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Abstract

Building codes in many countries require an absorber plate with an auto-sprinkler system to accelerate sprinkler system activation when this system cannot be installed on a ceiling. This study evaluated experimentally the function of absorber plates. A sprinkler with or without an absorber plate was installed in a room measuring 4.3(L) × 3.0(W) × 3.3 (H) m. Hanging walls 1.1 m long were installed at the edges of the room ceiling to help form a hot smoke layer during a fire. Heptane and methanol into circular pans with diameters of 20–60 cm were the fire sources. The fire sources were positioned at the room center and 0.5, 1, and 1.5 m from the room center to produce fire plumes that reached both the sprinkler head and absorber plate, directly reached the absorber plate but not the sprinkler head, or reached neither the sprinkler head nor absorber plate, respectively. Temperature and velocity, two parameters important to sprinkler activation, were measured near the sprinkler head and compared for cases with and without an absorber plate. Experimental data indicate that the absorber plate did not help accelerate sprinkler head activation from temperature and velocity measurements for all cases with and without an absorber plate.

Keywords

Detection • Activation • Absorber plate • Fire code

87.1 Introduction

After a fire starts in a compartment, a buoyancy-driven fire plume forms, and hot gases in the fire plume rise above the burning fuel and impinge on a ceiling. The ceiling causes the flow to turn and then move horizontally near the ceiling. When the flow reaches vertical barriers, such as walls, hot gases start accumulating below the

ceiling, generating a hot smoke layer. Many studies [1–3] have examined the behaviors of fire plumes and ceiling jets, as both are important when dealing with issues related to fire detection and suppression [4–8]. Heskestad [1] listed the relationships between plume radius, mean excess temperature, and mean velocity at the centerlines of fire plumes; Alpert [2] presented the correlations between temperature and the velocity distributions of ceiling jets [2].

Temperature and velocity are the two key thresholds for activating an auto-sprinkler system. The response time index (RTI), which is related to the temperature, velocity, and other sprinkler sensor properties, is a measure of sprinkler sensitivity.

To accelerate the activation of auto-sprinkler system during a fire, various related facilities have been developed.

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Fig. 87.1 A practical case of using an AP

This study evaluates absorber plates (APs). According to building codes, such as those in Japan, Taiwan, and China, auto-sprinkler systems request an AP to accelerate the activation of auto-sprinkler system when a system cannot be attached on a ceiling. Figure 87.1 shows an example in which water pipes obstructed heat from a fire from reaching sprinkler heads directly when the sprinkler heads were attached on a ceiling. Moreover, water drops may not reach fires due to obstructions after sprinkler system activation. The “Standard for Installation of Fire Safety Equipments Based on Use and Occupancy” [9] Article 47 in Taiwan’s Fire Code codifies the use of APs. Where the distance between the deflector of the nozzle and the ceiling or floor slabs is more than 30 cm, an AP shall be equipped pursuant to the following provisions: (1) The AP shall be made of metal materials, and the diameter shall be not less than 30 cm. (2) The distance between deflector and AP shall be not more than 30 cm.

However, based on fire dynamics, heat flowing with a fire plume reaches an AP and a sprinkler head via three scenarios (Fig. 87.2). Figure 87.2a presents the first scenario in which a fire plume centerline reaches a sprinkler head without obstructions when a fire occurs just below the sprinkler head. Figure 87.2b shows the second scenario in which the fire plume centerline does not reach a sprinkler head and AP, but the fire plume reaches an AP. Heat flowing from the fire plume travels to the sprinkler head along the lower surface of the AP. Finally, in the third scenario, when a fire does not occur near below an AP and sprinkler head, the fire plume does not reach the AP and sprinkler head directly. The heat that reaches a sprinkler head is from the hot layer that forms below a ceiling. Additionally, in the first and second scenarios, the presence of an AP influences the flow velocity around a sprinkler

head, consequently affecting sprinkler activation. Experiments are designed to validate the function of an AP for auto-sprinkler activation during a fire. The extinguishment performance of the auto-sprinkler system was not discussed.

87.2 Experimental Design

Figure 87.3 shows a schematic diagram of the experiment. A fire source was placed on the floor of a room $4.3(L) \times 3.0(W) \times 3.3(H)$ m. Noncombustible curtains 1.1 m in length made of 10-mm-thick gypsum board were installed at the edges of the room ceiling to facilitate the formation of a smoke layer beneath the room ceiling during a fire [10]. A sprinkler head with or without an AP was located at the ceiling center in a room with a water pipe. The metal AP was 40 cm in diameter and positioned 30 cm below the ceiling. Four thermocouples (T11–T14) were installed at an interval of 10 cm moving radially from the sprinkler head at 5 cm below the ceiling to investigate the flow behavior of ceiling jets. A thermocouple tree (TR1–TR15) with a thermocouple interval of 5, 20, or 30 cm was utilized to measure room temperature. Figure 87.4 shows the experimental setup around the AP and sprinkler head. Thermocouples T1–T7 measured the temperature of, and around, the sprinkler head. Thermocouple T8 recorded the temperature rise of the water pipe. As an AP influences the fire plume around the water pipe, the pipe may receive less heat from the fire [8] than when the AP is absent. The reduction in the amount of heat reaching the water in the pipe increases the temperature difference between the sprinkler head and the water. More heat can conduct to the water from the sprinkler head, and sprinkler head activation may be consequently delayed. Thermocouples T9 and T10 were used to measure the temperature rise of the AP and were not used for scenarios without an AP. A bi-directional probe was installed near the sprinkler head to measure the horizontal velocity of flows in scenarios with an AP and near the ceiling in scenarios without an AP. Sprinkler head activation was simulated not using glass bulbs but temperature and velocity readings. These readings were used for further flow and thermal analyses.

The primary fuel used was heptane; methanol was used in several cases for comparison. Table 87.1 lists the fuel type, diameter of fuel pan, and fuel position from the room center in the experiment. The fuel was poured into 2-cm-deep circular pans with diameters of 20, 40, 50, and 60 cm. Fuel depth was fixed at 1.5 cm.

Fig. 87.2 Three scenarios for a fire plume to reach an AP and a sprinkler head

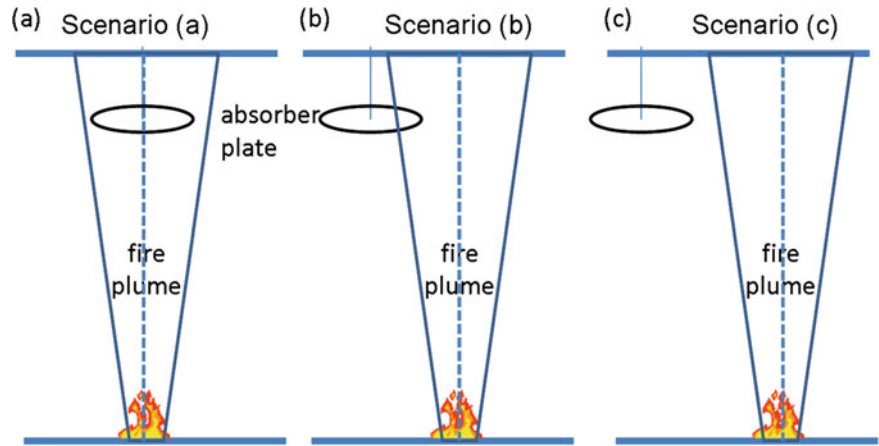


Fig. 87.3 Schematic diagram of the experimental design

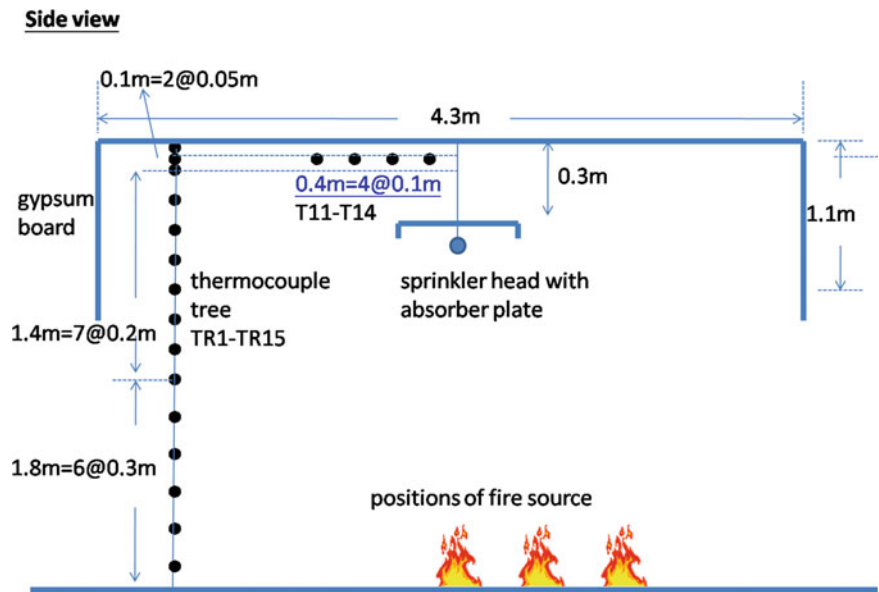


Fig. 87.4 Detailed design of experimental setup around the AP and sprinkler head

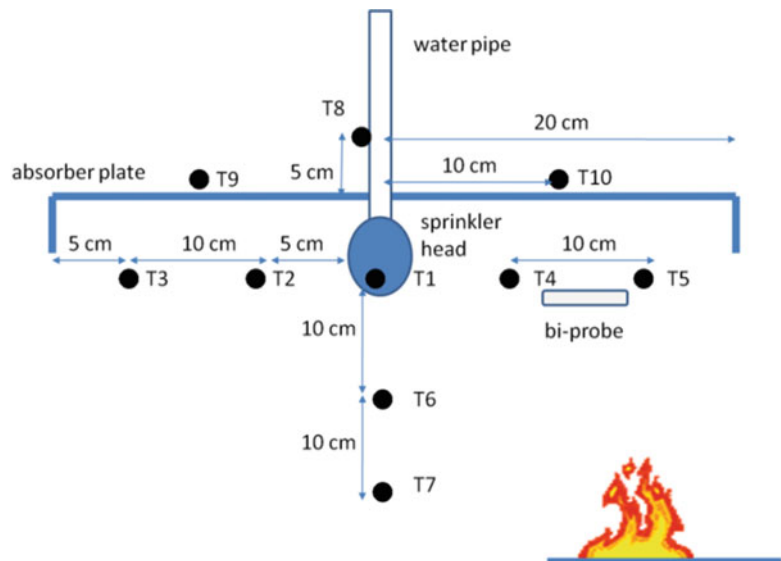


Table 87.1 The fuel type, diameter of fuel pan, fuel position from the room center in the experiment, condition of fire plume, and corresponding scenario. 0.2 + 0.2 m denotes that two pans with diameter of 0.2 m were used

Fuel	Fuel pan diameter	Fuel position	Fire plume condition	Corresponding scenario	
Heptane	0.2 + 0.2 m	Center	Plume centerline reached AP	(a)	
		0.5 m	Plume reached AP	(b)	
		1 m	Plume did not reach AP	(c)	
		1.5 m	Plume did not reach AP	(c)	
	0.4 m	Center	Plume centerline reached AP	(a)	
		0.5 m	Plume reached AP	(b)	
		1 m	Plume did not reach AP	(c)	
		1.5 m	Plume did not reach AP	(c)	
	0.5 m	Center	Plume centerline reached AP	(a)	
		1 m	Plume reached AP	(b)	
	Methanol	0.6 m	Center	Plume centerline reached AP	(a)
			1 m	Plume reached AP	(b)
1.5 m			Plume did not reach AP	(c)	

87.3 Results

87.3.1 Experimental Results

This study used heptane and methanol as fuels, and the following experimental results from tests using the two fuels were consistent. After igniting the fuel, a fire started and a fire plume formed. A hot smoke layer then accumulated below the ceiling. After the hot smoke layer descended below the lower edge of the gypsum curtain, the hot smoke started flowing out of the experimental compartment. According to experimental observations, the T4 and T6 temperature readings were very close in all tests with an AP.

This observation is consistent with what occurs in the stagnation region of ceiling jets [2]. The flow behavior below an AP resembled that of ceiling jets. The T8 readings decreased as the distance between the fire source and room center increased. The T8 readings in tests without an AP

were higher than those with an AP because the fire plumes can reach the water pipe without an AP. Additionally, the heat conducted through water with an AP was higher than that without an AP. This experimental finding was partly caused by conduction via water which influences sprinkler head activation, as Yamauchi et al. [11] demonstrated in his numerical analysis.

87.3.2 Fire Plume Scenarios

As described in Fig. 87.2, a fire plume interacts with an AP and sprinkler head in three scenarios in this study. However, assigning each test to one of the three scenarios by eye observation during this experiment was difficult because the fires were not very sooty. Therefore, four methods according to measurements were developed. Figure 87.5 shows a schematic of these four methods.

- Method 1: When T12 readings were lower than those of T4 and T6, plume centerline reached the AP. When T12 readings were slightly higher than those of T4 and T6, plumes reached the AP, but plume centerlines did not reach the AP. When T12 readings were markedly higher than those of T4 and T6, fire plumes did not reach the AP.
- Method 2: When T10 readings increased very rapidly, plume centerlines reached the AP. When T10 readings increased gradually, plumes reached the AP, but plume centerlines did not reach the AP. When T10 readings increased slowly, fire plumes did not reach the AP.
- Method 3: When T4 readings increased suddenly and were higher than those of TR4 (thermocouple tree temperature at same height), plumes reached the AP. When T4 readings were lower than TR4 readings, plumes did not reach the AP.
- Method 4: When T8 readings increased very rapidly, plume centerlines reached the AP. When T8 readings increased gradually, plumes reached the AP, but plume centerlines did not reach the AP. When T8 readings increased slowly, fire plumes did not reach the AP.

Notably, the above methods must be considered together to group the tests. Table 87.1 lists the groups to which the conditions of the fire plumes interacting with the AP and sprinkler head belong based on the four methods.

87.4 Discussions

This study discusses the function of an AP for sprinkler head activation. Temperature and velocity are the two most important parameters. Figure 87.6 shows the three possible

Fig. 87.5 Four methods to group the behaviors of fire plumes

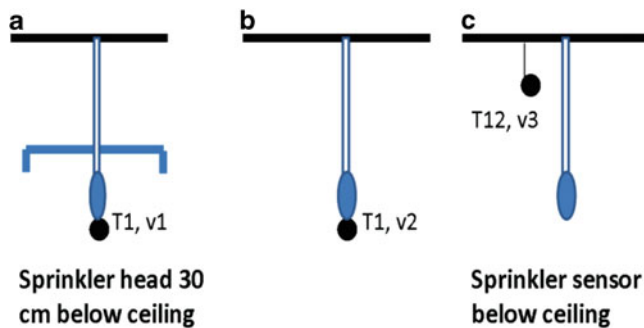
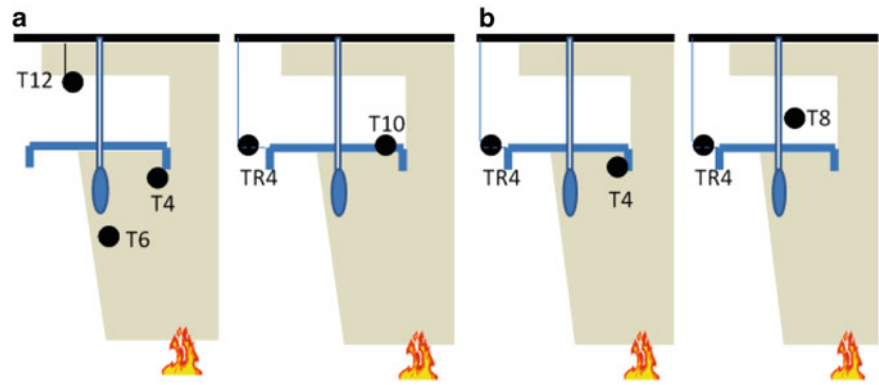


Fig. 87.6 Three possible sprinkler designs in this study (a) With AP (b) Without AP (c) Sprinkler sensor below ceiling.

sprinkler designs addressed in this study. By comparing temperature and velocity in Fig. 87.6a, b, the influence of an AP on activation of a sprinkler head located 30 cm below a ceiling is evaluated. By comparing the readings in Fig. 87.6a, c, the function of an AP in enhancing sprinkler system effectiveness is assessed.

87.4.1 Temperature

Figure 87.7 shows the temperatures at the three positions corresponding to the three possible sprinkler designs (Fig. 87.6) with 0.2 + 0.2-m heptane fires located at the center and 0.5 m from the room center. Clearly, when the fires were located in the room center and the plume centerlines of the fires directly reached the AP (Fig. 87.2a), the AP did not increase the heat received by the sprinkler head (Fig. 87.7a). Figure 87.7b shows the temperature histories at different locations corresponding to the three possible sprinkler designs (Fig. 87.6) with the 0.2 + 0.2-m heptane fires located 0.5 m from the room center. The plumes directly reached the AP but not the sprinkler head. The presence of the AP did not increase T1 temperature. The T12 temperatures were highest in the three possible sprinkler designs (Fig. 87.6). The heat thermocouple T1 received was from the hot smoky layer that accumulated below the ceiling while T12 received heat

from ceiling jets. The temperatures of ceiling jets were higher than those of the hot smoky layer accumulated at 30 cm below the ceiling. Therefore, the AP in this scenario (Fig. 87.2b) did not accelerate the activation of the sprinkler system. Furthermore, when a fire occurred that was not below a sprinkler head (Fig. 87.2c), T1 readings were much lower than those of T12 (data not shown). The AP in this situation (Fig. 87.2c) did not enhance the heat transfer to the sprinkler system.

87.4.2 Velocity

Figure 87.8 shows the velocity measurements at two locations (v1 and v3 in Fig. 87.6) corresponding to two of the three possible sprinkler designs (Fig. 87.6a, c) with 0.2 + 0.2-m and 0.4-m heptane fires located at the room center and 0.5, 1, and 1.5 m from the room center. Experimental results show that the plume velocity decreased as the distance between the fires and the room center increased. The v1 readings were very close to v3 readings when plume centerlines directly reached the sprinkler head. However, v1 readings were smaller than those of v3 in the other two scenarios (Fig. 87.2b, c). Furthermore, the velocity v2 (Fig. 87.6b) was not measured in this study.

87.4.3 Sprinkler System Activation

Table 87.2 compares temperature and velocity measurements near the sprinkler head corresponding to the three possible sprinkler designs (Fig. 87.6) and sprinkler activation assessed by the temperature and velocity comparison. When the plume centerlines directly reached the sprinkler head (Fig. 87.2a), the sprinkler systems activated almost simultaneously. When the plume centerlines did not directly reach a sprinkler head but reached an AP (Fig. 87.2b), the sprinkler system installed close to the ceiling (Fig. 87.6c) activated fastest among the three possible sprinkler designs. When the sprinkler system was equipped 30 cm below the ceiling, the AP did not cause differences in the temperature

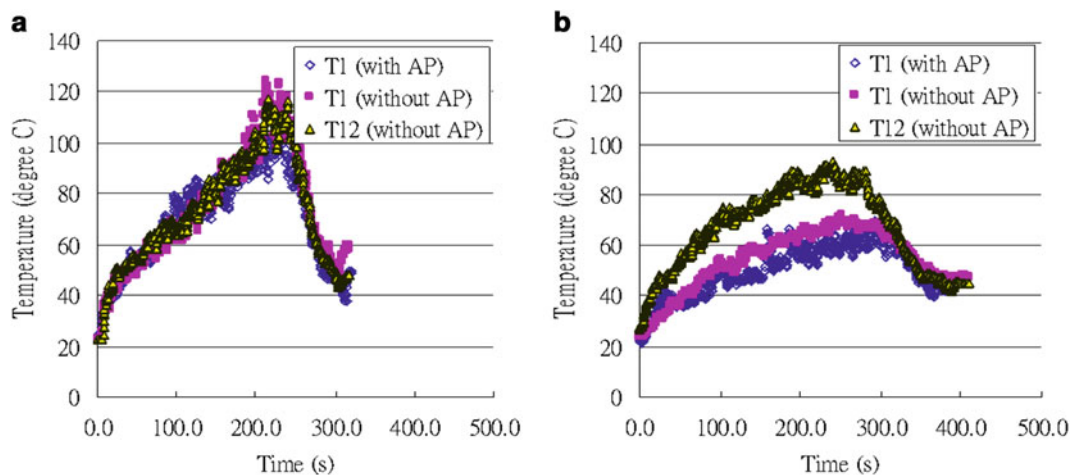
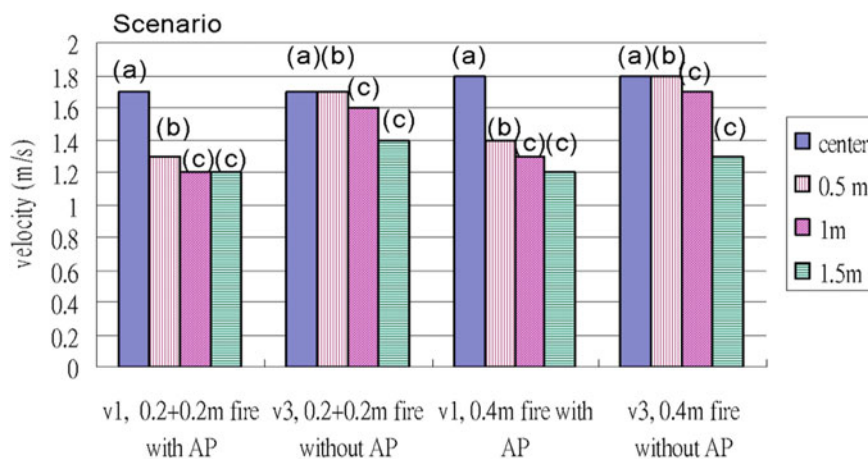


Fig. 87.7 Temperatures at different locations corresponding to the three possible sprinkler designs in Fig. 87.6 for 0.2 + 0.2 m heptane fires located at the room center (a) and 0.5 m from the room center (b)

Fig. 87.8 Velocity measurements v_1 and v_3 in Fig. 87.6 for 0.2 + 0.2-m and 0.4-m in diameter heptane fires located at the room center and 0.5, 1, and 1.5 m from the room center. The corresponding scenarios described in Fig. 87.2 are addressed



and velocity near the sprinkler head and reduce consequent time to sprinkler activation. Furthermore, the AP did not accelerate the activation of the sprinkler system when a fire occurred far from the sprinkler system (Fig. 87.2c).

87.5 Conclusions

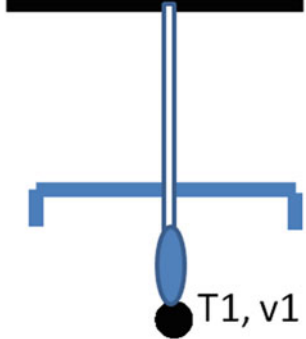
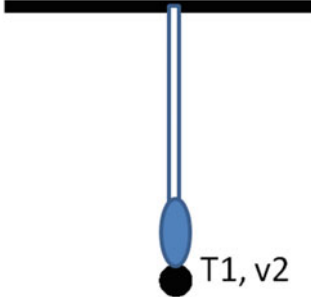
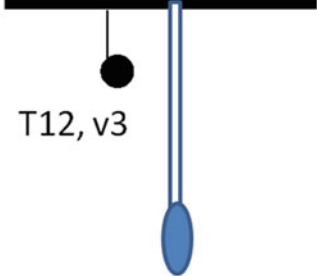
1. All cases can be grouped into three scenarios from the perspective of sprinkler activation and according to the interaction between a fire plume and sprinkler. The three scenarios are as follows:

- The fire plume centerline reaches the sprinkler head and AP.
- The fire plume reaches the AP but the plume centerline did not reach the sprinkler head or AP.

(c) The fire plume does not directly reach the sprinkler head and the absorber.

- The temperatures of the sprinkler head and that below the AP (T4 and T6) were very close in all the cases when fire plumes reached the AP, demonstrating that ceiling jets formed below the AP.
- The temperature of water pipe (T8) decreased when the distance between the room center and fire source increased. The T8 readings in cases without an AP were higher than those with an AP. Thus, conduction loss of heat via water in the cases with an AP was more than that without an AP.
- From temperature and velocity measurements for all cases with and without an AP, the AP did not help accelerate sprinkler head activation. Thus, APs are not

Table 87.2 Comparison of temperature, velocity, and time to sprinkler activation corresponding to the three possible sprinkler designs in Fig. 87.6

Sprinkler design		With AP Fig. 6 (a)	Without AP Fig. 6 (b)	Sprinkler sensor below ceiling Fig. 6 (c)
Fire position relative to sprinkler head				
Scenario Fig. 87.2a (direct hit of plume)	Temperature	Almost equal ^a	Almost equal	Almost equal
	Velocity	Almost equal	Almost equal	Almost equal
	Sprinkler activation	Almost equal	Almost equal	Almost equal
Scenario Fig. 87.2b (partial hit of plume)	Temperature	Almost equal	Almost equal	High
	Velocity	Almost equal	Almost equal	High
	Sprinkler activation	Almost equal	Almost equal	Fast
Scenario Fig. 87.2c (no hit of plume)	Temperature	Almost equal	Almost equal	High
	Velocity	Almost equal	Almost equal	High
	Sprinkler activation	Almost equal	Almost equal	Fast

^a“Almost equal” means the values of parameters associated with the designs are very close

useful! Even when a sprinkler head is installed 30 cm below a ceiling, APs are not useful!

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