RECONSTRUCTING THE STATION NIGHTCLUB FIRE – COMPUTER MODELING OF THE FIRE GROWTH AND SPREAD

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ABSTRACT

On February 20, 2003, during a band performance, pyrotechnics ignited foam insulation lining the walls and ceiling of the platform that was being used as a stage in The Station Nightclub, Rhode Island, USA. The fire spread quickly along the foam lined walls and ceiling, smoke emerged from the exit doorways in less than one minute, smoke dropped quickly to near the dance floor, and flames broke through the roof in less than five minutes. One hundred people lost their lives in the fire and hundreds were injured. As part of its technical investigation of the fire, the National Institute of Standards and Technology (NIST) utilized a computer fire model to reconstruct the fire growth and spread through the entire nightclub. Input data for the fire model were developed from a wide range of sources including pre- and post-fire photographs, site visits, floor plan drawings, small scale material testing, and real-scale mockup experiments. A commercial television station's video tape of the nightclub on the night of the fire provided information on the start and spread of the fire that was almost unprecedented in fire forensics. The model simulation of the entire nightclub was consistent with the video record during the early stages of fire development. The reconstruction predicted quick fire growth due to the burning of the convoluted polyurethane foam and the rapid growth led to rapid production of smoke, high temperatures, and low oxygen levels throughout most of the simulated nightclub. The fire model predicted that many of the occupants had less than 90 seconds after ignition to exit the structure. Although the nightclub was not equipped with automatic water sprinklers, a second simulation included sprinklers. For a sprinklered nightclub, examination of the predicted temperature and the oxygen volume fractions shows tenable conditions would have existed throughout the duration of the simulation (300 s), as the fire was extinguished approximately 114 seconds after ignition. Based on the results of the model and the findings of the investigation, NIST made a number of recommendations that are aimed at improving life safety in nightclubs.

INTRODUCTION

The Station Nightclub was a single-story wood frame structure with an area of approximately 412 m^2 (4484 ft^2) [1]. A plan view of the nightclub is shown in Figure 1. In order to reconstruct the growth and spread of fire, the model simulation requires data on the ignition source, fuel package including composition and location, the material properties of the various interior finishes, vent locations, and event timelines. Dimensions, materials of construction, and window and door locations were collected from pre- and post-fire photographs, site visits, interviews, and floor plans. Fire growth, ventilation openings, and fire department response timelines were developed from videos recorded inside and outside the nightclub by a television camera operator[2], information from 911 phone calls, and fire department radio communications. The reconstruction also required the ignition and thermal properties of the interior materials. Lacking adequate literature values, the essential fire properties were obtained from small scale tests on wood paneling, carpeting, ceiling tile, and polyurethane foam[3]. In addition to the small-scale tests, a series of real-scale experimental mockup burns of a portion of the nightclub were conducted to collect additional data on fire growth and smoke movement[4].

The mockup burns, each of which involved about 20% of the nightclub interior, included both non-sprinklered and sprinklered configurations. The non-sprinklered mockup experiment led to a flashover conditions within the drummer's alcove in approximately 60 s. The resulting high temperatures, low oxygen, high carbon monoxide, and high hydrogen cyanide levels all suggest that conditions in the un-sprinklered test became untenable in less than 90 s. In the mockup experiment with sprinklers, near ambient temperature and oxygen levels were maintained 1.5 m above the floor throughout the experiment. The mockup experiments provided insight into the how the fire spread, how and when the interior became untenable, and possible impact of automatic water sprinklers.

Modeling the mockup experiments with FDS offers an opportunity to compare the computer model results with a known fire, prior to applying the model to the actual nightclub geometry. Since the FDS model was successful in simulating the fire spread and smoke movement in the mockup burns, it was then used to examine the conditions in the entire nightclub. In addition to reconstructing the fire, FDS was also used to investigate the impact that automatic sprinklers may have had on the fire. Computer fire models are a tool that can help to fill in critical details of a specific fire incident, but can also be used to demonstrate the value of alternative building designs and fire safety measures.

FIRE MODEL SIMULATION

NIST researchers utilized the Fire Dynamic Simulator (FDS) [5,6], a computer fire model to reconstruct the fire conditions in the nightclub. The Fire Dynamics Simulator is a computational fluid dynamics model of fire-driven fluid flow. It solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flow with an emphasis on smoke and heat transport from fires. The data from an FDS simulation are displayed using Smokeview visualization software[7].

The FDS simulation reconstructed the fire growth and spread during first 300 seconds of the incident. This time period began with the ignition of the foam insulation and continued to the approximate time of water application by the fire department. The computation included simulated fire and smoke spread, potential temperatures, oxygen concentrations and visibility that may have existed in the actual incident. In order to gauge the accuracy of the full nightclub simulation results, they were compared with the WPRI video of the incident. In addition, analysis of the simulation considered published tenability criteria and the location of the victims within the nightclub.

The reconstruction divided the nightclub or computational domain into approximately 1,250,000 individual computational or grid cells which were 100 mm x 100 mm x 100 mm. Each side of the domain, as well as the top, was modeled as open to the environment outside of the domain to allow air to enter and combustion products to exit. The bottom of the domain was considered to be an inert, adiabatic solid. The ignition and initial fire growth was simulated by a thermal input of 1500 kW/m^2 for 35 s over a 200 cm^2 area on both sides of the platform in the regions impacted by the pyrotechnics.

The interior finishes of the structure were modeled in a similar manner as the interior finishes of the real-scale mockup experiments. The material properties that were used in the simulation are tabulated in Table 1. While it may not be obvious from Table 1, each of the interior finishes or materials created different challenges to the model. The model simulated the foam and wood as surfaces that were consumed by the fire although the foam basically disappeared as it burned and the wood formed a char layer. Neither the ceiling tile nor gypsum board, which the model also treated basically as non-combustible surfaces, contributed significantly to the fuel load, but did play a role in the transfer or movement of energy released by the burning fuel. Carpet flooring represented a composite fuel package composed of loops or piles woven into a denser backing layer. As the carpet burned, some of the pile melted and formed semi-liquid "melt" fires which intermingled with unburned carpet pile. The carpet material was also modeled as a surface, with the model using the material properties from the FDS Material Database. The database for carpet does not specifically identify the thickness, specific heat, or density, but uses a combined term which is the product of all three properties. For this reconstruction, a value of 1.29 $kJ^2\ m^{-4}\ K^{-1}\ s^{-1}$ was used for this combined property term.

The structure's doors and windows were opened during the simulation based on visual or audible cues from the video. The opening times of each door or window that were used in the model simulation are shown in Table 2.

Figure 1. Floor plan of The Station Nightclub.

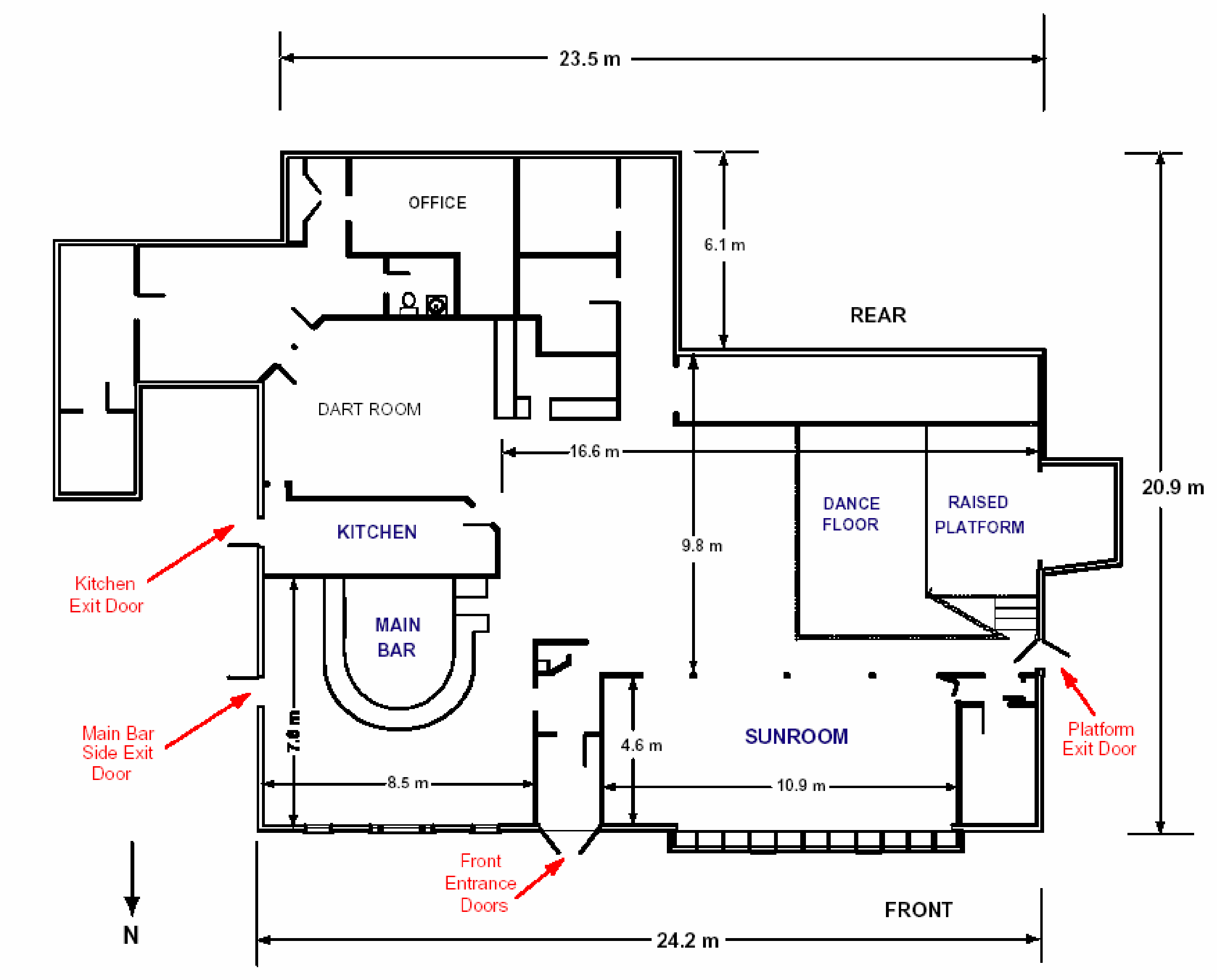


Table 1. Material Properties Used In Simulation

Material	Thickness (m)	Ignition Temperature (°C)	Heat of Vaporization (kJ/kg)	Thermal Conductivity (W/m K)	Density (kg/m^3)
Foam	0.03	370	1350	0.034	22.0
Paneling	0.01	360	500	0.13-0.29	450
Ceiling Tile	0.016	N/A	N/A	0.0611	N/A
Gypsum Board	0.013	400	N/A	0.48	N/A
Carpet	N/A	280	3000	N/A	N/A

Table 2. Time of Openings for FDS Simulation

Location of Opening	Time of Opening (s)
Stage Door	29
Front Double Door	30
Side Door (near main bar)	45
Side Door (kitchen)	60
Front Bay Window (lower portion)	78
Front Windows	80
Left Side Bay Window	100
Three Bay Windows	110, 120, 130

FDS SIMULATION RESULTS

Fire Growth and Smoke Spread

Simulation results as visualized using the Smokeview software were compared to images selected from the WPRI video. FDS generated iso-surfaces of the heat release rate per unit volume and three dimensional smoke density parameters are displayed in Figures 2 through 4 (It should be noted that the orange color in Smokeview tracked the location of the stoichiometric fuel and air mixture). Qualitative agreement was seen between the pairs of images from the simulation and the video for both the initial growth prior to the videographer leaving the structure, and the outside view. This similarity helped the investigation draw conclusions as to the conditions inside the structure even though the video was no longer recording inside. All of the times that accompany the figures below are times after ignition. The times were chosen based on the image availability from the WPRI video. The images were chosen based on the visibility of the fire or the smoke from the fire. As noted in the figure captions the image sets may not reflect the exact same time. In Figure 4, the simulation stops at 300 s while the image from the video showing flames from the front of the nightclub was not recorded until 337 seconds after ignition. At this point in the fire, conditions were not changing as rapidly as during the fire development, so the comparison between the two images is reasonable.

Heat Release Rate

The total heat released in the fire is plotted in Figure 5. The graph shows that after the alcove became fully involved with fire, at approximately 50 to 60 seconds, the heat release rate increased from approximately 2 MW to 54 MW in less than 50 seconds. Hence the rate of increase was more than 1 MW per second. As the fire spread throughout the structure and the fire became oxygen limited the heat release rate became steady at approximately 45 MW for approximately 150 s. After that time, the simulation began to deplete the fuel contained in the interior finish materials. The fire in the actual nightclub had spread into the structure and burned in and through areas of the roof and walls by this time. The simulation only provided fuel based on the interior finish and did not account for fuel being provided by structural elements and materials in building outer envelope.

Temperature

Temperature slices were examined to assess the tenability conditions that existed during the evolution of the fire. Horizontal slices were taken at both the 1.5 m and the 0.6 m levels above the floor with the ceiling rendered transparent to examine the temperature distribution throughout structure as a whole. This analysis utilized 120 ºC as the temperature tenability threshold[8] . Figure 6 shows that the dance floor and adjacent areas reach untenable temperatures in the simulation within 90 seconds after ignition. At the 0.6 m height above the floor conditions remain tenable for a longer period of time than at the higher elevation shown in Figure 7.

Figure 2. Initial growth of fire on foam insulation lining sides and corner of the alcove

(simulation 10 s, video 10 s after ignition).

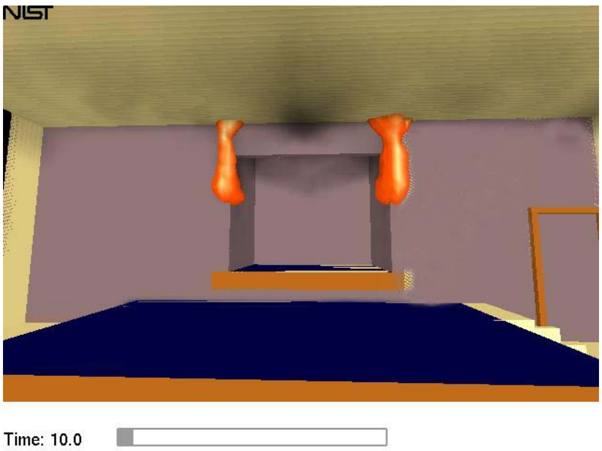


Figure 3. Smoke beginning to roll across ceiling above dance floor
(simulation 60 s, video 53 s after ignition).

Figure 4. Flames breaking through front door and sunroom windows on front side of nightclub
(simulation 300 s, video 337 s after ignition).

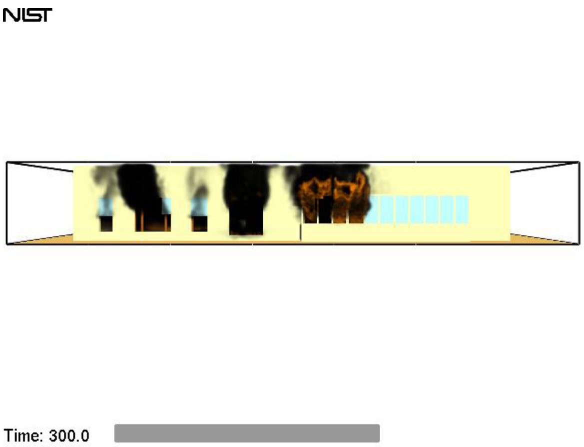


Figure 5. Total Heat Released in Building Fire Simulation as a Function of Time.

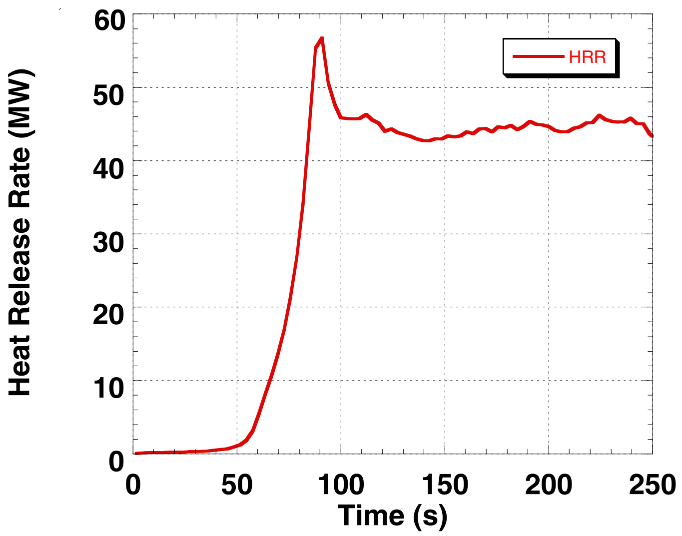
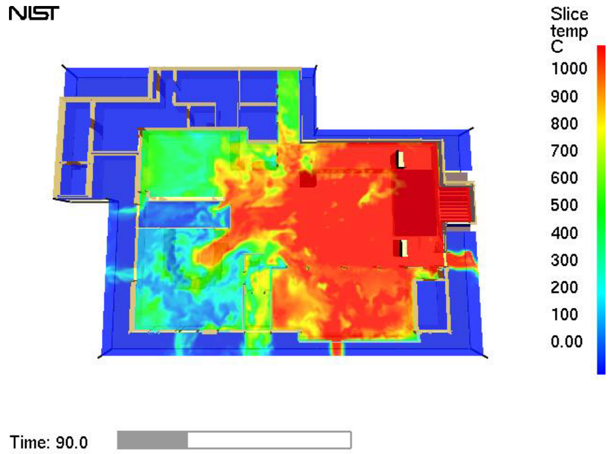


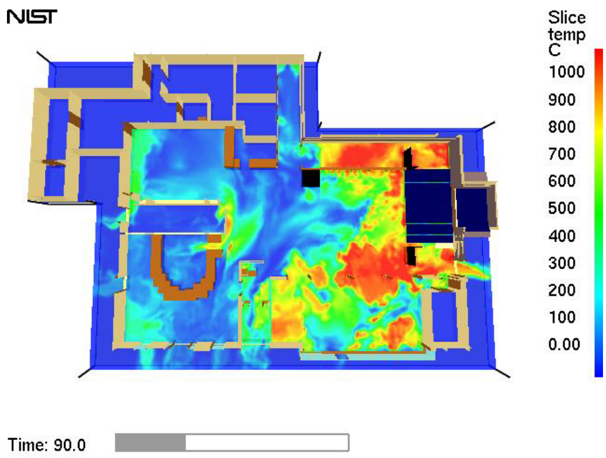
Figure 6. Temperatures at 1.5 m above the floor at 90 s.



Temperatures

The significant differences in temperature between the 1.5 m elevation and 0.6 m occur in the main bar room and the main entrance. This area remains tenable at the lower level due to the inflow of fresh air through the open windows and open doorways. The cooler temperatures towards the floor at both the front door and main bar area explain why occupants were seen in the video escaping from the windows and doorway later into incident.

Figure 7. Temperatures at 0.6 m above the floor at 90 s



Oxygen

Oxygen volume fraction concentrations were also examined in the simulation to assess the tenability conditions that existed during the evolution of the fire. Horizontal slices were taken at both the 1.5 m and 0.6 m levels with the roof removed to examine the structure as a whole. Figures 8 and 9 show the predicted oxygen volume fractions 1.5 m and 0.6 m above the floor, respectively, at 90 s after ignition. At this lower level it is apparent that the tenability limit, taken as a volume fraction of 12 % oxygen[8], is exceeded in all areas except the main bar area and the entranceway right inside the front door. The opening of the windows at the front of the main bar room creates a more tenable atmosphere.

The simulation indicates that sufficient fresh air was drawn in to maintain a level of tenability with respect to oxygen near the floor in the areas adjacent to the open windows and the main entry way. This trend is shown to continue through the end of the simulation. In the video, the last person recorded being assisted through a window from the main bar room occurs at 250 s seconds after ignition. This is consistent with the predicted oxygen concentrations near the windows.

Figure 8. Oxygen volume fractions at 1.5 m above the floor at 90 s

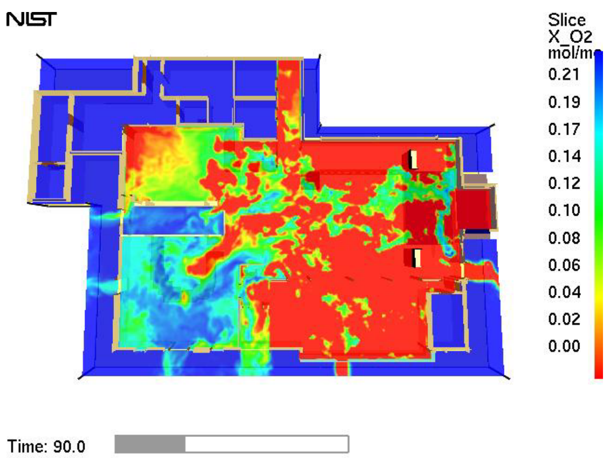
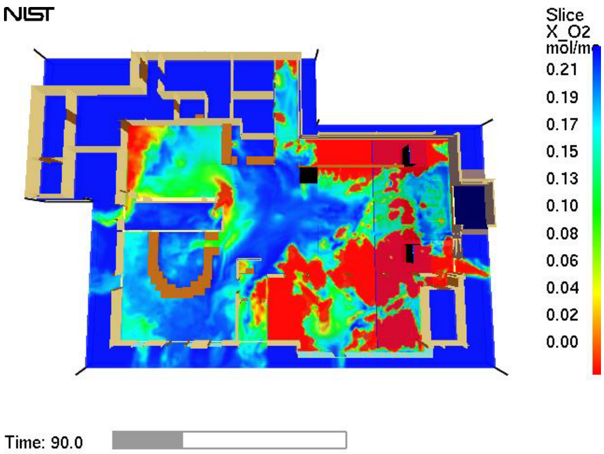


Figure 9. Oxygen volume fractions at 0.6 m (2 ft) above the floor at 90 s



Simulation of The Nightclub Equipped With Sprinklers

Another simulation of the nightclub was completed in order to examine the effects that sprinklers may have had on the fire and the environment. The input from the FDS incident simulation was combined with the sprinkler input from the FDS sprinklered full-scale mock-up simulation[4]. Five sprinklers were placed in the simulation. One was located in the center of the alcove and the other four were placed using 3.6 m spacing. While, the allowable sprinkler spacing based on NFPA 13[9], could have been greater than 3.6 m throughout the nightclub, the alcove would require a sprinkler regardless of the sprinkler spacing used throughout the rest of the nightclub. In the un-sprinklered cases, flashover of the alcove changed the rate of hazard development significantly. The sprinkler in the alcove was shown to prevent flashover in the experiments and the simulations, significantly mitigating the hazard. The sprinkler activation times from the full nightclub simulation, the mockup experiment, and the FDS simulation of the mockup are given in Table 3.

Table 3. FDS Predicted Sprinkler Activation Times

Sprinkler Location	**Nightclub Simulation**	**Mockup[4]**	
	FDS Sprinkler Activation Times (s)	**Experimental Sprinkler Activation Times (s)**	**FDS Sprinkler Activation Times (s)**
Southwest	20	24	23
Northwest	16	29	35
Alcove	29	30	36
Southeast	Did Not Activate	Did Not Activate	Did Not Activate
Northeast	Did Not Activate	Did Not Activate	Did Not Activate

Figure 10 provides another means of looking at the simulation. This image, rendered two seconds after the first sprinkler activated, includes the visualization of the sprinkler droplets but does not include the visualization of the smoke. Notice that the activated sprinkler has changed color from red to green.

Figure 11 shows the FDS predicted heat release rate for the sprinklered simulation. The heat release rate reached its maximum of approximately 220 kW at 20 seconds. This heat release rate quickly declined as the three sprinklers activated and suppressed the fire. By contrast, the predicted peak heat release rate for the unsprinklered nightclub was almost 54 MW (Figure 5, note change of scale) which was almost a factor of 250 greater than the predicted peak for the sprinklered nightclub of 0.22 MW (Figure 11).

An isothermal plot is shown in Figure 12 to assess the tenability conditions based on temperatures that were predicted during the simulation of the fire. The figure shows the horizontal isothermal image 1.5 m above the floor at 90 s after the time of ignition. The oxygen concentrations at the 1.5 m at the same time is shown in Figure Due to the rapid activation of the sprinklers (three sprinklers were operating by 30 s after ignition), the temperatures at the 1.5 m level remain well below the temperature tenability threshold of 120 ºC [8]. Given the limited fire spread and the resulting tenable gas temperatures, the heat flux and oxygen level tenability criteria[8] were never exceeded in the sprinklered case.

Figure 10. Simulation of northwest sprinkler activation 18 seconds after ignition, showing water flow with smoke "turned off." (Note that the large black boxes are the speakers on either side of the raised platform).

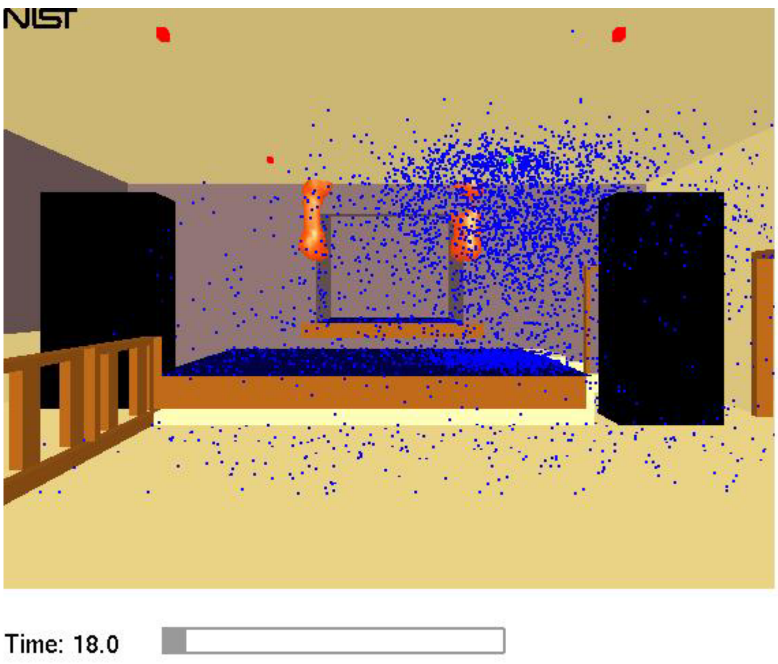


Figure 11. FDS predicted heat release rate for the sprinklered nightclub.

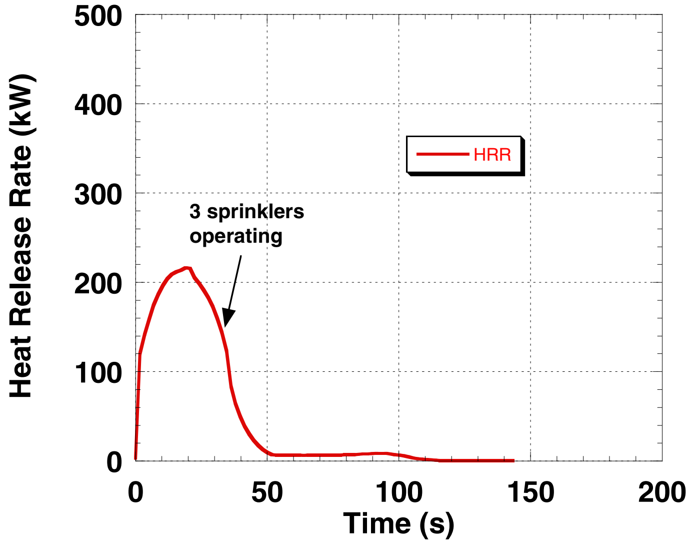


Figure 12. Temperatures at 1.5 m above the floor, 90 seconds

SUMMARY AND RECOMMENDATIONS

According to the computer predictions, many of the occupants had less than 90 seconds after ignition to exit the structure. The quickly spreading fire and rapid production of smoke led to high temperatures and low oxygen levels throughout most of the simulated nightclub. The exceptions were a few areas close to the floor and near the open windows of the main bar room and the open doorway to the main entry foyer. In these areas air from outside the structure was being drawn in providing a more tenable environment and more time for escape.

The FDS simulation predicted rapid fire growth due to the burning of the convoluted polyurethane foam. The simulation is consistent with the video record during the early stages of fire development. The conditions in the actual nightclub transitioned from a fire within a compartment to a fully involved wood structure fire burning in void spaces, the attic area, structural elements, and roofing materials. In the computer simulation, such regions and materials were not included, which led to a diminishing of the fire after 250 seconds as the fuel was consumed.

The simulation of the mockup experiments and this reconstruction also demonstrated difficulties in modeling the pyrolysis of the foam and carpet. The low density foam burned quickly with little char or residue and was hard to model as a simple fuel surface. As the carpet burned, portions of the carpet pile melted and the melt pool exhibited more complex burning than a simple fuel surface.

In the simulation of the full nightclub equipped with sprinklers, examination of the predicted temperature and the oxygen volume fractions showed tenable conditions would have existed over the duration of the simulation (300 seconds), as the fire was fully extinguished approximately 114 seconds after ignition.

Based on the reconstruction of the fire using FDS and the findings of the technical investigation[1], NIST made a number of recommendations that were aimed at improving life safety in nightclubs. Calling for changes to the national model building codes, the key recommendations included:

- requiring the installation of an NFPA 13 compliant automatic fire sprinkler system in all new nightclubs regardless of size and in all nightclubs with an occupancy limit greater than 100 people;

- clearly identifying and specifically forbidding materials that ignite easily and propagate flames rapidly, such as non-fire retarded polyurethane foam, as an interior finish material in all nightclubs;

- increasing the factor of safety for determining occupancy limits in all new and existing nightclubs. These include setting a maximum permitted evacuation time (90 seconds for nightclubs similar in size to or smaller that The Station), calculating the number of required exits and permitted occupancies (assuming that at least one exit will be inaccessible during an emergency), increasing staff training and evacuation planning, and improving means for occupants to locate emergency routes when standard exit signs are obscured by smoke.

- conducting studies to better understand fire spread and suppression and human behavior in emergency situations, to predict the impact of building design on safe egress in emergencies.

References

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