0.00037 60 0.8
Ceiling Material Thickness (in) Thermal conductivity (kW/mK) Density (kg/m^3) Specific heat (KJ/kg K)	Gypsum board 0.5 0.00017 960 1.1

program can only treat a single sprinkler. Hence the prediction of a 253 second activation would correspond to the condition wherein only one sprinkler, the sprinkler at the north position, is present. In reality, the northeast sprinkler head is also present, and it activates prior to the north sprinkler, due to its closer proximity to the fire. Activation of the northeast sprinkler head impacts upon the ceiling jet temperature at the link of the north sprinkler head, as seen from Figure 4, thereby affecting the activation of the north sprinkler head.

CEILING JET TEMPERATURE AT THE SPRINKLER HEADS

Figure 5 compares the predicted and measured ceiling jet temperatures at the sprinkler head location for the northeast sprinkler. FPETool overestimates the ceiling jet temperature during the mid portion of the test, but compares well with the measured results for approximately 60

Table 2. Heat Release Rate Input

Time (s)	Heat Release Rate (kW)
0	0
20	2
40	4
60	11
80	13
100	24
120	41
140	76
160	98
180	135
200	171
220	188
240	211
260	202
280	210
300	252
320	295
340	345
360	356
380	429
400	437
420	453

Table 3. Sprinkler Activation Times

Sprinkler	Radial distance to fire, feet	Measured Activation Time, seconds	Predicted Activation Time, seconds	Measured Ceiling Jet T at bulb at activation ^{o}F	Predicted Ceiling Jet T at bulb at activation, ^{o}F
NE	10.6	278	249	288	249
N	11.3	352	253	276	250

seconds prior to sprinkler activation. FPETool predicted that activation would occur at a jet temperature of 249 ^{o}F; this compares with the measured value of 288 ^{o}F.

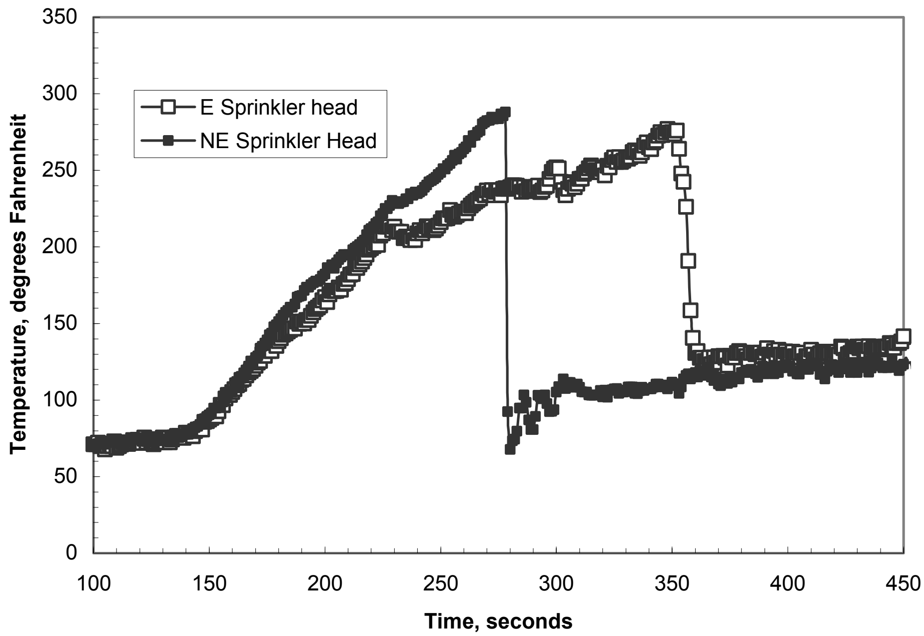

Figure 4. Ceiling Jet Temperature at Sprinkler Heads

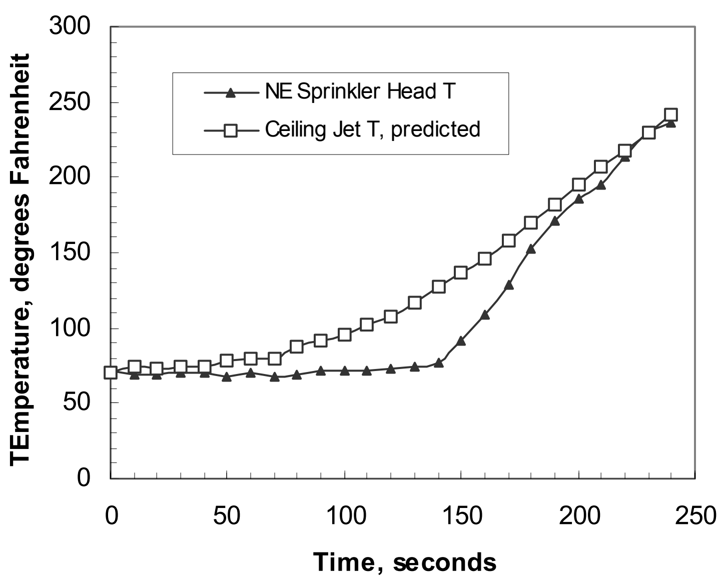

Figure 5. Ceiling Jet Temperature at Northeast Sprinkler Head

COMPARISON OF GASEOUS AGENT AND SPRINKLER SYSTEM PERFORMANCE

As discussed above, the primary purposes of gaseous agent and sprinkler systems differ significantly. The goal of the sprinkler system is to *contain the fire* to the room of origin and to manage the temperatures at the ceiling to prevent structural damage and/or collapse. The goal of the gaseous clean agent system is to *extinguish the fire* quickly, limiting fire damage to the object(s) involved in the origin of the fire. The results of this study clearly demonstrate these differences.

FM-200® SYSTEM

For the test involving the FM-200® system, the air sampling system went into alarm at approximately 78 seconds after ignition of the fire; at this point there was no obscuration of vision due to smoke, all smoke produced from the fire being confined to the immediate vicinity of the cabinet containing the fuel array. The FM-200® system actuated 30 seconds later, and the fire was observed to be extinguished 17 seconds after system actuation. At the time of system actuation the fire size was approximately 20 kW. At this point, ceiling temperatures anywhere within the enclosure were less than approximately 85 ^{o}F. Fire damage was limited to scorching of the cabinet in which the fire was situated, and the extent of non-fire damage to the enclosure was limited to the displacement of several ceiling tiles and the slight bending of a small section of the ceiling panel runners.

The FM-200® system was observed to perform exactly as designed: the fire was rapidly extinguished and fire damage was limited to the object involved in the origin of the fire.

SPRINKLER SYSTEM

For the test involving the sprinkler system, the photoelectric and ionization detectors went into alarm at 94 seconds and 112 seconds after ignition, respectively. The fire size at these times were approximately 20 kW and 35 kW, respectively, based upon the heat release rate data shown in Figure 3. For a pre-action sprinkler system, the pipe would be filled with water upon the alarm of the smoke detectors. At approximately 210 seconds from ignition, the entire enclosure was filled with thick smoke and the burning of the fuel array could only be observed via infrared camera. At 278 seconds from ignition (fire size approximately 200 kW) the northeast sprinkler actuated. At 352 seconds from ignition, the north sprinkler head activated. The fire was not extinguished by the sprinkler system and continued to burn until manually extinguished with a portable CO_2 unit at approximately 1300 seconds (22 minutes) after ignition. The ceiling temperature near the fire cabinet reached a maximum of 560 ^{o}F at 480 seconds from ignition.

The sprinkler system was observed to perform exactly as designed: the fire was contained to the room of origin and ceiling temperatures were managed such that structural damage/and or collapse did not occur.

Secondary damage to the enclosure and its contents was extensive. A black "ring" of soot extended around the entire enclosure below the suspended ceiling. The suspended ceiling itself was discolored from smoke damage. Soot particles scrubbed from the smoke layer by the water spray covered the entirety of the floor and all items within the enclosure. Paper products were observed to have suffered damage due to the large amounts of water delivered. Restoration of the facility in this case would require a complete gutting of the enclosure, with replacement of walls, ceilings and floor, in addition to the replacement of equipment damaged by smoke or soot.

The results of these tests demonstrate the vastly different nature of gaseous clean agent and sprinkler systems. The purpose of a sprinkler system is to *protect the structure,* and to confine the fire to its room of origin. The purpose of a gaseous clean agent system is to *protect the valuable and/or sensitive assets* within the enclosure. As seen in this study, relying on a sprinkler system for protection of the enclosure's assets can be unnecessarily costly. At the same time, gaseous clean agent systems are not ideally suited for the protection of structures. For applications involving expensive and sensitive equipment, the use of a gaseous clean agent to protect the assets, in combination with a sprinkler system to protect the structure, is a logical and viable solution to the fire protection needs of such facilities.

CONCLUSION

The compartment zone fire model FPETool was employed to aid the design of a test series aimed at illustrating the differences between the performance of gaseous clean agent and sprinkler systems on in-cabinet fires. The ability to predict heat release rates at the time of sprinkler activation, sprinkler response times and ceiling jet temperatures was found to be useful in designing these tests. In general good agreement was observed between measured values and those predicted by FPETool.

REFERENCES

1. Underwriters Laboratories, Inc., "Standard for Halocarbon Clean Agent Extinguishing System Units," UL 2166, Underwriters Laboratories, Inc., Northbrook, IL, 1999.

2. FM Global, <u>Property Loss Prevention Sheets</u>, “Telecommunications”, Sheet 5-14, Factory Mutual Insurance Company, Norwood, MA, 1998.

3. National Fire Protection Association, “Standard on Installation of Sprinkler Systems”, NFPA 13, National Fire Protection Association, Quincy, MA, 2002.