AN ANALYSIS TO ESTABLISH A NIGHTCLUB SPRINKLER THRESHOLD

PREPARED FOR:

NATIONAL FIRE PROTECTION ASSOCIATION
TECHNICAL COMMITTEE ON ASSEMBLY OCCUPANCIES

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I. EXECUTIVE SUMMARY

On March 13, 2003 the National Fire Protection Association (NFPA) called a special meeting of its Technical Committee on Assembly Occupancies. The meeting was in response to the fire at the Station Nightclub in Warwick, Rhode Island. The Station Nightclub did not have an automatic sprinkler system. NFPA 101, *the Life Safety Code*, and NFPA 5000, *Building Construction and Safety Code*, require new assembly occupancies to have an automatic sprinkler system when the occupant load exceeds 300. The International Building Code requires nightclubs to have an automatic sprinkler system when the area exceeds 5,000 square feet.

As a result of the meeting, Code Consultants, Inc. has prepared this analysis for review, which utilizes computer fire and egress modeling in a timed egress analysis to determine the threshold for automatic sprinkler protection specifically in a nightclub. For the purposes of this analysis a nightclub usually involves: (1) alcohol consumption, (2) possible low lighting levels, (3) highly concentrated occupant loads, and (4) conditions where occupants are not immediately cognizant of a developing fire condition. This analysis consists of a fire modeling analysis of the conditions in a representative nightclub using the Computational Fluid Dynamics (CFD) model Fire Dynamics Simulator (FDS) and an egress analysis of the time to exit the building using the computer egress model SIMULEX. The analysis is used to determine how many occupants are expected to exit from the building during a given fire prior to conditions in the building becoming untenable.

A 5,000 sq. ft. building with dimensions of approximately 71 ft. by 71 ft. and a ceiling height of 10 ft. was modeled. The fire modeling included two scenarios. The first, was a medium t-squared fire as defined in NFPA 72 Annex B. The second, was a fast t-squared fire. Each fire was modeled in the middle of the building and continued to grow throughout the simulation. Tenability criteria based on the smoke layer interface position, temperature, carbon monoxide concentration, and visibility were developed based on the Fire Protection Handbook, published by NFPA, and National Institute for Occupational Safety and Health (NIOSH) guidelines.

Two egress scenarios were modeled, (1) egress from the building with both required exits available and (2) egress from the building with only one available exit from the instant the fire is ignited. The second scenario was used to investigate the condition where one of the exits is blocked, not used, or otherwise unavailable. The egress modeling initially included 300 occupants, the maximum number permitted in an unsprinklered assembly occupancy. The number of occupants was then reduced until all of the occupants were able to egress from the building prior to untenable conditions as defined in Section IV.

The results of the modeling show that tenable conditions are expected to be maintained in the building during a fast t-squared fire for long enough to permit 150 occupants to exit, even with only one available exit. The modeling also indicates that with two exits available, 300 occupants is close to the threshold where untenable conditions would be expected during a fast t-squared fire.

It should also be pointed out that depending on building design, basing the threshold for sprinklers on a building area of 5,000 sq. ft., such as the International Building Code does, can lead to much higher occupant loads than 300 for the threshold. For example, a 4,900 sq. ft. night club with 70% of the floor area devoted to the concentrated assembly use at 7 sq. ft. per occupant can result in occupant loads in excess of 500 without requiring automatic sprinkler protection. Conversely, basing the threshold on the number of occupants, such as 300, the concentrated assembly area of only 2,100 sq. ft. would trigger the requirement for automatic sprinkler protection.

II. METHODOLOGY

A representative small nightclub was used for the analysis. The building was 5,000 sq. ft. in area with a ceiling height of 10 ft. The time to egress from the building was calculated and compared to the time when conditions are expected to become untenable at 6 ft. above the floor. The Life Safety Code defines the 6 ft. criteria in Section 8.2.5.6(5).

The current threshold for requiring automatic sprinkler protection in assembly occupancies is an occupant load greater than 300. A building with 300 occupants is required to have a minimum of two remote means of egress, each providing not less than 32 inches of clear width. In addition, the analysis focused on the scenario where one exit is unavailable from the very inception of ignition of the fire.

The fire modeling analysis was conducted using two different potential fires. The first, was a fast growth t-squared fire, as defined in NFPA 72 Annex B. The second, was a medium growth t-squared fire. The time to untenable conditions at 6 ft. above the floor was calculated for each scenario using the Computational Fluid Dynamics (CFD) fire model Fire Dynamics Simulator (FDS). The fire modeling analysis is described in further detail in Section IV.

The time to untenable conditions at 6 ft. above the floor of the building was then compared to the egress time from the building. The egress time was calculated using the computer egress model SIMULEX. The SIMULEX model and the egress analysis are described in further detail in Section III. Initially, the egress time for 300 occupants was calculated. The number of occupants was then reduced until all of the occupants were able to exit from the building prior to the time when conditions became untenable.

The combination of the fire modeling and the egress modeling were used to investigate the threshold at which automatic sprinkler protection is needed to control a fire so that occupants can exit. The scenario outlined above assumes a relatively small building, in which conditions deteriorate more quickly during a fire as compared to a larger building. The analysis also focused on the scenario where only a single exit was available from ignition.

III. EGRESS ANALYSIS

The computer egress model SIMULEX was used to determine the egress time from the building. Two egress scenarios were modeled, (1) both required exits available and (2) only one available exit from the time of ignition. This analysis focuses on the scenario where there is only one available exit.

SIMULEX was developed by the Fire Safety Engineering Group at the University of Edinburgh and is currently maintained by Integrated Environmental Solutions, Ltd. SIMULEX was developed to simulate the escape movement of occupants from a building and uses floor plans for the building to provide a graphical representation of the building within the model. In this case, a simple, single floor building 5,000 sq. ft. in area was created.

Occupants are placed in the building and are given a set of characteristics that account for occupant size, turning rate, and speed. The behavior of each individual occupant is calculated to determine the egress time and route from the building. The movement of individual occupants is modified to account for obstructions (including other occupants), turning to move around obstructions, and the proximity to other occupants. The movement of individual occupants exiting the building combine to provide a complete picture of the egress from the building.

Egress from the building is assumed to start at the time the fire reaches 200 kW. Depending on the fuel configuration, a 200 kW fire would be expected to have flames approximately 5 ft. high according to the flame height equation in NFPA 72 Section B.2.3.2.4.1. Such a fire in a small club is expected to be significant enough to have some occupants to begin to exit from the building. The remainder of the egress time was calculated using the SIMULEX model.

IV. FIRE MODELING ANALYSIS

The effects of a fire in the representative nightclub were modeled using the Computational Fluid Dynamics (CFD) model Fire Dynamics Simulator (FDS) developed by the Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST). Version 3 of the FDS model was used for this analysis. FDS solves a form of the fundamental equations of the fluid motion (the Navier-Stokes equations) in order to calculate conditions in a space due to a fire. The model works by dividing the space being modeled into multiple regions or cells and for this analysis, the nightclub was divided into approximately 25,000 cells. The equations describing the motion of fire gases are solved for each cell and combining the results for all of the cells in the building creates a solution that describes the motion of fire gases throughout the building.

The fire was located in the center of the building 1-1/2 ft. above the floor. NFPA Annex B provides a description of the power law fire growth model used to characterize the growth of the fire. Two fire growth rates were used for the simulations, a fast growth fire and a medium growth fire, as shown in Figure 1. These fires are intended to represent a range of possible combustibles in the building.

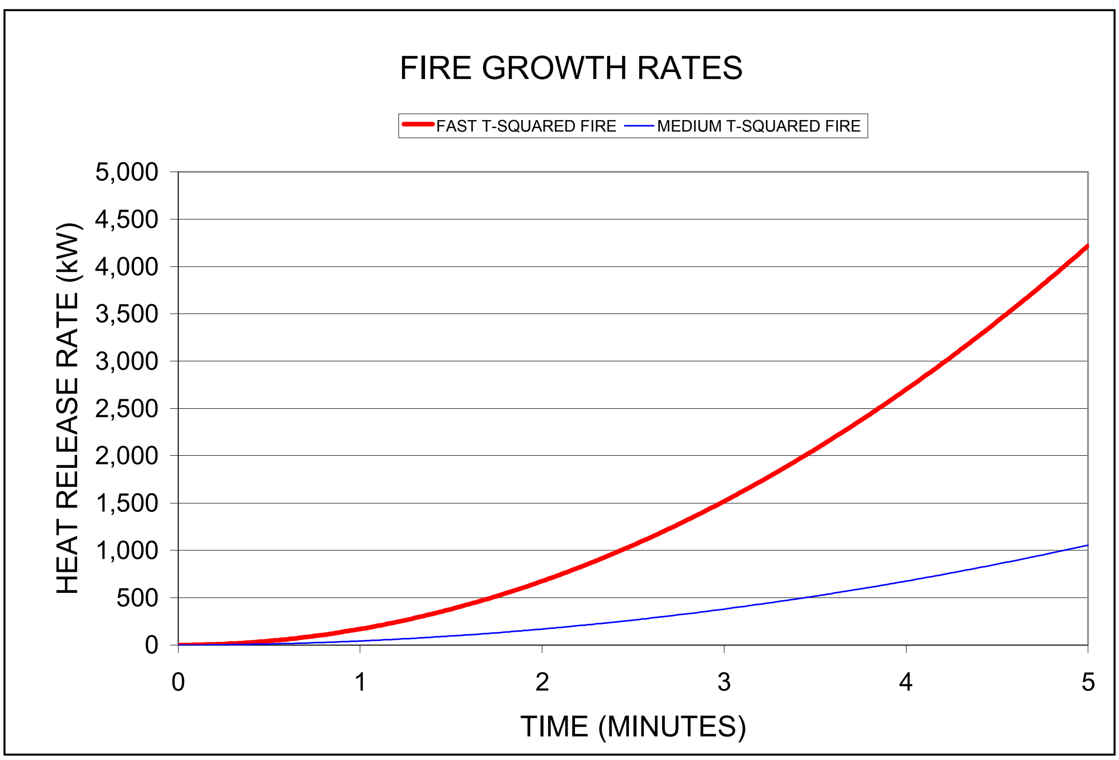


Figure 1. Fire growth rates.

The conditions throughout the building were calculated using the FDS model and the conditions at 6 ft. above the floor were used to evaluate tenability conditions. The effect of the smoke layer on exiting was defined using the following tenability criteria specified by NFPA 92B:

- Visible distance
- Smoke toxicity (carbon monoxide concentration)
- Smoke temperature
- Smoke layer interface position.

The National Institute for Occupational Safety and Health (NIOSH) sets limits for the exposure to toxic gases. The principal threatening component of fire smoke is carbon monoxide (CO). The Immediately Dangerous to Life and Health (IDLH) level for carbon monoxide is 1,200 ppm as defined by NIOSH.

Tenability criteria for smoke temperature and visible distance were taken from the NFPA Fire Protection Handbook, 18th Edition. Section 4 Chapter 2 of the Handbook provides guidance as to acceptable limits for visibility and smoke temperature. The cooling effect of skin moisture is found to compensate for the heat imposed on the skin up to a temperature of 140°F. A temperature of 150°F has previously been used as a criteria for the study of school children exiting and the 140°F criteria is used for this analysis. Suggested visibility limits range from a minimum of 6.6 feet (2 m) to 49.2 feet (15 m). A criteria of 50 feet of visibility has been used for this analysis, since it is the most conservative of the proposed values.

The Life Safety Code requires that the smoke layer interface be maintained 6 ft. above the level of egress for the purpose of smoke control system design. The 6 ft. criteria has been used for this analysis. The smoke layer interface has been calculated as being at the height where the temperature is 140°F, consistent with the tenability criteria outlined above.

The criteria used in this analysis are summarized in the following table along with the reference for the value.

TENABILITY CRITERIA	LIMIT	SOURCE
Temperature	140 °F	Fire Protection Handbook
Carbon monoxide concentration	1,200 ppm	NIOSH
Visibility	50 ft.	Fire Protection Handbook
Smoke layer interface position	6 ft.	Life Safety Code

V. MODELING RESULTS

The conditions in the building were calculated for both a fast and medium growth t-squared fire. After ignition, the fire grows according to the prescribed growth rate and conditions in the building deteriorate. Smoke from the fire collects in the upper portions of the building and begins to fill the building starting at the ceiling and moving towards the floor. As the smoke fills the building, conditions at 6 ft. above the floor deteriorate. The temperature at 6 ft. above the floor at different times during a simulation is graphically illustrated in Figure 2.

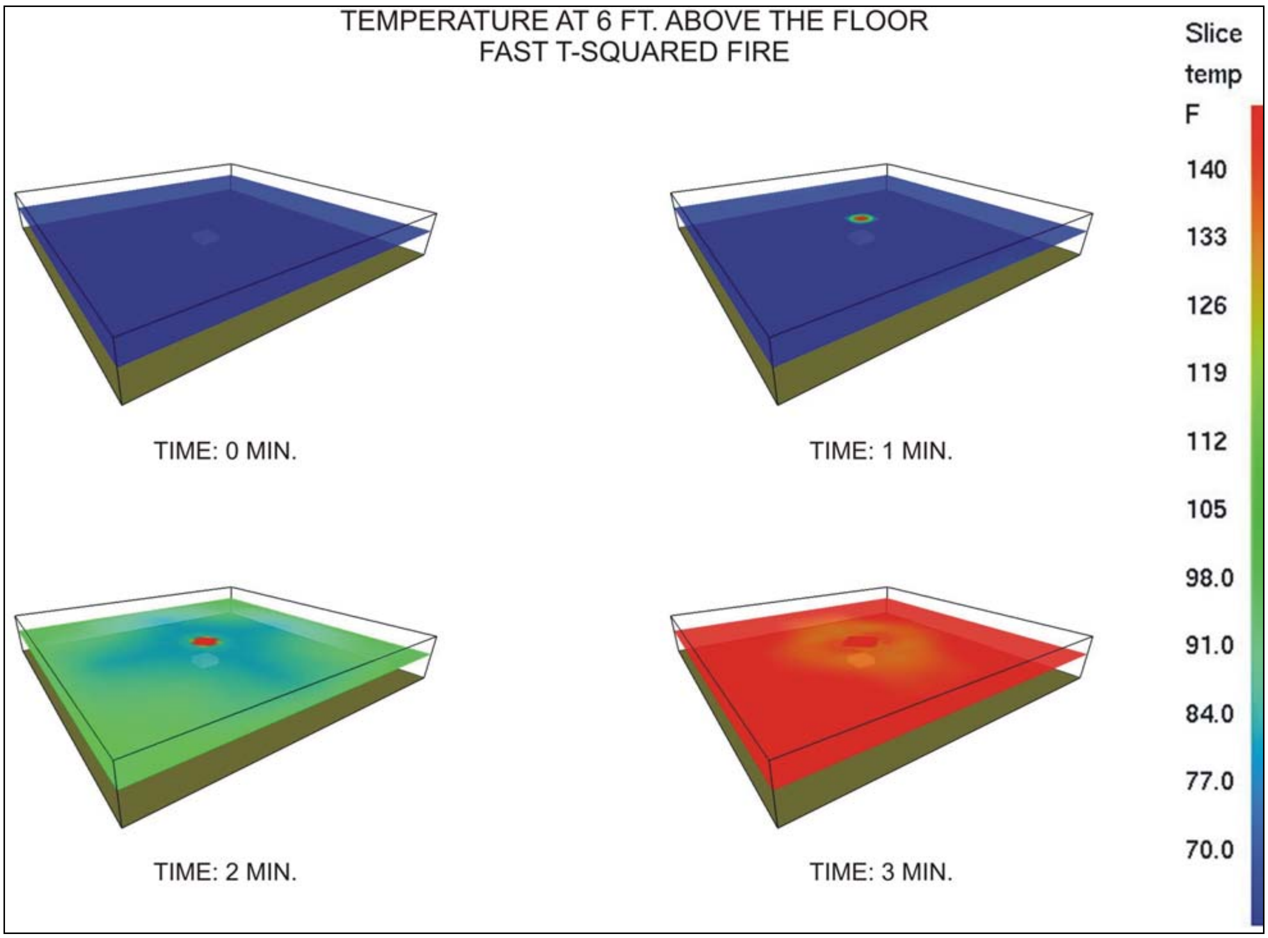


Figure 2. Graphical illustration of fire modeling results.

The temperature at 6 ft. above the floor during a fast growth t-squared fire is shown in Figure 1. The colored plane is used to illustrate the temperature at 6 ft. above the floor, where a temperature of 70°F is indicated using blue and 140°F, the tenability limit, is indicated using red. As time progresses, smoke fills the building and conditions at 6 ft. above the floor deteriorate. By 3 minutes after ignition of the fast growth fire, the tenability limit has been reached.

The tenability limit is reached at 177 seconds for the fast growth fire and 268 seconds for the medium growth fire. Figure 3, below, is a graph of the smoke layer interface position during both the fast and medium t-squared fires. Figures 4 through 9 show in graph form the average temperature, carbon monoxide, and visibility at 6 ft. above the floor along with the tenability limits outlined in Section IV.

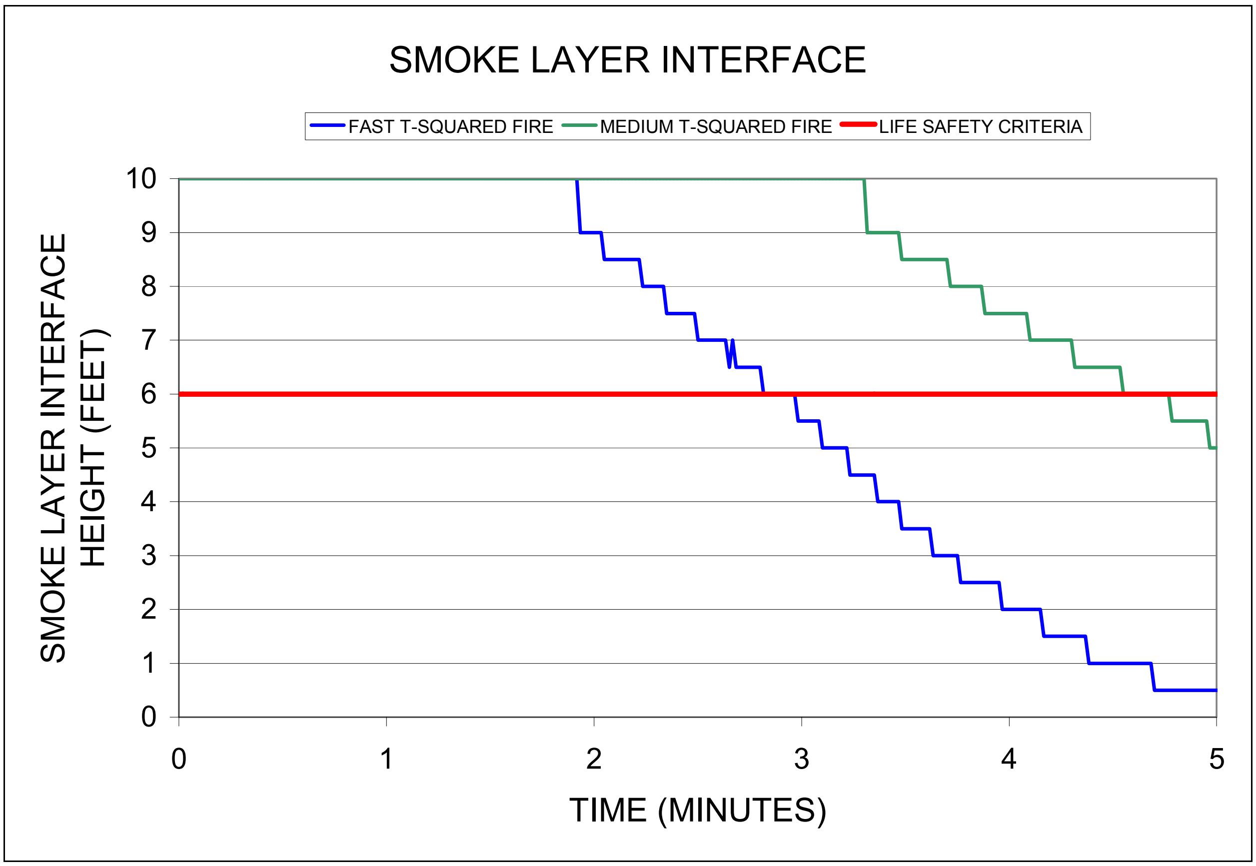


Figure 3. Smoke layer interface position.

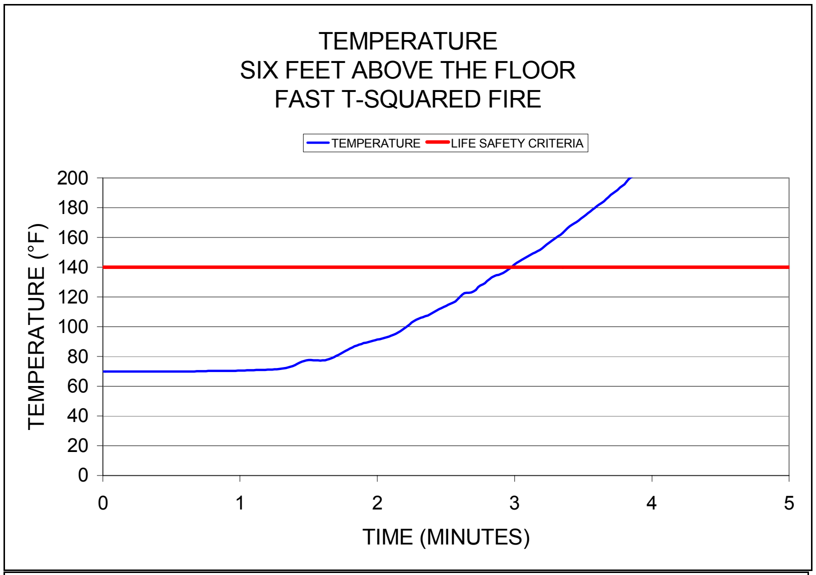


Figure 4. Temperature.

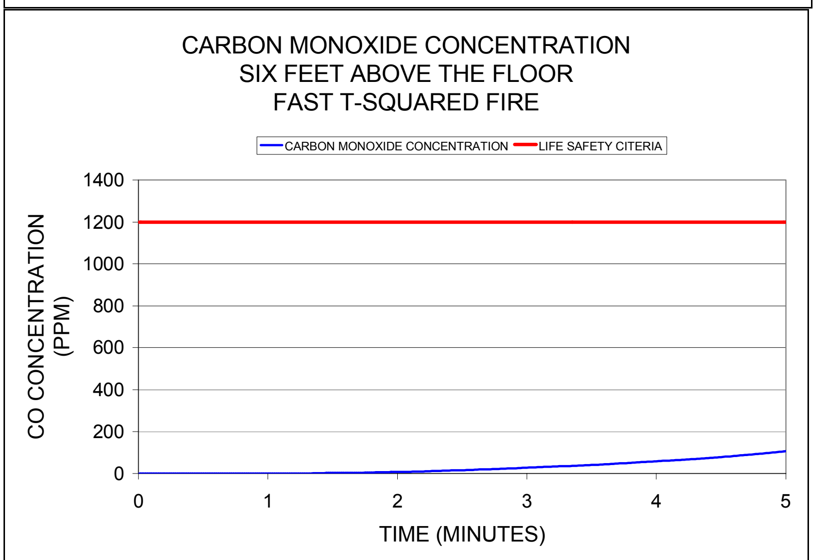


Figure 5. Carbon Monoxide.

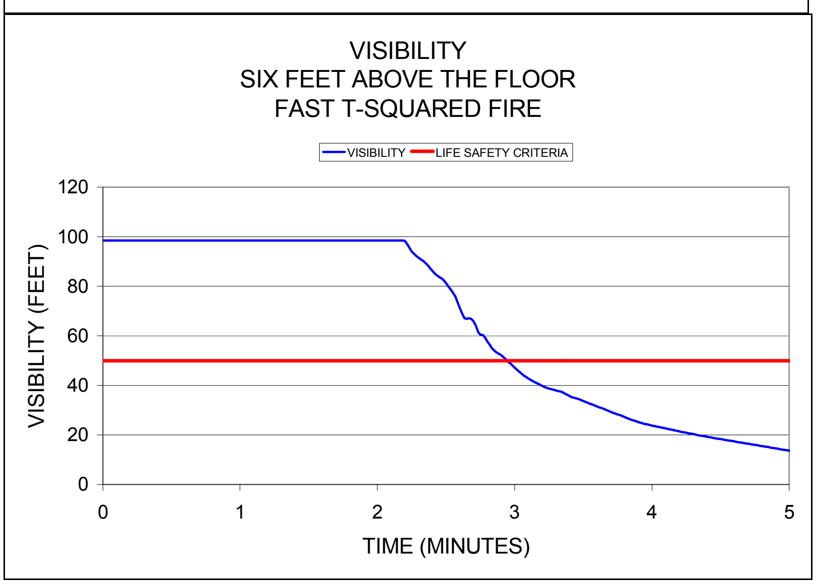


Figure 6. Visibility.

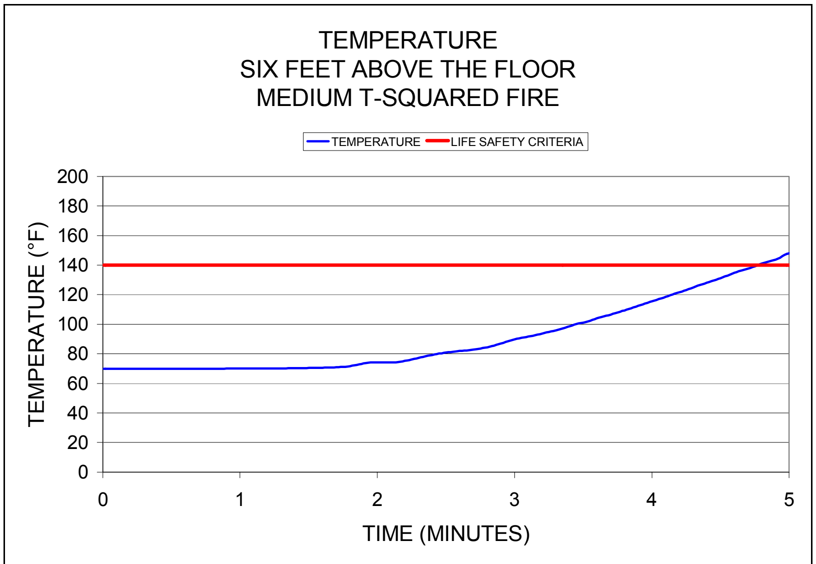


Figure 7. Temperature.

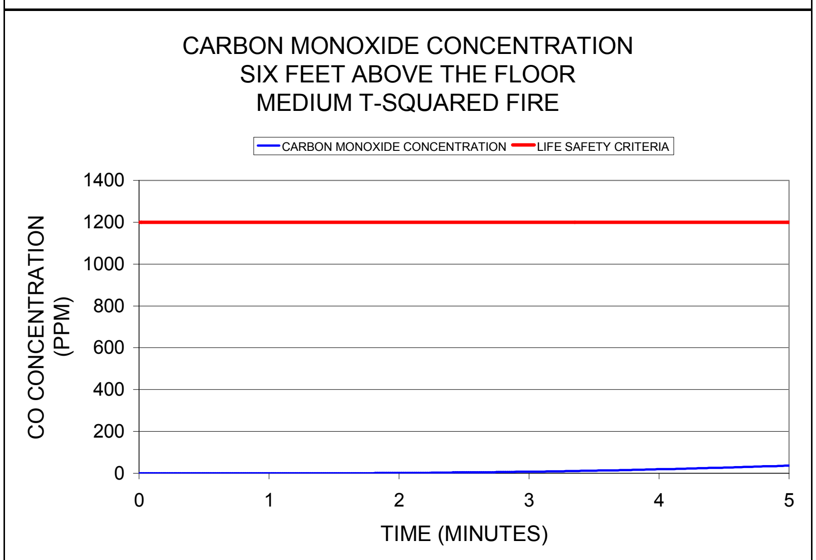


Figure 8. Carbon Monoxide.

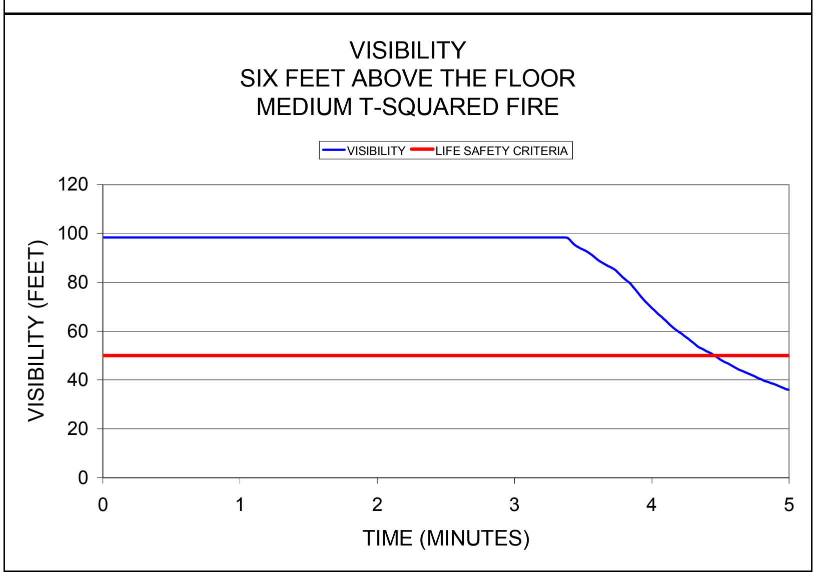


Figure 9. Visibility.

For each of the fires, the tenability within the space is limited by the temperature and visibility criteria at approximately the same time. Approximately 3 minutes after the start of the fast growth fire, the temperature at 6 ft. above the floor reaches 140^{o}F and the visibility is limited to 50 ft. For the medium growth fire, the temperature reaches 140^{o}F and the visibility is limited to 50 ft. at approximately 4-1/2 minutes after the start of the fire. In both fires, the carbon monoxide concentration at 6 ft. above the floor is significantly less than the 1,200 ppm tenability limit. The time to reach the tenability limits can be compared to the time to exit from the building to determine how many occupants are expected to safely exit.

The results of the egress analysis show that approximately 150 occupants will be able to exit from the building during a fast growth fire, even with only one available exit. The egress time is limited by the available exit width and not by the travel speed or distance. Figure 11 shows the egress simulation at different times during the simulation. Occupants can be seen at the door, waiting to exit from the buildings. The exit times calculated are summarized in Table 1:

Table 1. Egress Modeling Results.

NUMBER OF OCCUPANTS	**EGRESS TIME WITH ONE EXIT**	**EGRESS TIME WITH TWO EXITS**
150	1 MIN 45 SEC	1 MIN 6 SEC
300	3 MIN 27 SEC	1 MIN 57 SEC

The results of the egress analysis show the egress time to be roughly proportional to the number of occupants and the number of available exits. The total egress time includes both the egress travel time, summarized in Table 1, and the time from the start of the fire until occupants begin to exit. Occupants are expected to begin to egress when the fire size reaches 200kW, a flame height of approximately 5 ft. For the fast growth fire, the fire reaches 200kW at 65 seconds and for the medium growth fire, the fire reaches 200kW at 131 seconds. Combining the egress time from Table 1 with the egress start time outlined above gives the total egress time after ignition.

The egress time after ignition can be compared to the time to untenable conditions to determine if safe exiting is likely. The results of the analysis for 150 occupants exiting through a single exit are summarized in Table 2.

Table 2. Timed Egress Analysis Summary.

FIRE GROWTH RATE	TIME TO START EGRESS (SECONDS)	EGRESS TRAVEL TIME (SECONDS)	TOTAL EGRESS TIME FROM IGNITION (SECONDS)	TIME TO UNTENABLE CONDITIONS (SECONDS)
FAST T-SQUARED	65	105	170	177
MEDUM T-SQUARED	131	105	236	268

The results outlined in Table 2 show that for either a fast or medium growth fire, 150 occupants are expected to be able to exit from the building prior to untenable conditions at 6 ft. above the floor. The results are further illustrated in the graph provided as Figure 10. The graph shows the total egress time along with the smoke layer interface height and the times at which the other tenability criteria are reached.

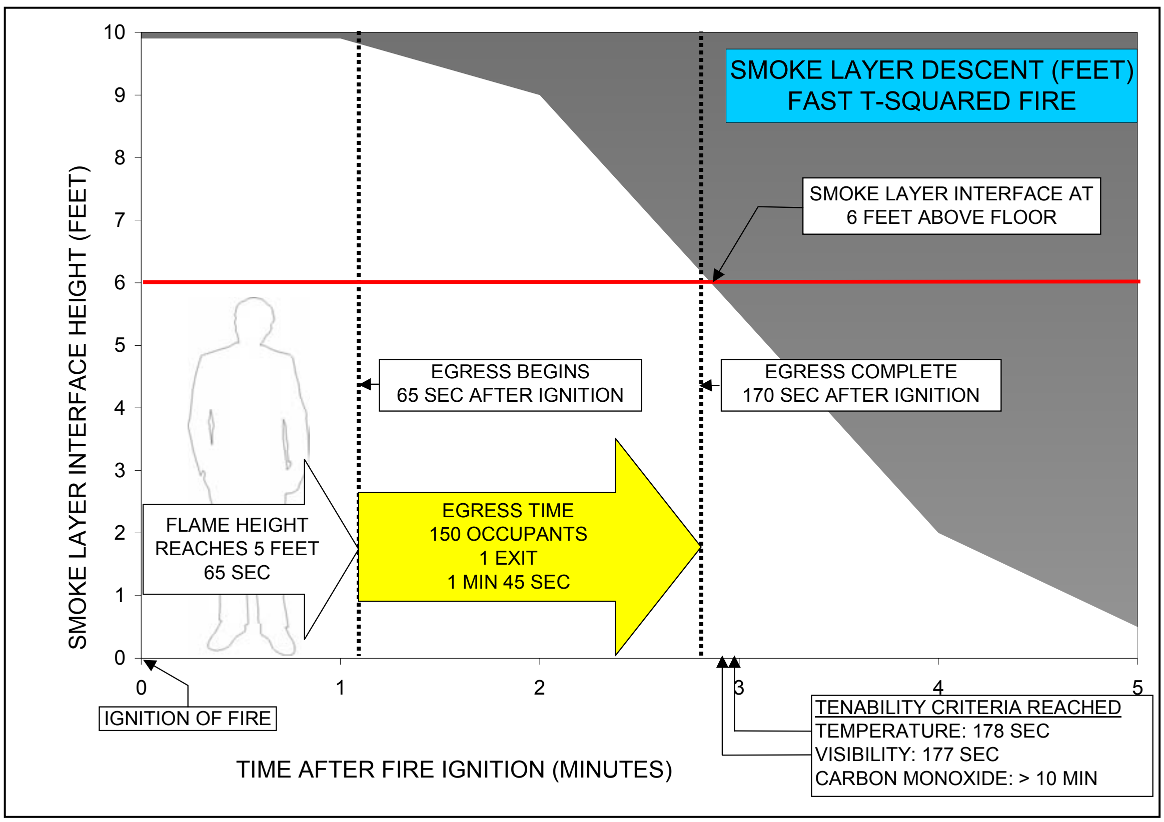
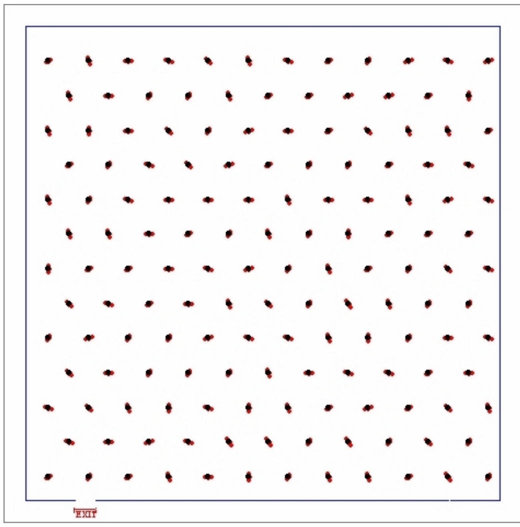
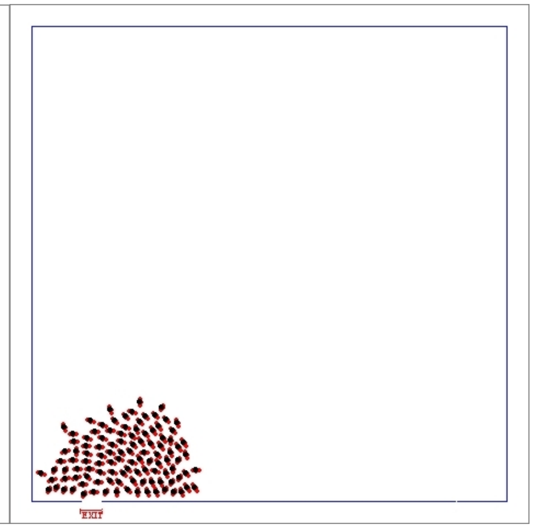


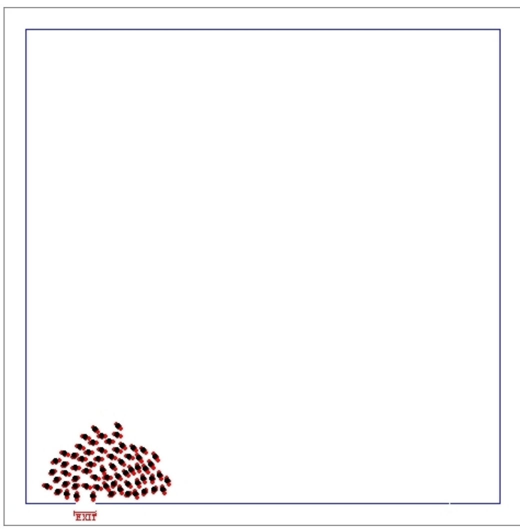
Figure 10. Timed egress analysis summary graph.



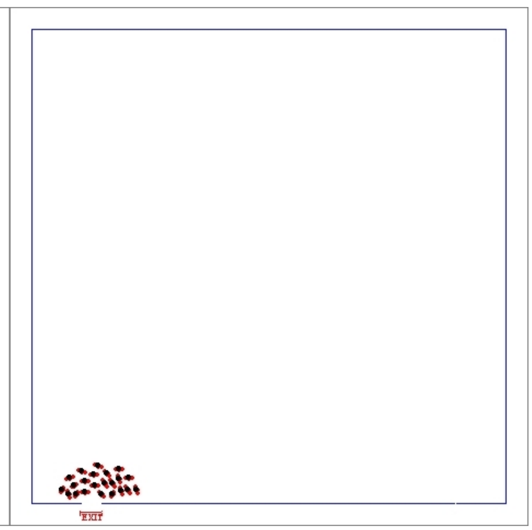
0 Min., 0 Sec.



0 Min., 30 Sec.



1 Min., 0 Sec.



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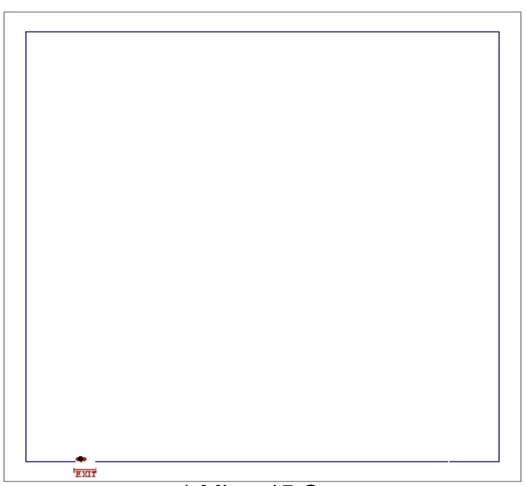

1 Min., 45 Sec.

Figure 11. Egress of 150 occupants through one door.

VI. SUMMARY

The 300 occupant sprinkler threshold has been investigated by modeling the effects of a fire in a representative small night club along with the egress from the building and having 50% of the exits blocked from the time of ignition. The time when untenable conditions are reached at 6 ft. above the floor was compared to the egress time to determine how many occupants are expected to safely exit from the building.

The egress analysis also includes the scenario where only a single exit is available. During a fast growth fire in the building, 150 occupants are expected to be able to exit prior to untenable conditions at 6 ft. above the floor, where only one exit is available. When two exits are available, the 300 person criteria is at the limit of the number of occupants that would be expected to be able to safely exit during a fast growth t-squared fire.