NIST NCSTAR 2: Vol. I

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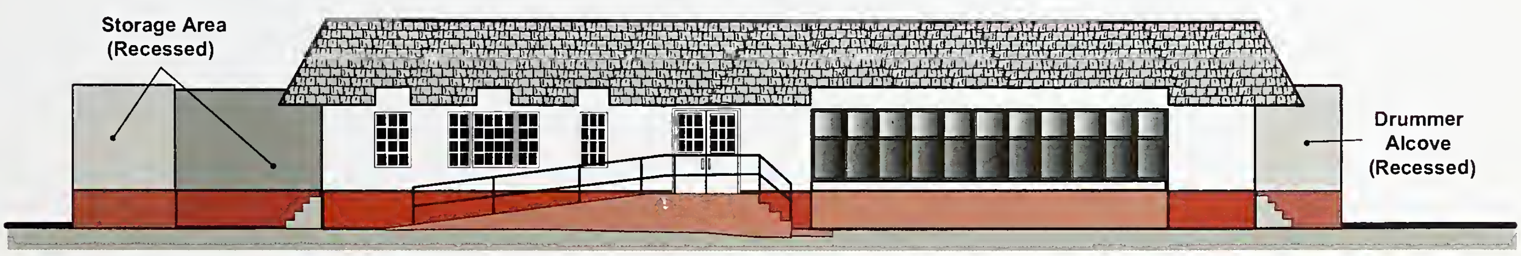

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Report of the Technical Investigation of The Station Nightclub Fire

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Disclaimer

The policy of NIST is to use the International System of Units (metric units) in all publications. In this document, however, units are presented in metric units or the inch-pound system, whichever is prevalent to the discipline. Conversion tables are provided in this report.

Disclaimer

The NIST-led investigation of The Station Nightclub fire was conducted during the same time period as civil and criminal legal actions involving the same incident, which limited the Team's access to physical evidence and limited the ability to interview many witnesses.

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No part of any report resulting from a NIST investigation can be used in any suit or action for damages arising out of any matter mentioned in such report (15 USC 281a; as amended by P.L. 107-231).

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ABSTRACT

A fire occurred on the night of Feb. 20, 2003, in The Station nightclub at 211 Cowesett Avenue, West Warwick, Rhode Island. A band that was on the platform that night, during its performance, used pyrotechnics that ignited polyurethane foam insulation lining the walls and ceiling of the platform. The fire spread quickly along the walls and ceiling area over the dance floor. Smoke was visible in the exit doorways in a little more than one minute, and flames were observed breaking through a portion of the roof in less than five minutes. Egress from the nightclub, which was not equipped with sprinklers, was hampered by crowding at the main entrance to the building. One hundred people lost their lives in the fire. On Feb. 27, 2003, under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) established a National Construction Safety Team to determine the likely technical cause or causes of the building failure that led to the high number of casualties in that fire. This report documents the procedures, findings, and issues that were raised by the investigation. Volume I contains the main report and Volume II contains appendix material.

The investigation concluded that strict adherence to 2003 model codes available at the time of the fire would go a long way to preventing similar tragedies in the future. Changes to the codes subsequent to the fire made them stronger. By making some additional changes – and state and local agencies adopting and enforcing them – we can strengthen occupant safety even further.

Ten recommendations to improve model building and fire codes, standards and practices (as they existed in February 2003) resulted from the investigation, including (i) urging state and local jurisdictions to (a) adopt and update building and fire codes covering nightclubs based on one of the model codes and (b) enforce those codes aggressively; (ii) strengthening the requirements for the installation of automatic fire sprinklers; (iii) increasing the factor of safety on the time for occupants to egress; (iv) tightening the restriction on the use of flexible polyurethane foam -- and other materials that ignite as easily and propagate flames as rapidly as non-fire retarded foam -- as an interior finish product; (v) further limiting the use of pyrotechnics; and (vi) conducting research in specific areas to underpin the recommended changes.

Keywords: fire investigation, NCST, nightclub fire, sprinklers, egress, fire spread, polyurethane foam, fire modeling, pyrotechnics

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List of Acronyms, Abbreviations, Units, and Conversion Factors

AC	alternating current
AG	Attorney General
AHJ	Authority Having Jurisdiction
AIA	American Insurance Association
ALS	Advanced Life Support
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATF	Bureau of Alcohol, Tobacco and Firearms
BBC	Basic Building Code
BCMC	Board for the Coordination of Model Codes
BFPC	Basic Fire Prevention Code
BLS	Basic Life Support
BOCA	Building Officials and Code Administrators (previously Building Officials Conference of America)
BST	barium strontium titanate
CFD	computational fluid dynamics, and Coventry Fire Department
CF	carpet flooring
CT	ceiling tile
DC	direct current
DHS	Department of Homeland Security
DSC	Differential Scanning Calorimetry
EMS	Emergency Medical Services
EMT	Emergency Medical Technician
EMT-C	Emergency Medical Technician - Cardiac
EST	Eastern Standard Time
FDS	Fire Dynamics Simulator
FEMA	Federal Emergency Management Agency

FIT	Flash Ignition Temperature
FPC	Fire Prevention Code
FR	fire retarded
HRR	heat release rate
IBC	International Building Code
IC	Incident Command
ICC	International Code Council
IEBC	International Existing Building Code
IFC	International Fire Code
IR	infrared
ISO	International Organization for Standardization
LCL_0	lethal concentration, low
LSF	life safety feature
MCI	Mass casualty incident
NCST	National Construction Safety Team
NBC	National Building Code
NFC	National Fire Code
NFPA	National Fire Protection Association
NFR	non-fire retarded
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
ODP	Office of Domestic Preparedness
OSHA	U.S. Occupational Safety and Health Administration
PUF	polyurethane foam
RI	Rhode Island
RTI	response time index
SBC	Standard Building Code
SIT	Spontaneous Ignition Temperature
SNEFEAP	Southern New England Fire Emergency Assistance Plan
t	time
TC	thermocouple
TGA	Thermal Gravimetric Analysis

TIA	Tentative Interim Amendment
UFC	Uniform Fire Code
UL	Underwriters Laboratories
USC	United States Code
USFA	United States Fire Administration
WFD	Warwick Fire Department
WP	wood paneling
WPD	Warwick Police Department
WWFD	West Warwick Fire Department
WWPD	West Warwick Police Department

Units

°C	degrees Centigrade
°F	degrees Fahrenheit
ft	feet
gpm	gallons/minute
in	inch
kg	kilogram
kPa	kilopascal
kW	kilowatt
L	liter
m	meter
mm	millimeter
min	minute
MW	megawatt
psi	pounds/in^2
s	second
W	Watt
μm	micrometer

Conversion Factors

°F = 1.8 x °C + 32

1 m = 3.281 ft

1 mm = 0.03937 in

1 L = 0.2642 gal

1 kg = 2.204 lb (mass)

1 kg/m^3 = 0.06243 lb/ft^3

1 kPa = 0.1450 psi

1 kJ = 0.9479 Btu

1 kJ/kg = 0.4301 Btu/lb

1 kJ/kg-°C = 0.2389 Btu/lb-°F

1 kW = 3413 Btu/hr

1 kW/m^2 = 317.1 Btu/hr/ft^2

1 kW/m^2-°C = 176.1 Btu/hr-ft^2-°F

1 W/m-°C = 0.5778 Btu/hr-ft-°F

1 kg = 1000 g

1 m = 1000 mm

1 μm = 0.001 mm

1 MW = 1,000,000 W

Preface

On Feb. 27, 2003, under the authority of the National Construction Safety Team (NCST) Act, the National Institute of Standards and Technology (NIST) established a Team to determine the likely technical cause or causes of the building failure that led to a high number of casualties in The Station nightclub fire in West Warwick, Rhode Island on the night of Feb. 20, 2003. The investigation consisted of the following tasks:

- identification of technical issues and hypotheses requiring investigation through consultations with experts in fire protection engineering, and emergency evacuation, and members of other teams investigating The Station fire;
- data collection from local authorities, contractors and suppliers, building and fire protection design documents, records, plans, and specifications, video and photographic data, telephone and radio transmissions, field data, a limited number of interviews and other oral and written accounts from building occupants and emergency responders, and other witnesses as reported by the news media;
- analysis and comparison of model building and fire codes and practices, as well as review and analysis of practices used in operation of the building;
- simulation and analysis of phenomena (with associated uncertainties), including fire spread, smoke movement, tenability, occupant behavior and response, evacuation issues, and operation of active and passive fire protection systems;
- testing to provide additional data and support computer predictions; and
- preparation of the final report, following established NIST Editorial Review Board procedures, augmented by the NCST Advisory Committee.

As required by the NCST Act and its implementing regulations, priority in the investigation was ceded to the local criminal investigation. No physical evidence was obtained from the scene and access to witnesses and local authorities was limited due to the criminal investigations and civil litigation.

It is important to note that state and local building regulations -- rather than model codes -- govern building design, construction and operation. Comparisons of the building design and operation to provisions within model codes were done to assess possible improvements in public safety through revision of model codes, standards and practices. Many of the recommendations are directed toward the current national model codes maintained by the National Fire Protection Association (NFPA) and the International Code Council (ICC), the standards within those codes and elsewhere (e.g., ASTM International, and Underwriters Laboratories (UL)), and the practices associated with their adoption and implementation. Other recommendations are aimed at nightclub owners and managers, occupants, and state and local regulatory authorities and first responders.

The NCST Act requires that at least one member of the Team be an employee of NIST, and that experts who are not employees of NIST shall also be appointed to the Team by the NIST Director. The members of the Team included the following:

- William Grosshandler (Lead Investigator), NIST Building and Fire Research Laboratory

- Nelson Bryner, NIST Building and Fire Research Laboratory
- Daniel Madrzykowski, NIST Building and Fire Research Laboratory
- Kenneth Kuntz, DHS/FEMA, US Fire Administration

Koffel Associates, Inc., provided a review of model building and fire codes; Ove Arup & Partners Massachusetts, Inc., assisted with the analysis of the evacuation process. Portions of both contractor reports have been integrated into this final report.

Acknowledgment

The number of people from NIST assisting the investigation extended beyond the official team members. Of particular note is Stephen Kerber, who devoted a tremendous amount of time and energy to running the fire simulations. The assistance provided by William Walton and Kevin McGrattan in this effort is also acknowledged. Erica Kuligowski was responsible for the egress simulations and was consulted regarding the behavior of humans in fire. The foam panel and full-scale mock-up experiments were ably supported by David Stroup, Laurean DeLauter, Roy McLane, Jay McElroy, Jack Lee, Alex Maranghides, Ed Hnetkovsky, Caron Nyquist, Tim Strunk, Joseph Schuh, Daniel Schuh, and Mike Schaefer.

Outside of NIST, the cooperation of the Bureau of Alcohol, Tobacco, and Firearms (Christopher Porreca in particular), and the assistance of the Army Research Laboratory (Steven Hoke) are acknowledged. Within the Department of Homeland Security, the Office of Domestic Preparedness coordinated its own investigation with NIST's work. The cooperation of the State of Rhode Island is acknowledged, in particular the Office of the State Fire Marshal and the Warwick field office of the Attorney General. WPRI-TV supplied the Team with the complete video taken on the night of the fire, and the *Providence Journal* provided NIST with information from their interviews with survivors of the incident. Both made invaluable contributions to the investigation. William Koffel and Eric Mayl of Koffel Associates, Inc. and Jeffrey Tubbs of Ove Arup & Partners Massachusetts provided outstanding contractor support in reviewing model building and fire codes and analysis of the evacuation process, respectively.

EXECUTIVE SUMMARY

Under the authority of the National Construction Safety Team Act, an investigation team was deployed by the NIST Director on Feb. 27, 2003 to investigate the failure seven days earlier of The Station nightclub in West Warwick, Rhode Island. The objectives of the investigation were:

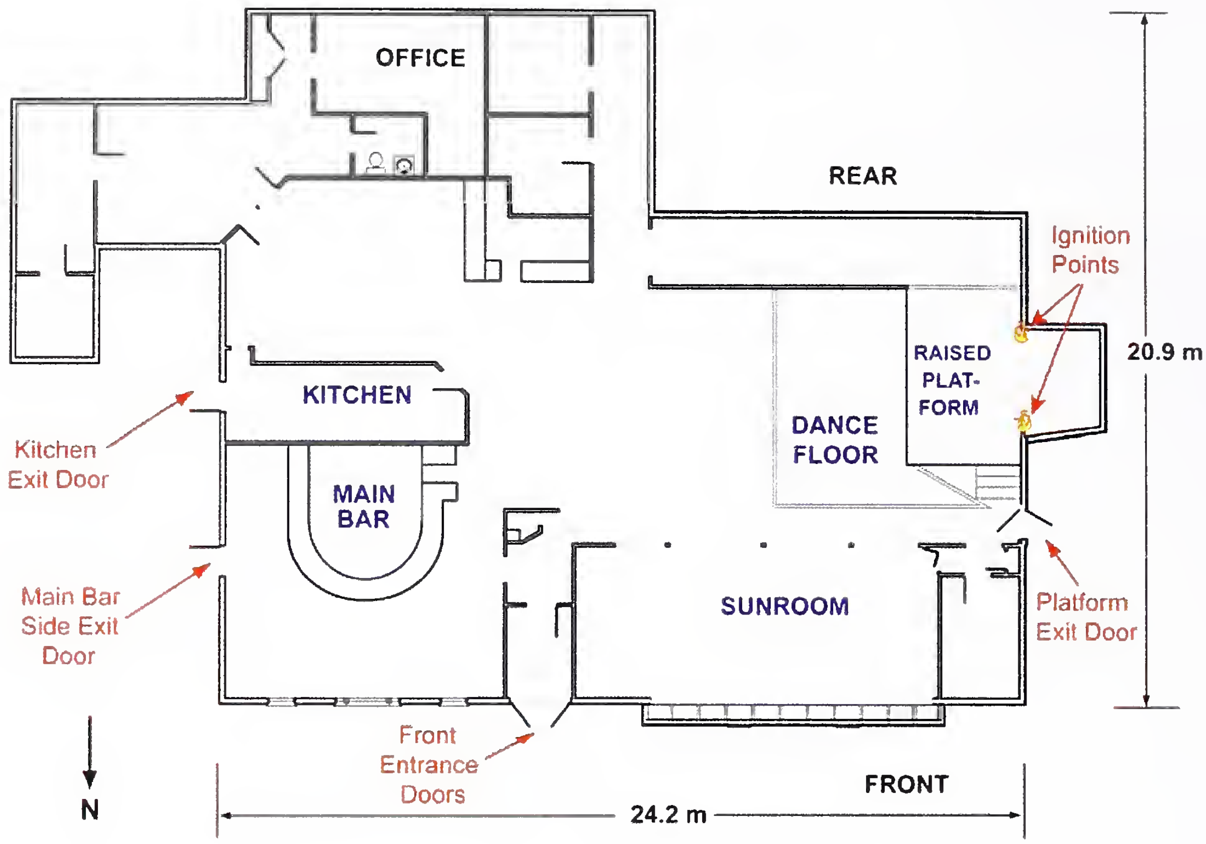
- to establish the likely technical cause or causes of the building failure;
- to evaluate the technical aspects of evacuation and emergency response procedures;
- to recommend, as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to the duties listed above; and
- to recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve evacuation and emergency response procedures, based upon the findings of the investigation.

The NIST team met these objectives primarily by reviewing and analyzing model building and fire codes, public documents, photographic and video data, telephone and radio transmissions, published accounts, and discussions with local authorities and several witnesses, by simulating and analyzing the fire spread, smoke movement, tenability, occupant behavior and response, and the impact of fire sprinklers, and by testing representative materials (not obtained from the fire scene) to provide additional data and support the simulation predictions. The simulations and supporting fire tests were particularly important given that NIST was not able to obtain any physical evidence from the incident scene due to the ongoing criminal investigation and civil litigation. While the access to physical materials was denied to NIST, the Institute's investigators were provided extensive video tape footage taken before, during and after the fire.

This report describes the methodology used to conduct the investigation, details what occurred on the night of Feb. 20, 2003, reviews the history of the building and the model codes and standards that would have applied to a building of this type, presents the results of testing and simulations, and includes recommendations to improve building safety, evacuation and emergency response procedures. **It is important to note that state and local building regulations -- rather than model codes -- governed The Station nightclub.** NIST's comparison of the nightclub with model codes has been done strictly to assess possible improvements in public safety through revision of model codes, standards and practices. The recommendations are directed toward the current model codes maintained by the National Fire Protection Association (NFPA) and the International Code Council (ICC), the standards within those codes and elsewhere (e.g., ASTM International, and Underwriters Laboratories (UL)), and the practices associated with their adoption and implementation. Other recommendations are aimed at nightclub owners and managers, occupants, and state and local regulatory authorities and first responders.

FINDINGS

The Station nightclub was a single-story wood frame building with a footprint of about 412 m^2 (4484 ft^2). A floor plan of the building is shown in the figure below. The main entrance on the north side, with double doors, led to a short hallway with a single interior door. In addition to the main entrance, there were doors leading directly to the outside adjacent to the platform (commonly, but less precisely, referred to as the stage) on the west end of the building, and at the side of the main bar at the east end of the building. The kitchen also had an exit door. There were windows along the north side of the building on



Floor plan of The Station nightclub

both sides of the main entrance. The fire began when pyrotechnics used during the performance of a band ignited polyurethane foam lining portions of the walls and ceiling of the platform, and spread quickly along the ceiling area over the dance floor. Smoke was visible in the exit doorways in a little more than one minute and flames were observed breaking through a portion of the roof in less than five minutes. Escape from the nightclub was hampered by the crowding at the main entrance to the building. One hundred people lost their lives in the fire.

The direct contributors to this large loss of life were found to be (1) the hazardous mix of building contents, (2) the inadequate capability to suppress the fire during its early stage of growth, and (3) the inability of the exits to handle all of the occupants in the short time available for such a fast growing fire. Both of the 2003 editions of the major model building and fire codes (*2003 International Building Code* and *NFPA 5000, Building Construction and Safety Code*) have provisions that address these problems.

Materials

The hazard associated with the building contents was created by the close proximity of a high temperature source (a pyrotechnic device) and a substantial amount of material with a relatively low ignition energy and high flame spread rate (polyurethane foam). As could be seen in the WPRI video, flames spread rapidly over the foam, generating smoke and enough heat to ignite the wood paneling underneath and adjacent to the foam. The wood structure and paneling in the nightclub was estimated to contain over 95 percent of the fuel load, so that once most of the foam was consumed, the fire transitioned to a wood frame building fire.

Pyrotechnic device impinging on non-fire retarded polyurethane foam panel

A non-fire retarded foam sample purchased by NIST ignited in less than 15 seconds when exposed to a pyrotechnic device in an arrangement shown in the adjacent photo, which was similar to the set up on the platform of the nightclub. When a fire retarded polyurethane foam purchased by NIST was exposed to a pyrotechnic source in the same manner, no ignition of the foam occurred, nor did the wood paneling ignite with no foam present.

In addition to the flexible polyurethane foam that was attached to the walls, a foam plastic thermal insulation, that had been installed in the stud space with no fire resistant barrier on the interior side of the walls of the drummer's alcove, contributed to the smoke and heat release from the fire. (Note that no foam samples from the walls nor the stud space in The Station were obtained by NIST for testing.)

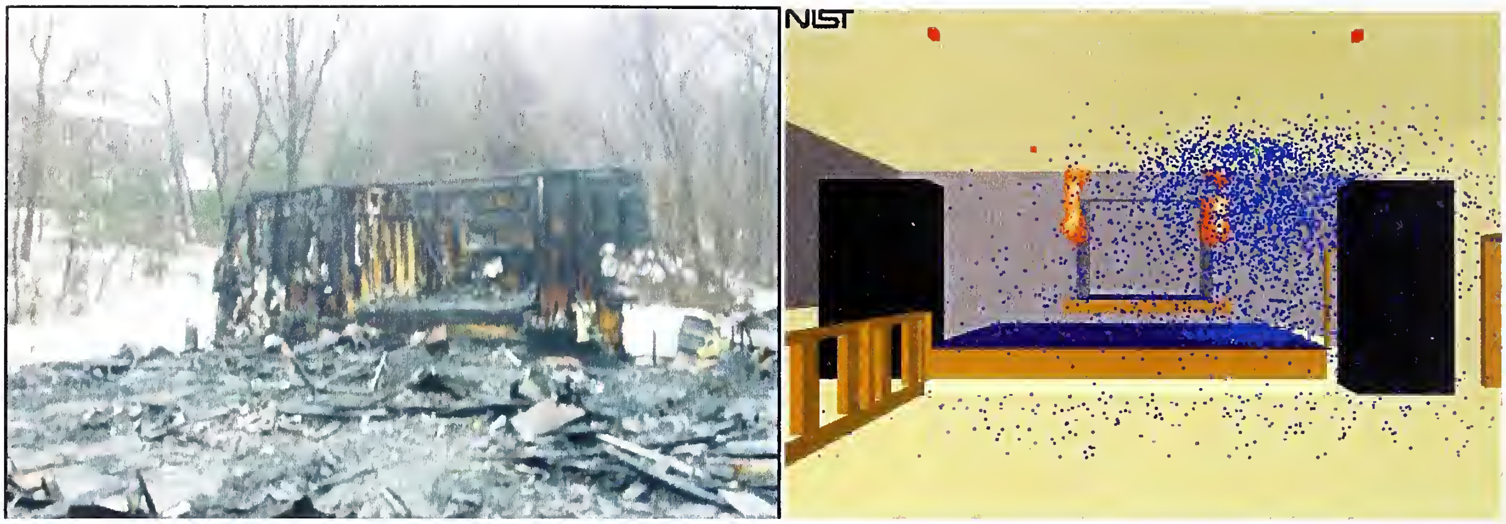
The platform area of the nightclub, including NIST-purchased flexible polyurethane foam on the walls, was reconstructed in the large fire laboratory at NIST to examine, in a controlled environment, how the fire may have spread in the full-scale nightclub, and to measure the temperature, heat flux, and gaseous products. In less than 90 seconds after ignition of foam at the corner of the reconstructed drummer's alcove, conditions in the middle of the room (5.5 m, or 18 ft, away) at head height (1.5 m, or 5 ft, above the floor) were found to be lethal.

Fire Protection Systems

The capability to suppress this fire during its early stage of growth was insufficient primarily because automatic fire sprinklers were not installed in The Station. (Note that while the 2003 editions of the model codes would have required sprinklers to be installed for new construction, sprinklers would not have been required for an existing structure like The Station.) The building was equipped with hand-held fire extinguishers, although they were not located convenient to where the fire started; NIST found no indication that the employees of The Station were trained to use the hand-held extinguishers, and it is unclear if the extinguishers would have been effective in controlling this fire.

Experiments conducted at NIST in a reconstruction of the platform area fire demonstrated that a water sprinkler system installed in the test room in accordance with NFPA 13 (*Standard for the Installation of Sprinkler Systems*) was able to control the fire initiated in non-fire retarded polyurethane foam panels and to maintain survivable conditions at head height in the test room for the duration (over five minutes) of the experiment. A computer simulation of the full nightclub with and without sprinklers led to a similar positive result for the sprinklered scenario.

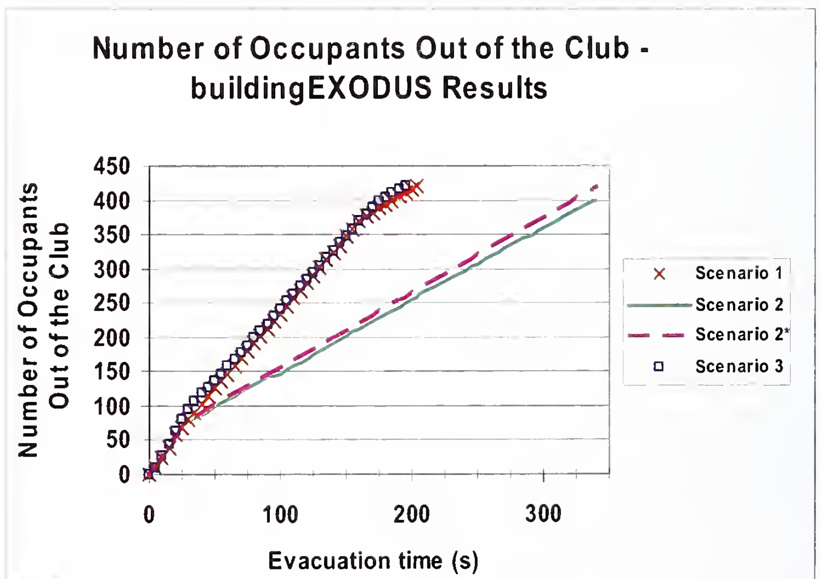
A heat detection/fire alarm system was installed in The Station Nightclub, which activated (sound and light strobe) 41 seconds after ignition of the polyurethane foam, by which time the crowd had already begun to move towards the exits.



Remains of the platform area after the fire (left) and an image from the simulation of The Station fire had sprinklers been installed (right)

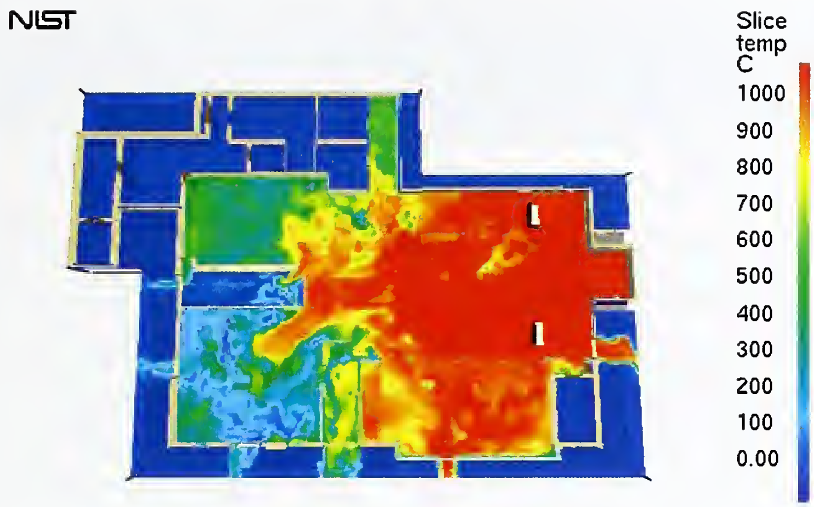
Occupant Load and Egress

The inability of the exits to handle all of the occupants in the short time available for this fast growing fire contributed directly to the large loss of life. The number of building occupants at the time of the fire was reported by the news media to range from 440 to 458; the occupant limit for a building similar to The Station nightclub would be around 420 persons according to the 2003 model codes. Three emergency exits were available: the front main entrance on the north (limited by the single door into the vestibule), the single door on the west near the performance platform, and the single door on the east side of the main bar. A fourth door in the kitchen was not considered accessible to the patrons. The first patrons recognized the fire danger about 24 seconds after ignition of the foam; the bulk of the crowd began to evacuate shortly after that, around the time the band stopped playing (30 seconds). The rate of egress from the main entrance at the front of the building was limited initially by the single doorway inside the vestibule, not the double doors visible from the outside. From 56 percent to 66 percent of the occupants appear to have attempted to leave through the single main entrance in the front of the building; many were unsuccessful. The windows in the main bar room and the sunroom became the secondary routes of escape once the main entrance became impassable, and, according to reports, they accounted for over 1/3 of the successful evacuations.



Simulation of egress for different scenarios

Prior to 1-1/2 minutes into the fire, a crowd-crush occurred in the front vestibule which almost entirely disrupted the flow through the main exit. Many people became stuck in the prone position in the exterior double doors.



Temperatures 1.5 m (5 ft) above floor 90 seconds after ignition, calculated from computer simulation of full-scale nightclub fire.

The precise event which led to the crowd-crush likely was related to the arrangement of the single interior door with merging streams of traffic and the pressure to escape the rapidly deteriorating conditions in the main area of the nightclub. Measurements of temperature, heat flux and gas species in a reconstruction of the platform area fire at NIST and computer models of the NIST experiment and the full nightclub suggest that the conditions around the platform, dance floor, sunroom, and dart room would have led to severe incapacitation or death within about 1-1/2 minutes after ignition of the foam for anyone remaining standing, and for not much longer even for those occupants close to the floor.

Emergency Response

The first 911 call reporting a fire was before 11:09 p.m., less than 40 seconds after ignition of the foam; West Warwick police officers on the scene reported the fire about one minute after ignition of the foam, leading to the dispatch of four engine companies, a tower-ladder truck, a rescue unit, and a battalion chief. The first fire engine, staffed with one firefighter and a fire officer, was confirmed on-scene less than five minutes after the first 911 call was received.

Given the hazardous mix of materials in The Station and the lack of installed sprinklers, nothing that the fire department could have done that night would have saved the building from the fast growing fire. To deal with the large number of victims, a mass casualty plan was implemented within about 10 minutes of arrival of the first engine on the scene. All occupants needing medical attention had been evacuated from the scene and transported to medical facilities within two hours of the start of the fire.

Summary Finding

The investigation concluded that strict adherence to 2003 model codes available at the time of the fire would go a long way to preventing similar tragedies in the future. Changes to the codes subsequent to the fire made them stronger. By making some additional changes – and state and local agencies adopting and enforcing them – we can strengthen occupant safety even further.

RECOMMENDATIONS

The findings presented above, and others that are documented in this report, raised a number of issues concerning model building codes and standards, and the practices surrounding their adoption, application, and enforcement. The specific sections of the current NFPA and ICC model codes that relate to these issues are identified in the report, as well as significant actions already taken by the state of Rhode Island and model code organizations in response to this tragedy.

NIST has made ten recommendations, listed in the following Table, that (a) support actions already taken by the state and by the model code development organizations, (b) extend or further improve the model

Table of Recommendations
1. **<u>Model Code Adoption and Enforcement:</u>** NIST recommends that all state and local jurisdictions a) adopt a building and fire code covering nightclubs based on one of the model codes (as a minimum requirement) and update local codes as the model codes are revised; b) implement aggressive and effective fire inspection and enforcement programs that address: (i) all aspects of those codes; (ii) documentation of building permits and alterations; (iii) means of egress inspection and record keeping; (iv) frequency and rigor of fire inspections, including follow-up and auditing procedures; and (v) guidelines on recourse available to the inspector for identified deviations from code provisions; and c) ensure that enough fire inspectors and building plan examiners are on staff to do the job and that they are professionally qualified to a national standard such as NFPA 1031 (*Professional Qualifications for Fire Inspector and Plan Examiner*).
2. **<u>Sprinklers:</u>** NIST recommends that model codes require sprinkler systems according to NFPA 13 (*Standard for the Installation of Sprinkler Systems*), and that state and local authorities adopt and aggressively enforce this provision, a) for all new nightclubs regardless of size, and b) for existing nightclubs with an occupancy limit greater than 100 people.
3. **<u>Finish Materials and Building Contents:</u>** NIST recommends a) that state and local authorities adopt and aggressively enforce the existing provisions of the model codes; b) that non-fire retarded flexible polyurethane foam, and other materials that ignite as easily and propagate flames as rapidly as non-fire retarded flexible polyurethane foam, (i) be clearly identifiable to building owners, operators, contractors, and authorities having jurisdiction (regulatory agencies); and (ii) be specifically forbidden, with no exceptions, as finish materials from all new and existing nightclubs; c) that NFPA 286 (*Standard Methods of fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*) be modified to provide more explicit guidance to building owners, operators, contractors, and authorities having jurisdiction for when large-scale tests that are covered in NFPA 286 are required to demonstrate that materials (other than those already forbidden in b above) do not pose an undue hazard for the use intended; and d) that ASTM E-84 (*Standard Test Method for Surface Burning Characteristics of Building Materials*), NFPA 255 (*Standard Method of Test of Surface Burning Characteristics of Building Materials*), and NFPA 286 be modified to ensure that product classification and the pass/fail criteria for flame spread tests and large-scale tests are established using the best measurement and prediction practices available.

Table of Recommendations

4. **Indoor Use of Pyrotechnics:** NIST recommends that NFPA 1126 (*Use of Pyrotechnics before a Proximate Audience*) be strengthened as described below, and that state and local authorities adopt and aggressively enforce the revised standard:

a) Pyrotechnic devices should be banned from indoor use in new and existing nightclubs not equipped with an NFPA 13 compliant automatic sprinkler system.

b) NFPA 1126 should be modified to include a minimum occupancy and/or area for a nightclub below which pyrotechnic devices should be banned from indoor use, irrespective of the installation of an automatic sprinkler system.

c) Plans for the use of indoor pyrotechnics in new and existing nightclubs should be posted on site; and in addition to the items listed in para. 4.3.2 of NFPA 1126, should describe the measures that have been established to provide crowd management, security, fire protection, and other emergency services.

d) Section 6.6.2 of NFPA 1126 should be modified to require the minimum clearance between (i) the nearest fixed or moveable contents, and (ii) any part or product (igniter, spark, projectile, or debris) of a pyrotechnic device permitted for indoor use in new and existing places of assembly, to be twice the designed projection of the device, until such time that studies show that a smaller minimum clearance can guarantee safe operation in spite of the possibility that building decorations or temporary features that greatly exceed flame spread or fire load provisions of the fire code may occur.

5. **Occupancy Limits and Emergency Egress:** NIST recommends that the factor of safety for determining occupancy limits of all new and existing nightclubs be increased in the model codes in the following manner, and that state and local authorities adopt and aggressively enforce these provisions:

a) Within the model codes, establish the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time; and, unless further studies indicate another value is more appropriate, use 1-1/2 minutes as the maximum permitted evacuation time for nightclubs similar to or smaller than The Station.

b) Compute the number of required exits and the permitted occupant loads assuming at least one exit (including the main entrance) will be inaccessible in an emergency evacuation.

c) For nightclubs with one clearly identifiable main entrance, increase the minimum capacity of the main entrance to accommodate 2/3 of the maximum permitted occupant level (based upon standing space or festival seating, if applicable) during an emergency.

d) Eliminate trade-offs between sprinkler installation and factors that impact the time to evacuate buildings.

e) Require staff training and evacuation plans for nightclubs that cannot be evacuated in less than 1-1/2 minutes.

f) Provide improved means for occupants to locate emergency routes -- such as explicit evacuation directions prior to the start of any public event, exit signs near the floor, and floor lighting -- for when standard exit signs become obscured by smoke.

Table of Recommendations

6. **Portable Fire Extinguishers:** NIST recommends that a study be performed to determine the minimum number and appropriate placement (based upon the time required for access and application in a fully occupied building) of portable fire extinguishers for use in new and existing nightclubs, and the level of staff training required to ensure their proper use.

7. **Emergency Response:** To ensure an effective response to a rapidly developing mass casualty event, NIST recommends that state and local authorities adopt and adhere to existing model standards on communications, mutual aid, command structure and staffing, such as

a) NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems*

b) NFPA 1561, *Standard on Emergency Services Incident Management Systems*

c) NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*

d) NFPA 1720, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments*

8. **Research on Human Behavior:** NIST recommends that research be conducted to better understand human behavior in emergency situations, and to predict the impact of building design on safe egress in fires and other emergencies (real or perceived), including the following:

a) the impact of fire products (gases, heat, and obscuration) on occupant decisions and egress speeds;

b) exit number, placement, size and signage;

c) conditions leading to and mitigating crowd-crush;

d) the role of crowd managers and group interactions;

e) theoretical models of group behavior suitable for coupling to fire and smoke movement simulations; and

f) the level of safety that model codes afford occupants of buildings.

9. **Research on Fire Spread and Suppression:** NIST recommends that research be conducted to understand fire spread and suppression better in order to provide the tools needed by the design profession to address recommendations 2, 3, and 5, above. The following specific capabilities require research:

a) prediction of flame spread over actual wall, ceiling and floor lining materials, and room furnishings;

b) quantification of smoke and toxic gas production in realistic room fires; and

c) development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

Table of Recommendations
10. <u>Research on Computer-aided Decision Tools:</u> NIST recommends that research be conducted to: a) refine computer-aided decision tools for determining the costs and benefits of alternative code changes and fire safety technologies, and b) develop computer models to assist communities in allocating resources (money and staff) to ensure that their response to an emergency with a large number of casualties is effective.

codes, standards, and practices, and (c) identify research necessary to underpin and provide additional technical justification for these actions.

The first recommendation, to adopt and enforce a building and fire code for nightclubs based upon one of the model codes, is a prerequisite for the subsequent recommendations, and is strongly supported by the finding that provisions in the 2003 model codes, if they are adopted and enforced, will significantly improve the safety of structures and occupants, and may well eliminate tragedies such as this in the future. Recommendation 2, to increase the requirements for the installation of sprinklers, is equivalent to the Tentative Interim Amendment (TIA) already adopted by NFPA. The laboratory testing and simulations performed by NIST as part of this investigation provide additional reinforcement of the appropriateness of NFPA's action.

Recommendation 3 recognizes the critical role that the non-fire retarded polyurethane foam played in the ignition and rapid flame spread process. While the use of foam plastics as exposed finish products is already inconsistent with current model codes, the standards development organizations such as ASTM and NFPA need to be enlisted to improve the technical basis for materials testing to ensure that the methods used to rate the flammability of finish materials and building products correlate with the actual fire hazard posed, even anticipating possible situations that may not be consistent with the building code. In addition, markings that are easily distinguishable by the contractor, building manager, and regulating authorities would decrease the possibility for the inappropriate use of these materials and products. To reduce the chance that a pyrotechnic device could be present in the event that unapproved materials are brought into a nightclub (which already is inconsistent with the provisions of NFPA 1126), recommendation 4 would make unequivocal those situations in which pyrotechnic devices are simply not permitted.

Model codes need to be robust and more redundant to minimize the chances of loss of life caused by the failure of a building that is out compliance, with codes. Adequate performance of the structure should be ensured even when one of the protective systems is compromised by uncertain behaviors of the building owner or occupants, including the installation of building decorations or temporary features that greatly exceed flame spread or fire load provisions (as discussed in the previous paragraph), as well as exposing the building to strong ignition sources; exceeding the posted occupancy limits; temporarily blocking an exit; and disabling sprinklers or other life safety systems for maintenance.

Adequate exits literally provide the lifelines for a building's occupants in the event of a fire. For this reason the safety factor for the number, size and location of exit paths must be large enough to account for the uncertainties in the structure caused by the conditions listed above and for the uncertainty in our ability to predict the time for complete egress during an emergency. Recommendation 5, on occupancy limits and emergency egress, acknowledges that uncertainty.

Portable fire extinguishers, if readily available to someone properly trained, can be effective early in a fire and delay fire spread in the event the sprinkler system is not functioning. However, the type of training required, the importance of timing, and the limitations on the size of fire that can be safely attacked require additional study. Recommendation 6 is for such a study.

Even though the first fire engine arrived expeditiously, the speed at which the fire engulfed The Station rendered it impossible for the fire department to save the structure or the lives of many victims. However, the importance of the role of fire prevention activities in avoiding a future tragedy was highlighted by this incident. As in all mass causality events, especially those where the window of opportunity for rescue is extremely limited, effective and efficient communication within and among the various responding agencies is imperative. Developing effective interoperable communications requires addressing numerous factors, including frequent test use of interoperable communications equipment and procedures, formal governance and collaboration, formal standard operating procedures, appropriate technology, and multi-agency training and exercises. Recommendation 7 identifies existing standards that address these issues. Tools and best practice models addressing many of these success factors, including a statewide communications interoperability planning methodology are available through the Department of Homeland Security's SAFECOM Program.

Based upon the findings of this investigation and the resultant recommendations presented above, additional research is recommended in three general areas: human behavior and people movement, material behavior and fire spread, and decision aids. Recommendation 8 addresses the first of these. There clearly is a need to understand better the behavior of people and crowds in emergency situations to pinpoint the factors that lead to crowd crush. This would enable sensible changes in building design to minimize the possibility of crowd crush, and improved ways to communicate to the crowd in emergency situations that go beyond the code, in direct support of recommendation 5.

The time available for safe egress is influenced by the building geometry and ventilation system, the materials of construction and furnishings, and actions to suppress the fire. Predicting sprinkler activation and suppression and the influence of fire fighting activities on the spread of the fire is another aspect of the problem that can be done today only at the grossest level of precision. Implementation of recommendation 9 would move us to the level of precision needed in support of recommendations 2 and 3, as well as recommendation 5.

Recommendation 10 recognizes the need for research into computer-aided decision tools specifically designed to deal with the costs and benefits of revisions to building and fire codes and standards, and to assist decision makers at the community level responsible for allocation of resources for public safety.

Chapter 1 BACKGROUND

1.1 INTRODUCTION

A fire occurred on the night of Feb. 20, 2003, in The Station nightclub at 211 Cowesett Avenue, West Warwick, Rhode Island. A band that was performing that night, during its performance, used pyrotechnics that ignited foam insulation lining the walls and ceiling of the platform being used as a stage. The fire spread quickly along the walls and ceiling area over the dance floor. Smoke was visible in the exit doorways in a little more than one minute, and flames were observed breaking through a portion of the roof in less than five minutes. Egress from the nightclub was hampered by crowding at the main entrance to the building. One hundred people lost their lives in the fire.

The National Institute of Standards and Technology (NIST), under the authority of the National Construction Safety Team (NCST) Act [1], established a National Construction Safety Team (Team) on Feb. 27, 2003, to determine the likely technical causes of the building failure that led to the high number of casualties in that fire. The investigation included the following tasks:

- identification of technical issues and major hypotheses requiring investigation through consultations with experts in fire protection engineering, and emergency evacuation, and members of other teams investigating The Station fire;
- data collection from local authorities, contractors and suppliers, building and fire protection design documents, records, plans, specifications, video and photographic data, telephone and radio transmissions, field data, and a limited number of interviews and other oral and written accounts from building occupants and emergency responders, and other witnesses as reported by the news media;
- analysis and comparison of building and fire codes and practices, and review and analysis of practices used in operation of the building;
- simulation and analysis of phenomena (with associated uncertainties), including fire spread, smoke movement, tenability, occupant behavior and response, evacuation issues, and operation of active and passive fire protection systems; and
- testing to provide additional data and support simulation predictions.

This document constitutes the draft report of the NIST investigation into The Station fire. The building and surroundings as they were prior to the fire are described in the following section of this chapter. The general history of the building is reviewed here as well. Chapter 2 provides a timeline of the incident, including the ignition and spread of the fire, the evacuation process, and firefighting activities. The fire and emergency response and procedures are detailed in Chapter 3. Chapter 4 describes the testing and supporting experiments, and Chapter 5 provides background and results of the computer simulation of the fire and smoke movement. An analysis of the evacuation process is provided in Chapter 6. Chapter 7 reviews the model building and fire codes that are relevant to a structure like The Station. The report concludes with a summary of findings and recommendations in Chapter 8. There are a number of appendices that provide more detail, or information that is peripheral to the main objectives. NIST video recordings and animations are included in the DVD that accompanies this report.

1.2 DESCRIPTION OF THE BUILDING AND SITE

The Station nightclub was located at 211 Cowesett Avenue, West Warwick, Rhode Island. It was a single-story wood frame building with a footprint of about 412 m^2 (4484 ft^2) and a small basement under the main bar room. Figure 1-1 is a photograph of the building on its lot. The north-facing front door of the nightclub was set back about 42 m (140 ft) from Cowesett Avenue, a three-lane, two way street that runs east-to-west. Kulas Road is two lanes wide and runs along the east side of the building, about 10 m (33 ft) east of the side bar exit. There was no direct street access to the building from either the west or south sides. Parking for over 100 cars was provided in the front and to the west side of the building.

A distant aerial view of the area, Figure 1-2, shows the nightclub in relation to the community. Note the location of Fire Station #4 at 110 Cowesett Avenue about 500 m (1650 ft) to the west of The Station.

Figure 1-3 is a sketch showing the north side of the building approximately as it looked on February 20, 2003. Note the windows on the left which are in the main bar area, the windows on the right in the sunroom/poolroom, the ramp and stairs leading from the main entrance in front, and the stairways leading from side exits on the west and east of the building. Inside the double doors of the main entrance is a vestibule with a single doorway. Figures 1-4a and 1-4b are photographs of the north side and north west corner of the building as they looked within a year or two of the February 20, 2003 fire. The external walls were primarily covered with painted wood shingles or panels above a concrete foundation. The roof was flat with a wood shingle façade along the front and sides, as seen in the photographs.

Figure 1-5 shows a plan view of the nightclub floor, a composite from multiple sources of information obtained during the investigation. Entering from the front through the double doors would have brought one into a short entrance hall with a single door at the far end that led to the ticket-taker area. To the right of the ticket taker was an assembly area containing the dance floor, sunroom (or poolroom), elevated dining area, and a platform (imprecisely referred to as a stage) with the drummer's alcove. A dressing room was situated in the northwest corner and an exit to the outside was located between the platform and dressing room. Except for the front of the sunroom, which was composed of darkened glass windows, there were no other windows in the right half of the nightclub.

Turning left at the ticket-taker area would have brought one into the main (or horseshoe) bar room. An exit to the outside was located on the far left wall. There were no windows on that wall but windows lined most of the front of the main bar room.

The kitchen separated the main bar room from a smaller assembly area (or dart room) and back bar. There was one door to the outside from within the kitchen. A storage area, office, and restrooms were located in the back of the nightclub. There were no additional exits leading directly to the outside from these rooms; any windows or exits that had been installed were covered with bars or paneling.

Figures 1-6a and 1-6b show different views inside the nightclub, highlighting the exit doors next to the platform and the exit from the main bar area.

1.3 HISTORY OF THE BUILDING[1]

The Station nightclub was a single-story wood frame building, with a small basement. Over the years the building was sold multiple times and changed function, as shown in Table 1-1.

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[1] This section is taken from the contract report prepared by Koffel Associates, Inc. [11]

Figure 1-1. General orientation of building and site [2]

Figure 1-2. Aerial photograph of the community around The Station nightclub [2]

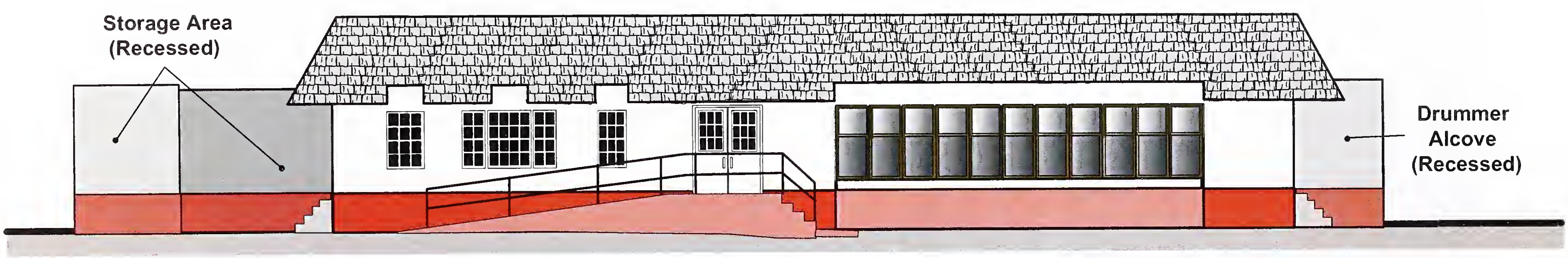

Figure 1-3. Sketch of the north side of The Station nightclub locating the main entrance, front stairway/ramp, windows in the main bar area (left), sunroom/pool room (right), and exit stairs from the east and west sides

Figure 1-4a. Front view of The Station nightclub showing the main entrance [3]

Figure 1-4b. View of the northwest corner showing the sunroom windows [3]

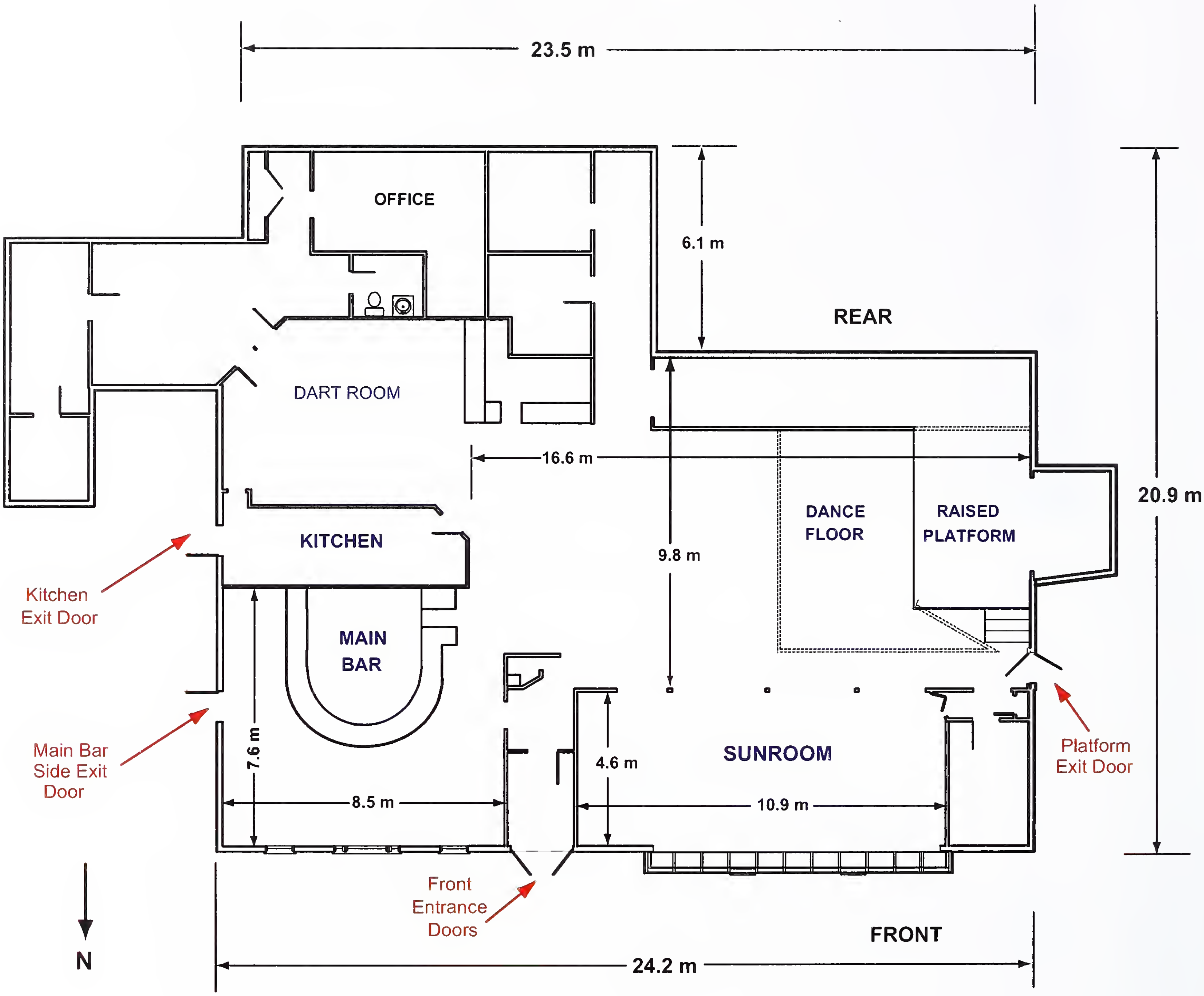

Figure 1-5. Plan view of The Station showing different rooms and exits.

Figure 1-6a. View of inside of nightclub showing exit sign above door near platform [13]

Figure 1-6b. View of inside of nightclub showing exit sign above door in main bar area [4]

On the night of the fire, The Station nightclub looked different from when it was built in 1946 [5]. While the club was still a single-story wood building with a small partial basement, it was modified numerous times over its 57 years [6, 7]. Although the original plans of the building were not located, several sources reported that the building was modified over the years. The modifications included small additions, multiple reconfigurations of the interior, rebuilding after a fire, and rebuilding after a car rammed the front of the building [5].

The original date of construction has been variously reported to be 1946 or 1950. The 1946 date is based on a *Providence Journal* article dated July 13, 2003 [5]. The article reports the land was purchased in 1945; the nightclub (originally named Casey's Inn) was constructed in 1946 and changed hands in 1947. The Town of West Warwick tax records, dated May 30, 2001, indicate that the building was constructed in 1950 [8]. West Warwick land records indicate the property changed hands in November 1945 and 1947, suggesting the construction took place in 1946 as reported by the *Providence Journal* (W. Warwick Land Use Record undated, [5,9]). For the purposes of this report, the date of construction will be 1946.

In an effort to document the original building construction date, construction permits were reviewed at the Town of West Warwick for 211 Cowesett Avenue. The permits document dates of construction and provide brief narratives of work to be completed. However, the details of the construction are not included in the permits. It is not possible to determine from the permits the extent of work completed, or if the work was completed in compliance with model codes of the time.

The building was damaged by fire in March 1972. The July 2003 *Providence Journal* article reported the firefighters cut holes in the roof [5]. The contents of the building sustained fire and smoke damage, but the building structure remained. The first building permit issued after the fire was in November 1974. The permit makes no mention of roof fire damage repair. It simply states that the work included interior paneling and partitions. Workmen reported that smoke-stained and charred structural framing remained in the building continuously up until the February 2003 fire.

In June 2001, a car ran through the front of the building. A building permit was issued on June 19, 2001 to repair the damage [10]. The extent of the damage is not detailed; however, the permit indicates that a window and a portion of the exterior wall adjacent to the window were replaced.

The Town of West Warwick tax records indicate the building consisted of a small basement, 165 m^2 (1794 ft^2) in area, and a main level of 412 m^2 (4484 ft^2) [5]. The tax record depicts the general outline of the building with dimensions, not including windows or doors.

1.4 PREVIOUS INCIDENTS AT THE STATION[2]

At the time of the 1972 fire mentioned above, the building housed a nightclub named Julio's [5]. The ensuing fire alarm alerted responders; firefighters arrived to find the building engulfed in flames. They contained the fire, but much of the interior of the club had been significantly damaged. Investigators determined that the fire started in the rear center of the building and worked up through the ceiling and into the attic. No occupants were in the club at the time of the fire.

No other significant fire incidents or egress difficulties were reported to have occurred in this building prior to February 20, 2003.

[2] This section taken from the contract report prepared by Ove Arup & Partners Massachusetts [12].

Table 1-1. Time Line of Construction and Changes of Use		
Date	**Modification**	**Extent of Construction**
Spring 1946	Original construction as a night club	New construction
June 1964	Change of ownership Converted to meeting house (same Use Group as restaurant)	Unknown if any
May 1967	Change of ownership and name Converted to night club	See permit July 27, 1967
July 27, 1967 (building permit 6748)		Commercial alterations Paneling inside Rebuild two porches in front New sign outside
1968	Name change	Unknown
June 1969	Nightclub closed	
April 1970	Change of ownership and name	See permit May 18, 1970 Converted to restaurant and removed the bar
May 18, 1970 (building permit 8018)		Alterations to Business Roofing, paneling etc.
Fall 1970	Renamed	Unspecified remodeling
June 1971	Bank forecloses Reopens as night club	
October 18, 1971	Alterations and remodeling	
March 1972	Fire Club may have remained closed until 1974	
June 1974	Change of ownership	
November 15, 1974	Convert to restaurant	Commercial alterations Interior paneling and partitions
April 29, 1975 (building permit 10558)	Commercial exterior alterations and renovations	
July 1, 1975 (building permit 10641)	Addition	Addition 30.6 m^2 (330 ft^2)
February 1985	Change of ownership Change of name Converted to "pub"	
February 20, 1985 (building permit 14930)		Remodeling and renovations to existing restaurant
Late 1980's	Pub closed	
1991	Reopened as nightclub	
January 1993	Change of ownership renamed	
January 1995	Change of ownership	
December 1999	Non-permitted work	
March 2000	Change of ownership renamed	
June 19, 2001 (building permit B01-1098)	Repair damage from car ramming building	Remove damaged window and replace size for size, replace damaged sill plate and reframe damaged exterior wall and interior wall and exterior siding

1.5 JURISPRUDENCE

Subsequent to the events of February 20, 2003, a large number of public and private legal actions have begun. While they are outside the scope of this investigation, NIST notes that a Grand Jury has returned indictments and a trial is pending; private suits have been filed seeking damages; disputes have arisen involving Workers Compensation; and OSHA has issued a citation which is presently being contested. NIST expresses no views on the merits of any of these proceedings.

In addition, these ongoing legal actions limited NIST's access to some physical evidence and limited the ability to interview some witnesses.

1.6 REFERENCES FOR CHAPTER 1

[1] National Construction Safety Team Act, Public Law 107-231 -- Oct. 1, 2002, Congress of the United States of America.

[2] purchased from GlobeXplorer 2004

[3] photograph by Anthony Baldino III (undated)

[4] Butler, Brian, Video by WPRI, Channel 12, February 20, 2003.

[5] *Providence Journal*, Zachary R. Mider July 13, 2003.

[6] West Warwick Application for Building Permit Number 6748. July 27, 1967.

[7] West Warwick Application for Building Permit Number 8018. May 18, 1970.

[8] West Warwick, Rhode Island Commercial /Industrial Property Record Card May 30, 2001

[9] West Warwick, Rhode Island Land Use Record. Undated.

[10] W. Warwick Application for Building Permit Number B01-1098, June 19, 2001.

[11] "Code Analysis of the Station Nightclub Warwick Rhode Island," Koffel Associates, Inc., Ellicott City, MD, NIST contract report # KA 03732-004, June 23, 2004.

[12] "Evaluation of Limitations to Egress through Doorways in Emergency Situations," Ove Arup & Partners Massachusetts Inc., NIST contract report #32979, February 18, 2004.

[13] photograph courtesy of K. Corbin

Chapter 2 DESCRIPTION AND TIMELINE OF THE INCIDENT

2.1 INTRODUCTION

A basic element of any fire investigation is the development of the timeline of events. Most of the deaths in The Station fire occurred during the evacuation process; hence, a focus of the NIST investigation was on documenting the egress event. Overlaying the progress of the fire, the movement of occupants, and the collapse of the building was the response to the emergency by the fire and police departments and EMS teams in West Warwick and surrounding regions. The intent of this review is to help understand the incident so that the details and occurrences that resulted in the large loss of life can be identified.

The timelines generated in this chapter integrate information from a range of sources to identify the specific events that occurred starting just after 11:07 pm, Eastern Standard Time (EST), Feb. 20, 2003 as well as the order in which they transpired. The timeline is presented as a collection of overviews and snapshots. Overviews describe a series of significant events that occur on the time scale of hours, and serve to place the events in a broader framework. Snapshots focus on a shorter time period, and provide details resolved down to a few seconds.

2.2 OVERVIEW NARRATIVE

About 11:07 pm, the lights were dimmed just prior to the band stepping onto the performance platform. Once the band was on the platform, a set of multi-colored lights were activated and four pyrotechnic devices (gerbs) were ignited to begin the show. The hot particulates which were part of the stream of white sparklers discharged by the gerbs struck both sides and the top of the opening to the alcove where the band's drummer was situated. In a matter of seconds the hot particulates ignited the polyurethane foam on both sides of the platform.

Eleven seconds after ignition, the band noticed the flames and the crowd soon began to realize that the fire was not an intentional part of the show. Within 25 seconds, the flames reached the ceiling on both sides of the platform. The fire spread very quickly across the polyurethane foam. The band stopped playing 30 seconds after the fire had started, and the bulk of the crowd began to evacuate. At approximately 41 seconds, the fire alarm sounded and the emergency strobe lights began to flash.

In less than 60 seconds, the Rhode Island Emergency 911 Center began receiving calls from cell phones reporting a fire, and at about the same time, a West Warwick Police officer who was at the nightclub reported to the police dispatcher that there was a fire inside The Station on Cowesett Avenue. This information was immediately relayed to the West Warwick Fire Department (WWFD). The fire department assigned and dispatched Engine 4, Engine 1, Engine 2, Engine 3, Ladder 1, Rescue 1, and Battalion Chief 1 to the fire scene.

Inside the nightclub, the fire continued to develop and in about 90 seconds, the thick black smoke layer appeared to have dropped to within 0.3 m (1 ft) of the main floor of the nightclub. Less than 100 seconds after ignition, the main front doorway became clogged with occupants trying to exit the main floor. Club patrons and staff were breaking windows on the front of the nightclub from the area of the main bar and sunroom and were exiting through the windows. Patrons who had escaped were attempting to extricate people who had been wedged in the front doorway. Shortly after 11:13 pm (5 minutes after ignition), flames were observed extending out of the windows and front doorway.

A few seconds later, Engine 4 arrived at the nightclub and began to pull a hose line to near the front door. Water from the booster tank on Engine 4 was initiated at approximately 11:14 pm (about 6 min into the fire). Additional fire fighters arrived on Ladder 1, Engine 2 and Engine 3. Battalion 1 activated the Warwick Task Force which invoked a mutual aid agreement and dispatched seven additional engine/ladder companies from surrounding communities. Battalion 1 also requested 12 rescues (ambulance units). At approximately 11:22 pm, the West Warwick Fire Chief indicated that he was responding to the fire scene. As the chief was responding, he asked the fire dispatcher to contact Metro Fire Control and implement the Mass Casualty Plan. The Engine 3 officer had set up a triage area in the parking lot of and inside the Cowesett Inn. Engine 4 was applying water on the fire by about 11:24 pm, and at least three hose lines were being used to apply water to the area around the front door by 11:28 pm.

Shortly after 11:32 pm, the fire chief asked the fire dispatcher to contact the State Fire Marshal's Office and request a state fire marshal be sent to the scene. The fire dispatcher advised Triage that Kent County Hospital was overwhelmed with injured victims and that additional victims should be directed to Rhode Island Trauma Center, and Triage responded that the rescue units were using their own discretion as to which hospital the victims were being transported.

At about 11:57 pm, a portion of the nightclub roof appeared to collapse. The fire chief ordered a roll call to account for all fire fighters on the fire ground. Around midnight the Warwick ladder unit raised its ladder, and began applying a master stream to the fire. Approximately ten minutes after the collapse of the main roof section, a portion of the roof around the sunroom collapsed. Sometime between 12:15 am and 1:00 am, February 21,the State Fire Marshal arrived on the fire scene, the incident commander asked the fire dispatcher to cancel additional rescue units, and Triage reported that all patients had been transported.

An overview timeline is shown in Figures 2-1a and 2-1b. Detailed events are summarized in Table 2-1.

2.3 OVERALL INCIDENT TIMELINE

The overall incident timeline was assembled from the video footage inside and outside The Station filmed by WPRI-TV [1], published interviews with occupants by the *Providence Journal,* a video taken by an amateur using a handheld camcorder [2], audio tapes, and fire department records. A high-quality digital version of the TV video was provided to NIST by WPRI. The amateur video [2] was retained as evidence by the Office of the Attorney General for Rhode Island. The Attorney General's staff permitted the NIST investigators to review the tape in the West Warwick Fire Investigation field office. Audio tapes from two sources were also retained by the Attorney General. The first audio set contained digital recordings of cellular phone calls to the Rhode Island Emergency (911) Center. The second audio set included cassette tapes of radio communications from the WWFD. The Attorney General's staff allowed investigation team members to listen to both the 911 and fire department recordings at the field office.

In order to integrate the events on the two videos with the audio recordings, it was necessary to establish a common time reference. Each of the two videos was time-stamped by the camera/camcorder, but the two clocks were not synchronized. The 911 audio recordings were time-stamped, but it appeared that the 911 clock did not match either of the two video clocks. The fire department radio transmissions were not continuously time-stamped, but the central dispatch (fire alarm) periodically inserted a clock time either before or after a transmission. The fire department communication system did not record continuously, but instead recorded only when a radio transmission occurred. The result is that the dispatcher may have inserted a clock time twice in 5 minutes, but then not provided another clock time for 30 minutes.

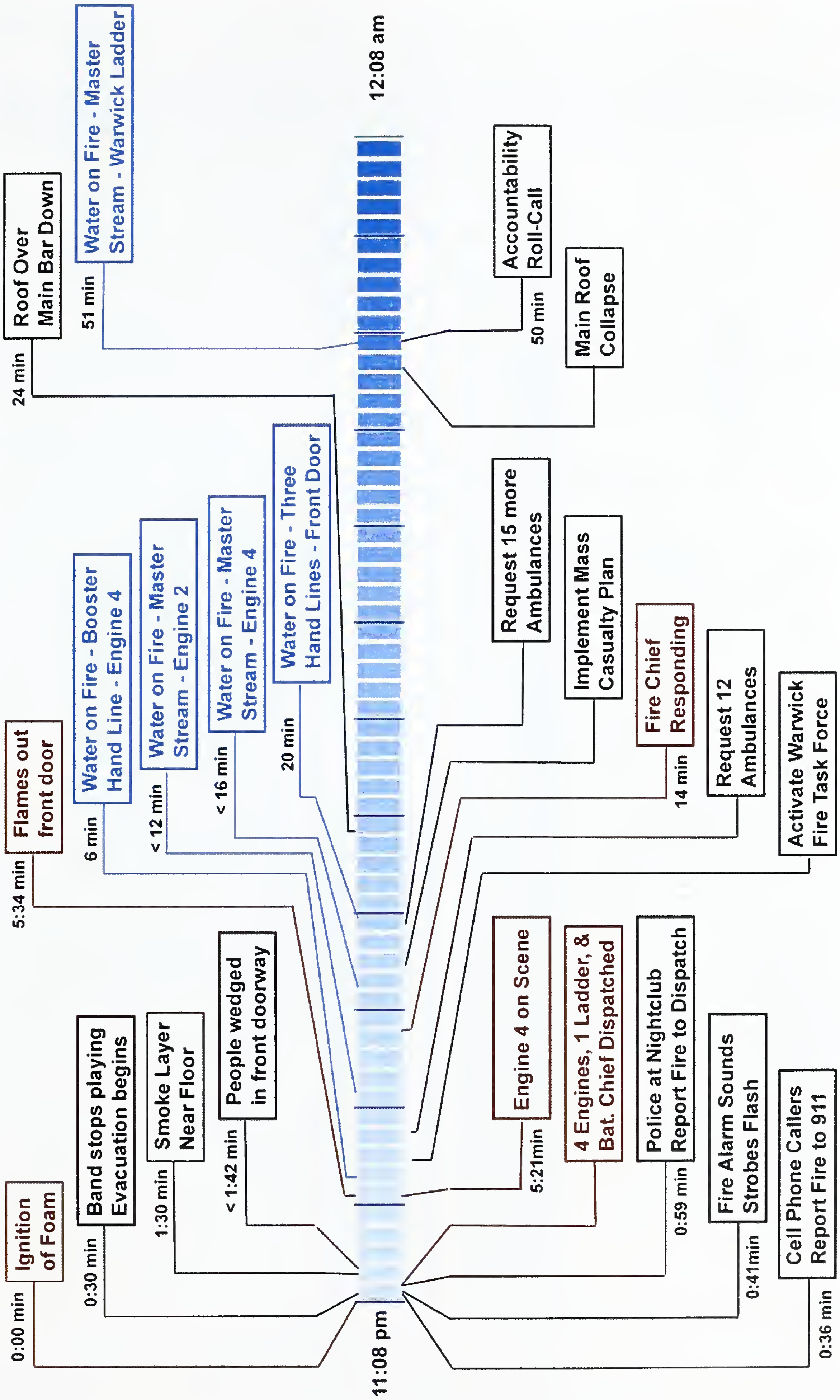

Figure 2-1a. Overview Timeline of The Station Nightclub Fire

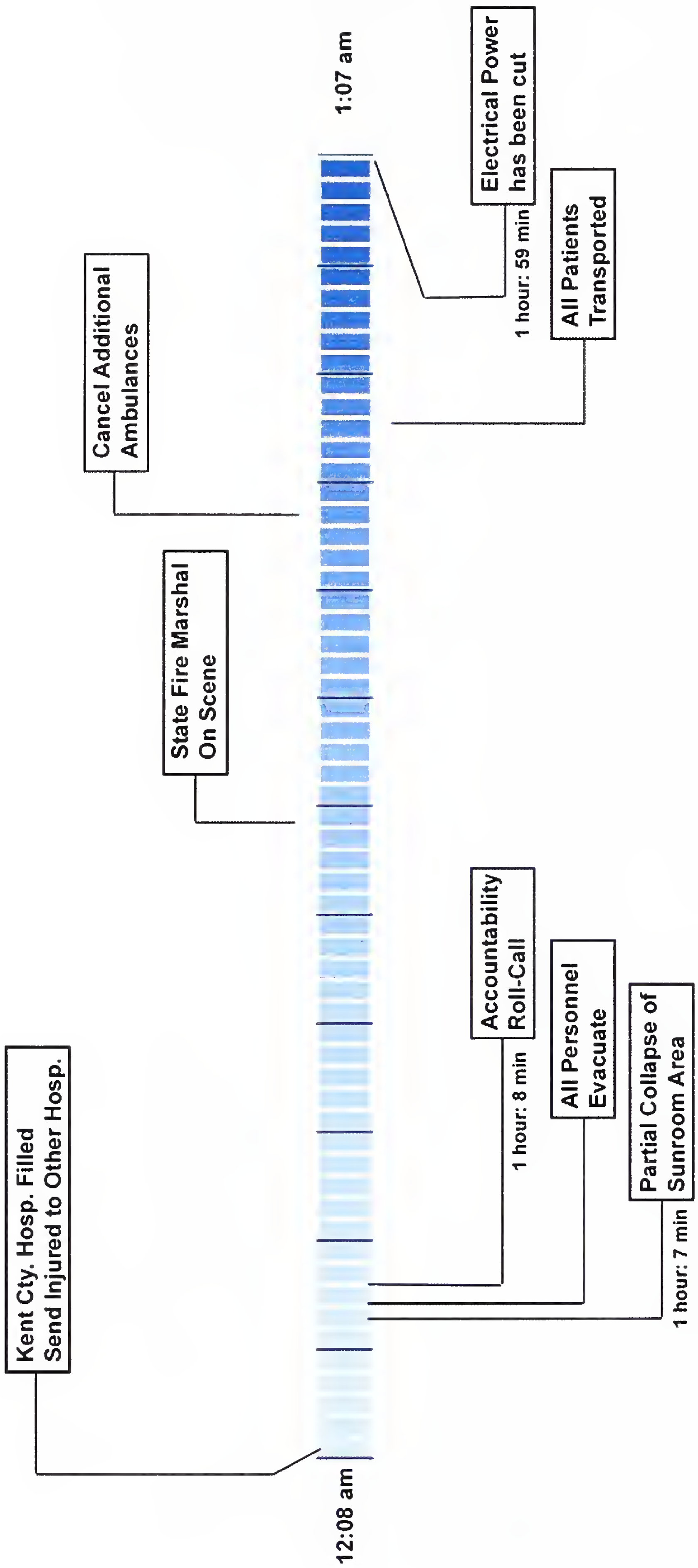

Figure 2-1b. Overview Timeline of The Station Nightclub Fire (cont.)

Table 2-1. Summary of Incident Timeline. (Uncertainty is less than +/- 5 seconds for times showing seconds, and +/- 30 s for times without seconds.)

EST	Fire Time	Description
11:08 pm	0:00:00	First flames on upper wall, left of platform
	0:00:25	Flames touching ceiling on both sides of platform
	0:00:30	Band stops playing, crowd begins to evacuate
11:09	0:00:36	Three Cell phone caller reports fire to 911
	0:00:41	Fire alarm sounds and strobes begin to flash
11:09	0:00:59	Report received of fire at Station Nightclub- Police on Scene,
11:09	0:01:13	Fire alarm recorded at WWFD
	0:01:30	Thick black smoke from pool room windows. Smoke appears to be at floor level inside.
	0:01:42	People piled up in doorway. Smoke pouring out above people.
11:10	0:02:00	E-4, E-1, E-2, E-3, L-1, B-1assigned/dispatched
	0:04:38	Smoke approximately 0.3 m above floor inside. Flames near door
	0:05:12	First observation of flames out front of building
11:13	0:05:21	Engine 4 on scene. Fire department confirmed on scene, front of building
	0:05:34	Fire Department commences running first hose line (1 ¾"). Flames (2.5 m to 3 m) extending from front exit
	0:05:43	Flames extend from front windows
11:14	0:06	Engine 4 on scene reporting heavy fire
		Water from 1 ¾" hose line directed to the main entrance
		Battalion 1 – activate Warwick Task Force (seven additional engines/ladders) Mutual Aid
		Battalion 1 to Fire Alarm – request 12 rescue units
	0:11	Engine 2 – monitor; knock it down, Master Stream from E-2 on fire at club entrance
11:22	0:14	Fire Chief responding
		Fire Chief 1 to Fire Alarm- Metro Fire Control; Implement Mass Casualty Plan
11:24	0:16	Master Stream off Engine 4 operational – water on center of fire
		any available rescue units, request 15 more

EST	Fire Time	Description
11:28	0:20	Three hose streams, three hand lines streaming on front door area
11:32	0:24	Area/Roof over Main Bar appears down
11:33	0:25	Master Stream off Engine 4 still operating
		Fire Chief 1 to Fire Alarm – need State Fire Marshal asap
11:40		Rescue 2 at Kent County Hospital
		Command to Triage-Triage –need 10-24 stretchers
		Fire Alarm to Triage – Kent County overwhelmed; send to RI Trauma
		Engine 3 to Fire Alarm – repeat; rescues using own discretion; Engine 3 triaging out of here
		Battalion 1- accountability Roll Call – roof down?
11:57	0:49	Middle of Accountability Check- Accountability –Fire Alarm to E-1,E-2,E-3,E-4, Rescue 1, FC, SH
11:58	0:50	Warwick Ladder platform water operating
		Fire Alarm to Command – Kent filled to max; Rescue 1 – approaching scene with doctor from Kent Cty
12:09 am	1:01	Master stream off ladder platform still operating
12:15	1:07	Partial collapse of pool room area begins
12:16	1:08	Warble tone ----- partial collapse; all personnel out
		Accountability Check – E-1, E-2, E-3, E-4, L-1, R-1, E-5, E-7, R-3
12:22	1:14	Master stream from ladder platform still operating
12:23	1:15	Streets appear clear and casualties gone
12:37	1:29	Narragansett Electric Power Truck visible on Cowesett
		State Fire Marshal on scene; Narragansett responding
		Command to Fire Alarm – notify chaplain; cancel additional rescues; cancel LifeFlight helicopter
		Command to Fire Alarm – Chief Rock (Fire Chief 2) and State Fire Marshal meet in front of building
		Safety – cancelled all Rescue, Triage to Fire Alarm – all patients transported
1:06		Rescue 1 clear
1:07		Fire Alarm – Power has been cut

After careful review of the video and audio recordings, links were discovered which allowed all the recordings to be tied to a common clock. West Warwick Fire Department records indicated that the first unit, Engine 4, arrived on the scene at 23:13:22. Engine 4 also notified the WWFD dispatcher over the radio that they were on scene and the dispatcher inserted a clock time of 23:14. While it was not clear that the same clock was used to record the arrival and the dispatcher's time stamp of the radio transmission, the two clock times suggested that both clock times were relatively consistent. It was also possible that the same clock was used for both times and there was a short delay after Engine 4 arrived and their report of being on scene. For development of this timeline, it was assumed that the earlier time, 23:13:22, was the time of arrival of Engine 4.

The arrival time of Engine 4 provided a link to the WPRI video because Engine 4 was visible in the video. A siren could be heard in the background of the WPRI video and seconds later, Engine 4 appeared on the video. The video did not actually show Engine 4 pulling into the parking lot of the nightclub. But 5 minutes 21 seconds after ignition, Engine 4 was shown to be in the parking lot of the nightclub. It was possible that Engine 4 arrived slightly earlier, but was simply not visible in the field of view of the WPRI camera. The arrival time from the fire department records, 23:13:22, was paired to the appearance of Engine 4 in the WPRI video at 5:21 after ignition. This link allowed the fire department records, fire department radio tapes, and the WPRI video to be tied to a common clock.

The fire department radio tapes could be linked to the 911 audio tapes because one of the cell phone callers was relayed from the 911 center to the WWFD. Part of the communication between the cell caller and the WWFD could be overheard on the fire department radio transmissions. Unfortunately, the dispatcher did not insert a clock time on that specific radio transmission, but had inserted a clock time with a preceding transmission. Again, since the radio transmissions were only recorded during actual transmissions, it was not possible to ascertain how much time had passed between the previous clock time insertion and the cell call being transferred to the WWFD. Since each cell call to the 911 center was time stamped automatically, it was possible to link the fire department radio transmissions to the 911 calls.

While the WPRI video captured the first 6 minutes of the fire, the amateur video tape was longer and recorded later in the evolution of the incident. A link between the two video times was found through common events captured on the amateur tape and fire department transmission records. During the fire department response and suppression operations, the WWFD conducted two roll calls of personnel on the fire ground. The first roll call appeared to be associated with the collapse of a significant portion of the nightclub roof. The second roll call was requested when part of the sunroom collapsed. The warble tones used by the fire department to signal a roll call could be heard on both the amateur video tape and the fire department radio transmissions. The fire dispatcher did insert a clock time on the radio transmission announcing the second roll-call. Comparing the time stamp on the amateur video with the fire department radio transmissions identified the amateur video clock to be 3:32 min behind the fire department clock. The amateur video times were adjusted by adding 3:32 min to each time mark.

By linking the fire department radio transmissions to the WPRI video, the 911 cell calls, and the amateur video, all the events were placed on a common timeline. Combining this with the fire department incident record allowed the timeline to reference a single clock time. However, since most of the fire department radio transmissions did not have an inserted clock-time, the timeline shown in Figure 2-1 provides the order in which all of the events occurred, but not necessarily the specific times at which they occurred.

2.4 EVACUATION TIMELINE[1]

Three types of data were used to develop a reasonable and verified description of the evacuation: video footage, photographs and eyewitness statements from the *Providence Journal*. While many newspaper articles reported various details of the incident, the building, and the evacuation, no conclusions were drawn from such sources unless they could be independently verified through review of photographs, video footage, or eyewitness statements.

Short of personal observation, visual evidence can provide investigators with the most reliable depiction of the events of an incident such as this. By considering visual evidence, the investigator does not rely upon the interpretations or views of other observers. Due to inherent inaccuracies involved with eyewitness accounts, visual evidence was given priority in developing the timeline.

The evacuation timeline presented here was assembled with the assistance of Ove Arup & Partners Massachusetts, Inc. Their final report to NIST [3] is quoted freely in this chapter without further reference; however, any conclusions and findings that are presented are solely those of NIST. The timeline includes events specific to the evacuation of the building, as well as those specific to the development of the fire. Various sources were contacted as part of this effort. However, because litigation activities were underway, some potential sources were unable to provide us their information.

The video footage recorded inside and outside of the club before and during the fire by WPRI-TV camera operator [1] was of great benefit to this task. This video showed various activities prior to the incident, as well as the initiation of the fire and portions of the ensuing evacuation. The television news crew's video was used as the primary source of data for this task. Available photographs were used to confirm various details observed in the video, as well as to gain observations of different parts of the club, both before and during the fire.

While eyewitness statements have some drawbacks, they can provide valuable insight, especially since video footage and photographs were not available for all aspects of this incident, or of areas and features of The Station nightclub. In this review, eyewitness statements, primarily as reported by the *Providence Journal* and the *Boston Globe*, were used to draw conclusions regarding occurrences outside of the view of the available visual evidence sources. Unless they could be disproved, eyewitness statements were assumed accurate based on the experience of the eyewitness; conclusions drawn from these were independently verified, where possible. NIST also provided an anonymous toll free hotline and an email address for voluntary input from the general public to generate additional communications, none of which contradicted the published accounts.

Photographs used in this analysis were in digital form, and thus no software was necessary in their processing. The WPRI video was provided to NIST in digital form as well. In order to obtain still images from this video, the media editing software Pinnacle Studio SE, Version 7.15.1, was employed. This software allowed specific individual video frames to be extracted from the video while maintaining image quality.

The timeline that resulted from this analysis, with reference to the still frames from which events were identified (refer to Appendix A for images), is provided in Figures 2-2a through 2-2d . The timeline indicates times in relation to the initiation of fire on the platform, estimated to occur at 11:08:01 pm EST (06:22 video time).

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[1] This section taken from the contract report prepared by Ove Arup & Partners Massachusetts [3].

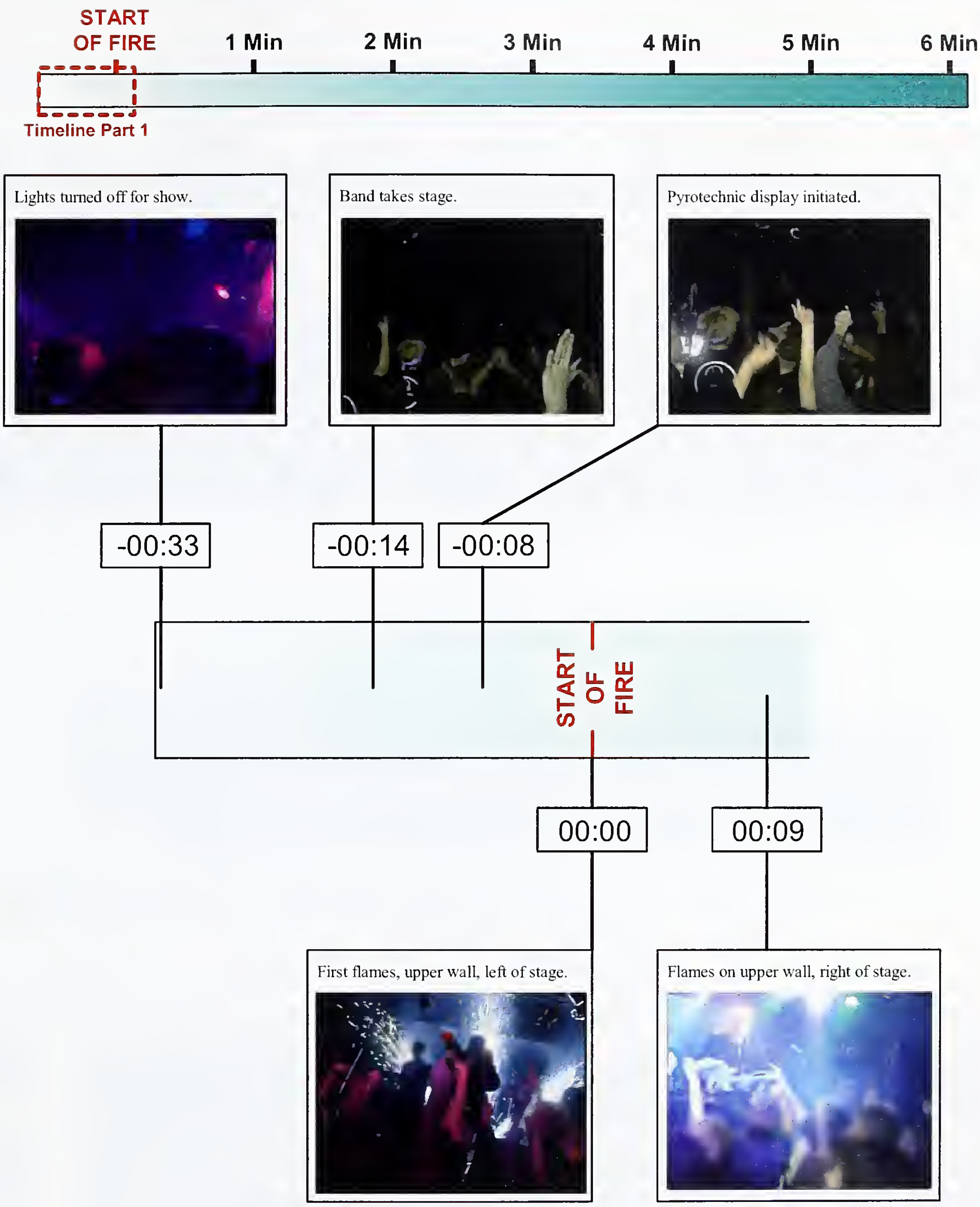


Figure 2-2a. Evacuation Timeline (33 seconds before to 10 seconds after ignition). Video stills copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

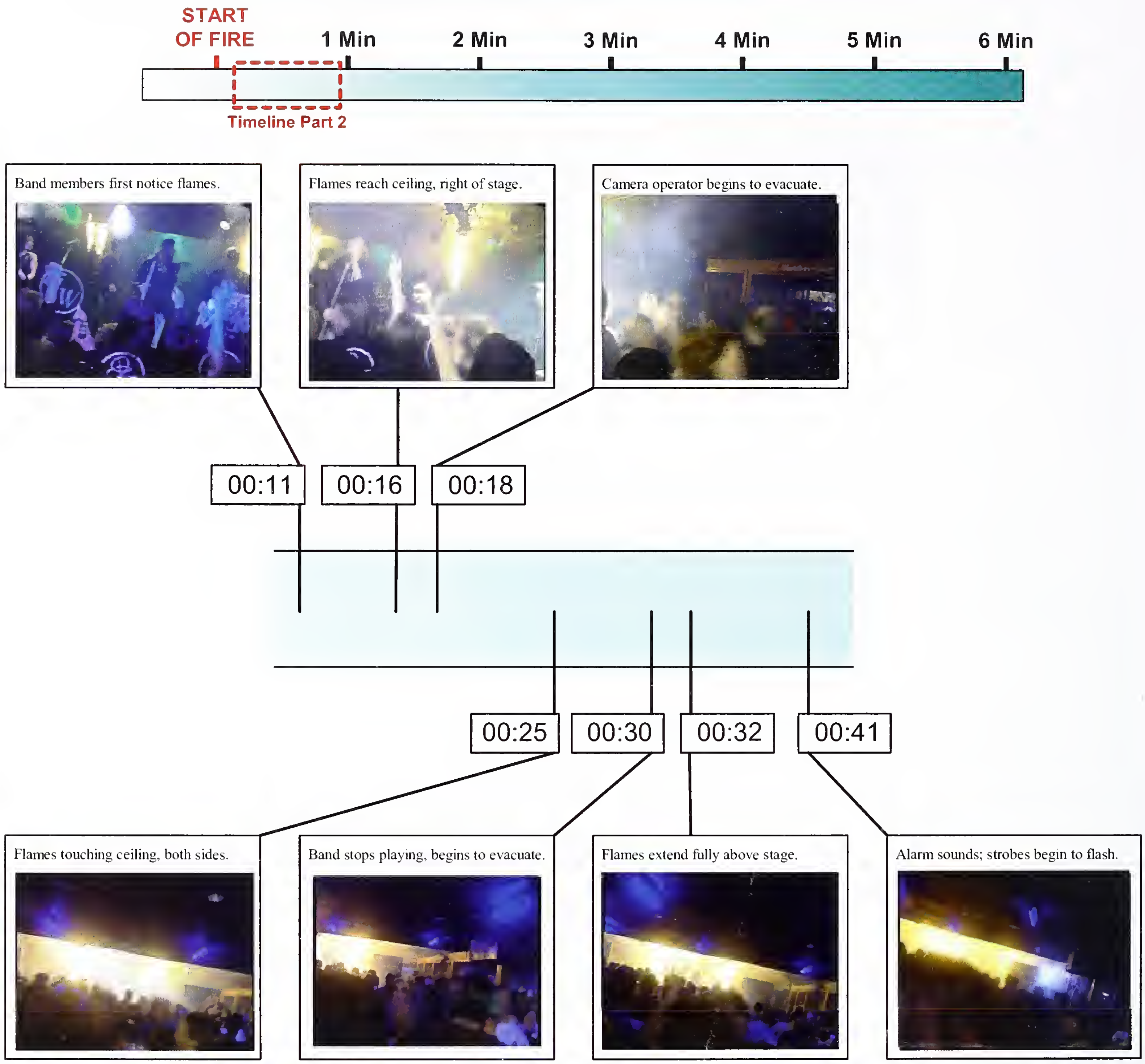


Figure 2-2b. Evacuation Timeline (10 seconds to 50 seconds after ignition). Video stills copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

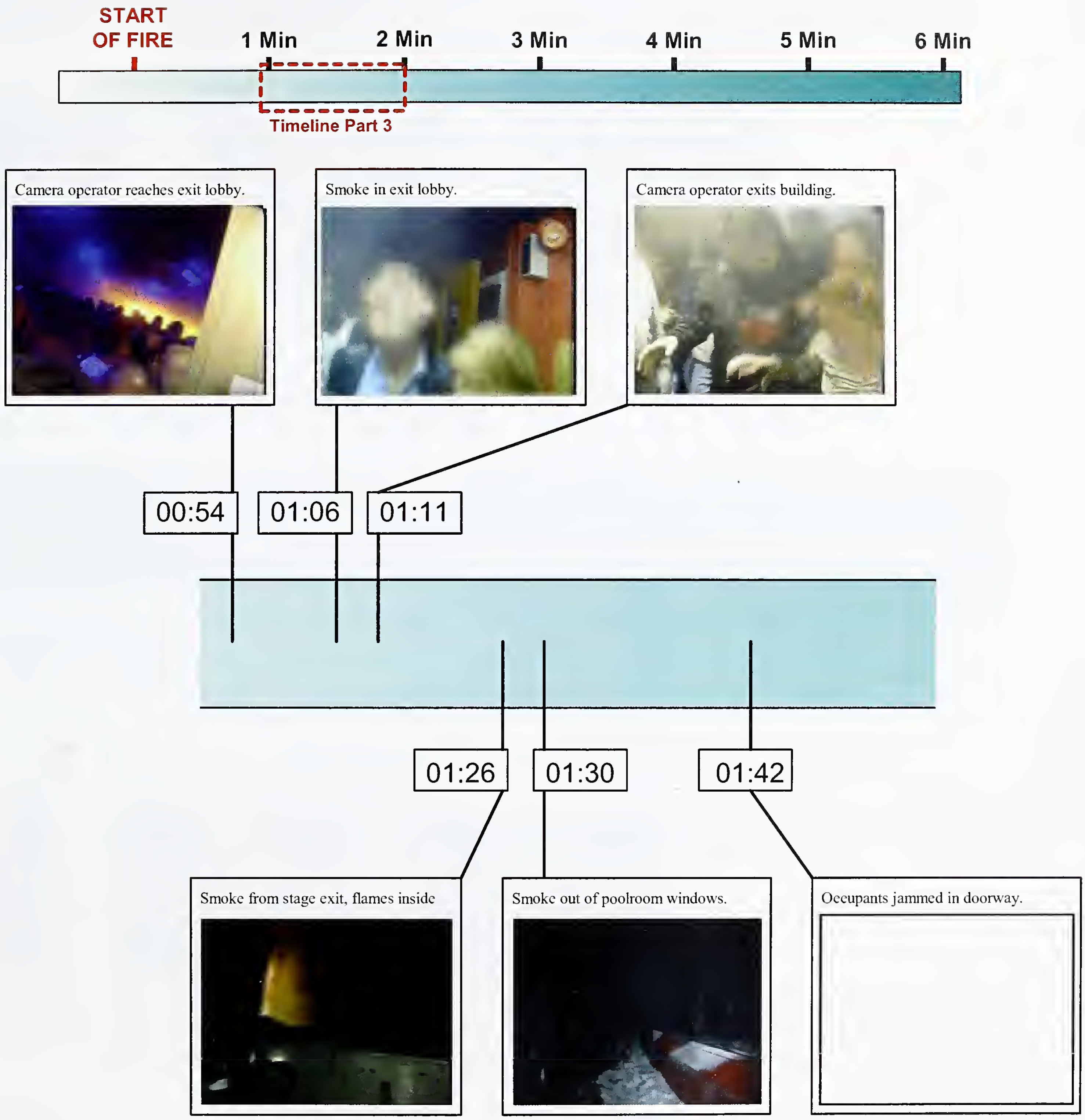


Figure 2-2c. Incident Timeline (50 seconds to 2 minutes after ignition). Video stills copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

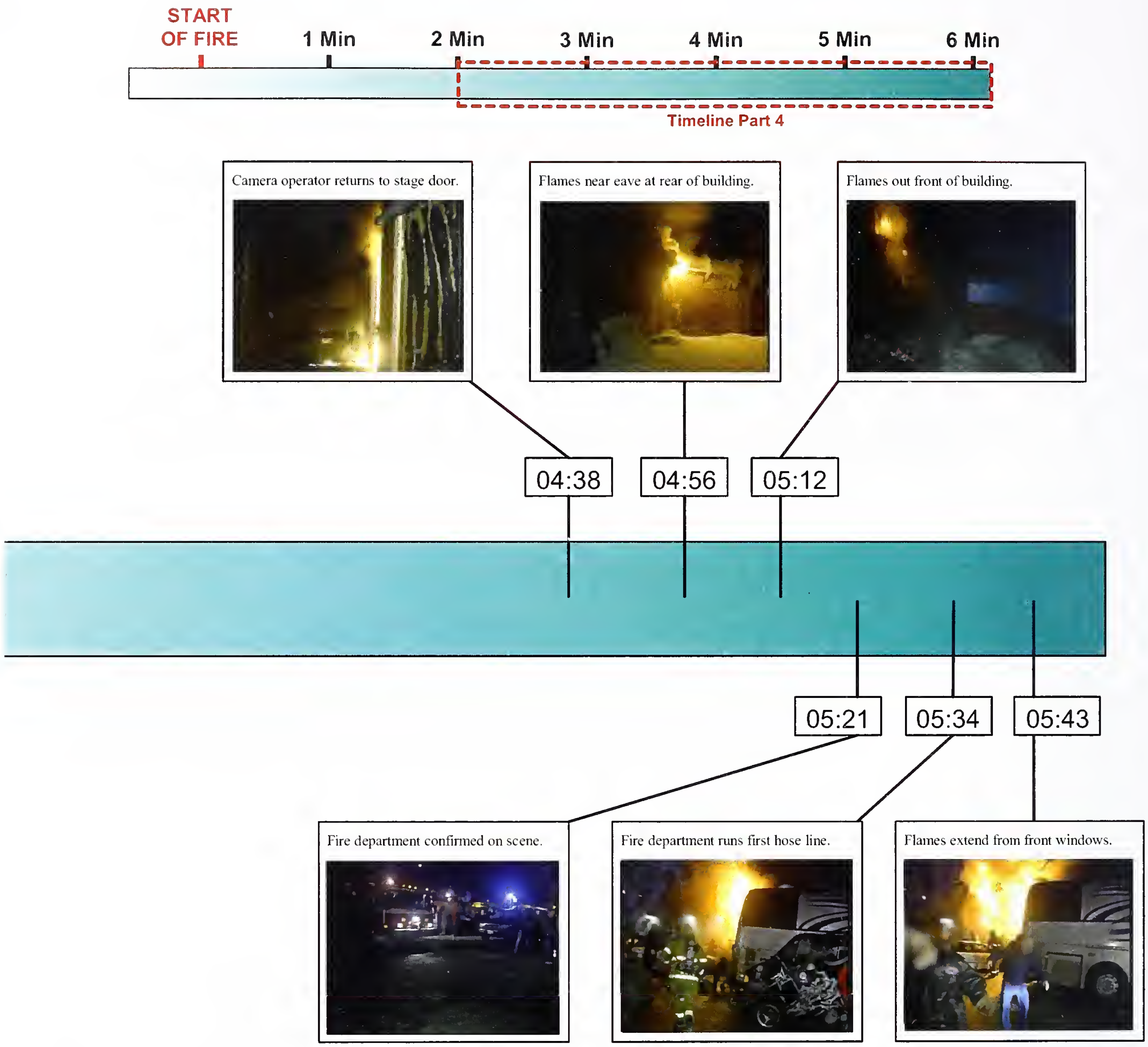


Figure 2-2d. Incident Timeline, Part 4 (2 minutes after ignition to 5:43). Video stills copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

The focus was the time period beginning when portions of the club lights were shut down in preparation for the show, until the videographer placed the camera on the ground in the parking lot and significant flames were seen at the front of the building. The polyurethane foam along the vertical corners of the walls forming the drummers alcove ignited 8 seconds after the pyrotechnic display was initiated, as seen in Fig. 2-2a.. The videographer moved his camera aside 7 seconds later to view the growing fire along the wall better; the band members near the back of the platform noticed the flames 4 seconds later. (Refer to Fig. 2-2b.) The videographer swung his camera around and headed for the exit at the front of the building 18 seconds after ignition of the foam; the first patrons could be seen on the videotape to

Table 2-2. Summary of Evacuation Timeline Developed from Video Analysis [1, 3] (Uncertainty in time is less than +/- 2 seconds)

Video Time	Fire Time	Description
0:05:49	- 0:00:33	Platform lights turned off for beginning of show.
0:06:08	- 0:00:14	Band first shown on platform.
0:06:14	- 0:00:08	Pyrotechnic display initiated.
0:06:22	0:00:00	First flames on upper wall, left of platform.
0:06:31	0:00:09	Flames on upper wall, right of platform. Pyrotechnic display ends.
0:06:33	0:00:11	Band members first notice flames.
0:06:38	0:00:16	Flames reach ceiling to right of platform.
0:06:40	0:00:18	Camera operator begins to evacuate.
0:06:47	0:00:25	Flames touching ceiling on both sides of platform.
0:06:52	0:00:30	Band stops playing, begins to evacuate.
0:06:54	0:00:32	Flames extend fully across ceiling above platform.
0:07:03	0:00:41	Fire alarm sounds and strobes begin to flash.
0:07:16	0:00:54	Camera operator reaches exit lobby.
0:07:28	0:01:06	Smoke in outer exit lobby.
0:07:33	0:01:11	Camera operator exits building.
0:07:48	0:01:26	Smoke coming out of platform exit. Flames visible inside at this location.
0:07:52	0:01:30	Thick black smoke from pool room windows. Smoke appears to be at floor level inside. Occupants egressing through windows.
0:08:04	0:01:42	Camera operator returns to main exit. People piled up in doorway. Smoke pouring out above people.
0:10:30	0:04:08	Occupants still being assisted through main bar windows
0:11:00	0:04:38	Camera operator returns to platform exit. Smoke ~1 ft above floor inside. Flames near door.
0:11:18	0:04:56	Flames outside building at roof level in rear.
0:11:34	0:05:12	Flames first recorded out front of building.
0:11:43	0:05:21	Fire department confirmed on scene.
0:11:56	0:05:34	Fire department commences running first hose line. Flames extending from main exit ~2.5 to 3 m.
0:12:05	0:05:43	Flames extend from front windows.

recognize the fire danger at 24 seconds. Around the time the band stopped playing (30 seconds fire time), the bulk of the crowd had begun the evacuation process. At 41 seconds the fire alarm could be heard and the strobe seen on the video. (See Fig. 2-2b.)

The videographer made his way to the exit lobby while continuing to capture the movement of the crowd leaving the area around the dance floor. As seen in Fig. 2-2c, he exited the building at 1 minute 11 seconds (fire time) along with a steady stream of occupants. Sometime estimated to be around 1 minute 30 seconds after ignition of the foam, the front exit became blocked with people, and occupants could be seen breaking windows and escaping from the poolroom/sunroom. The result of the crowd crush at the front exit was captured on the video at 1 minute 42 seconds (Fig. 2-2c). The latest time recorded for an occupant escaping from inside the main bar (through a window) was at 4 minutes 8 seconds; however, people stuck in the front entrance are seen in the video to have escaped as late as 5-1/2 minutes into the fire, just before the fire department ran its first hose line (Fig. 2-2d). (One patron claimed to have been pulled from the bottom of the pile by a firefighter considerably later, but this has not been confirmed by the NIST investigation.)

Table 2-2 provides a summary of the events making up the evacuation timeline. “Video Time” refers to the absolute counter time associated with the events as captured on the television crew video, while “Fire Time” refers to the time of events relative to the start of the fire.

2.5 REFERENCES FOR CHAPTER 2

[1] Butler, Brian, Video by WPRI, Channel 12, Feb. 20, 2003.

[2] Personal communication between N. Bryner and M. Stone, Rhode Island Attorney General's office, West Warwick, June 2, 2004.

[3] "Evaluation of Limitations to Egress through Doorways in Emergency Situations," Ove Arup & Partners Massachusetts Inc., NIST contract report #32979, Feb. 18, 2004.

Chapter 3
THE EMERGENCY INCIDENT RESPONSE

3.1 INTRODUCTION

Beginning late Thursday evening, Feb. 20, 2003, Rhode Island's fire/rescue, emergency medical services and law enforcement agencies were challenged by the largest life loss fire incident in the state's history. In a matter of minutes The Station nightclub became engulfed in flames, producing both a major mass fatality and mass casualty incident that drew upon the resources of virtually every fire and emergency medical services (EMS) provider in the State, a variety of law enforcement agencies and others.

The fire and resulting structure loss was principally limited to the single story, wood framed, unsprinklered, public occupancy, commercial building of relatively modest size [approximately 412 m^2 (4484 ft^2)]. Several vehicles in the vicinity of the building were also lost or damaged by the fire. As described in Chapter 1, the structure stood facing north, at the left rear of a roughly rectangular corner lot at the southwest intersection of Cowesett Avenue and Kulas Road. The corner lot had been carved from a steeply graded hillside and then leveled and re-graded to provide relatively level access along the length of the Cowesett Avenue frontage, while on the Kulas Road (east) side, the grade rose away to the rear and southeast corner of the lot from Cowesett Avenue at a significant incline. The south or back line and the west side property line were covered by relatively heavy brush comprised of various small trees, bushes and ground cover and accumulated snow pack. The length of the rear property line was also contained and obstructed by a privacy style fence.

The site's contours maximized the Cowesett Avenue access and parking (north half of the lot) and placed the structure lower than adjacent perimeter grades at the rear on the east and south (back) sides. The structure's proximity to the berm-like elevated boundary on the east and along the south/back side property line limited tactical operations at the rear and southeast corner of the building. This area also provided no personnel access/egress points to the structure on either side. The building's placement on the lot and its irregular configuration, the higher graded perimeters, and the narrow distance between firefighters and the southeast side and south facing rear walls of the structure presented a risk to fire ground operations due to the rapidly deteriorating conditions, including the possibility the building would collapse. The east side of the lot along Kulas Road also presented an electrocution hazard risk to fire ground operations due to overhead electrical lines and a pole-mounted transformer at the service drop to the structure.

The northeast front facing side, the full front (north facing) and west side of the structure each contained slightly elevated entrance ways into the building and were accessible from the relatively level parking areas extending from the building to the north and west.

In other respects, the structure presented no obvious hazards beyond those normally associated with comparable occupancies nor were there any other nearby at-risk structural exposures. However, vehicle fire exposure risks filled the parking area, in the front of and extending from the structure to the west. This area contained numerous vehicles of various types including a tour bus, media van, cars and trucks, as well as residual snow banks/piles from previous plowing. Although the tour bus was removed during the early minutes of the fire, other vehicles parked near the northeast side (adjacent to the single door bar area exit) in the immediate proximity of the building were exposed to sufficient radiant heat to produce secondary ignitions, requiring extinguishment and producing additional vehicle fire losses from the incident.

The human toll from the fire was far more devastating. Within only minutes of the pyrotechnic display ignitions, 96 people perished, unable to egress safely ahead of the intense and fast moving fire. Most of the fatalities occurred in the moments prior to the arrival of the first emergency services units. Three more died within days subsequent to hospitalization, followed by an additional death 70 days after the fire raising the final fatality count to 100.

More than 200 other victims, many seriously hurt from burns, respiratory insult and physical trauma, were provided emergency care and triaged at the scene, then transported to hospitals in multiple states. This major mass casualty incident (MCI) effectively concluded its emergency on-scene and pre-hospital care operation (casualty collection, triage and transport) phase in less than two hours from the fire's onset. The operation was accomplished expeditiously through the combined efforts of dozens of agencies (some 60 EMS units and untold number of individual care providers), notwithstanding the communications interoperability challenges experienced by many of the responding units.

Subsequent to the fire's suppression and once the scene was cleared of casualties, the next major phase began -- the recovery and identification of the fatality remains. These activities opened the opportunity for police, fire investigators and others to access the primary loss area to collect and document information in support of their investigations.

The State Fire Marshal and Medical Examiner's personnel coordinated the recovery of the dead. Fire Department personnel were utilized to collect individuals' remains and to move them to a holding area at the northwest corner of the lot while awaiting transport. The respective investigative teams documented the fire scene and the body recoveries, attempting to identify the deceased as early on in the process as possible. This phase of the operation continued until the recovery and removal of the last victims by late afternoon, on Friday, Feb. 21. The scene had been secured with temporary fencing and site control was transferred to the law enforcement authorities conducting the follow on investigations.

Fire department on-scene operations concluded with the last 'stand-by' engine company returning to quarters some 24 hours after the ignition of the pyrotechnics that came to produce the fourth deadliest nightclub fire loss in the Nation's history.

3.2 THE WEST WARWICK FIRE DEPARTMENT

The description of the West Warwick Fire Department (WWFD) provided in the DHS/ODP After-action Report (Annex A, p. A-1) [1] forms the basis of the information summarized here. The WWFD provided both emergency medical and fire suppression services to a community of approximately 30,000 people. West Warwick is situated geographically at about the center of the state, and comprises a primary response area of just under eight square miles. The Department operated from four stations with a combined response capability of four engine companies, one tower/ladder company, two rescue-ambulances and one special hazards unit or squad-type apparatus with a light tower.

The Department's 66 uniformed personnel were divided into four rotating platoons typically comprised of not less than one battalion chief and 12 other officers and firefighters per shift. An officer and firefighter each staffed Engines 1, 3 and 4. An officer and firefighter cross-staffed Ladder 1 and the special hazards unit and two firefighter/EMT-C's cross-staffed Engine 2 and Rescue 2 (ambulance), while two firefighter/EMT-C's staffed Rescue 1 (ambulance). (Note: cross staffing indicates the personnel responded on either of the indicated apparatus depending on the nature of the assignment.)

At the time of the fire, the WWFD's unit staffing (as noted above) was about half the minimum complement of engine and truck company personnel suggested in the applicable National Fire Protection Association (NFPA) Standards (1500 [4] and 1710 [5] respectively). The Standards advocate a minimum crew of four members operating from each type of apparatus. Unit staffing levels directly affect the firefighting crew's tactical performance capabilities, the speed at and duration of which they can be relied upon to accomplish various tasks, such as establishing water supply, advancing hand lines, or effecting rescues, as well as the overall scope and effectiveness of the tactical intervention strategy being applied in a given situation.

The WWFD routinely relied upon substantial mutual-aid augmentation [principally from the Warwick Fire Department (WFD) and the Coventry Fire Department (CFD)] to respond to its working structure fires due in large part to its below standard staffing levels. In general, the additional response times of mutual aid assets can delay the effective implementation of the Incident Command (IC) based strategies and tactics necessary to successfully mitigate significant incidents. In this case, however, the large loss of life was not connected to any delay in establishing the Incident Command.

3.3 THE FIRE AND EMERGENCY MEDICAL SERVICES RESPONSE

A "structure fire with person(s) trapped" type incident by its nature produces a situation where occupant rescue and fire suppression activities are competing for immediate priority attention. The response to this incident involved major concurrent tactical challenges (the fire suppression, the mass casualty management, scene control and traffic management and the subsequent victim identification, community support, and incident investigation) requiring concurrent intervention activities by fire suppression, EMS, law enforcement personnel and others from a plethora of agencies.

The following overview is intended to provide a general description of the incident's progression noting key tactical challenges and how they were addressed. The overview timeline (Fig. 2-1a and 2-1b, and Table 2-1) summarize the sequence of events that are described in more detail in this chapter. Invaluable contributions were made by literally hundreds of service providers from a host of agencies working in common cause, even though there were problems in the response.

3.3.1 The Initial Alarm

On Feb. 20, 2003, at approximately 11:09 p.m., the State's 911 call center began to receive calls reporting a fire at the Station Nightclub and requesting that help be sent to the nightclub. Simultaneously, the West Warwick Police Department dispatcher received a radio call from a paid detail officer (police) at the scene also reporting a fire at a nightclub which was located at 211 Cowesett Avenue. Within seconds reports from both the 911center and police officer were relayed to West Warwick's fire dispatcher who initiated a standard structure fire response at approximately 11:10 p.m.

The duty chief, four engine companies, the tower/ladder company and a rescue-ambulance responded to the initial alarm. Calls continued to come in, indicating the extraordinary severity of the fire and that numerous people were trapped and injured, which prompted the assignment of additional rescue-ambulances and other assets from both the adjoining jurisdictions and across the state.

At approximately six minutes into the fire, and within moments of his arrival, the WWFD's on-duty chief (acting Battalion 1) requested the activation of a task force from the nearby Warwick Fire Department for mutual aid. Warwick Fire Department units monitoring the alarm traffic and anticipating the assignment went "in-route" when dispatched at approximately 11:14 p.m. The WFD response was comprised of an augmented task force including a chief officer, 3 engines, 1 truck and 2 rescue-ambulances. The WWFD on-duty chief then requested 12 rescue-ambulances to be dispatched in addition to those already responding. The dispatchers received multiple alarm/mutual aid requests as the incident progressed.

3.3.2 The Incident Command

The initial Incident Command (IC) was established with the arrival of the WWFD on-duty Chief (acting Battalion 1) who positioned his command vehicle at the west end of the alarm assignment structure on Cowesett Avenue.

From this location the IC had a fair view of the front of the burning structure, the large number of casualties dispersed among the crowds of other people in the parking area in front of The Station and along both sides of the roadway to the east, the Kulas Road intersection with Cowesett Avenue, and some of the area on the street in front of the Cowesett Inn. As one scanned from a southerly direction to the east the following could be seen:

- directly south -
  - the immediate parking area in front of the building with numerous at-risk vehicle exposures, the at-risk structure with heavy fire showing, and the steep grade incline and wooded area to the rear of the lot
- to the southeast –
  - at a distance, the rise of Kulas Road up-grade away from Cowesett Avenue with adjacent utility poles and overhead wires with a transformer
  - in the near ground, the approximate length and width of the parking area and vehicle loading
- looking east -
  - on the right of Cowesett Avenue, the length of the street section in front of The Station
  - on the left, the area in front of and to the west side parking areas of the Cowesett Inn

The fire ground scene was chaotic. The fire was rapidly enveloping the structure with a large collection of victims trapped at the main entrance and an unknown number still likely to be in the building. Dozens of victims with obvious injuries were scattered across the operational area, including the parking lot and along the street looking east toward the Inn.

The concurrent and emerging operational objectives of rescuing victims, providing mass casualty care/transport and mounting an attack to extinguish the fire were apparent to the IC who immediately requested additional assistance.

The IC directed WWFD's Engine 2 to lay-in supply lines from the hydrant in front of the Cowesett Inn and to support the first due unit's (Engine 4) suppression operations. During these initial activities, the primary command focus was to establish a water supply and accomplish as many victim rescues as possible given the rapidly deteriorating fire conditions.

At 11:22 p.m., less than 14 minutes into the fire, WWFD's Chief of the Department notified dispatch that he was responding. Moments later while in route, he ordered the formal activation of the Mass Casualty Incident (MCI) component of the mutual aid plan.

Upon his arrival, approximately six minutes later, he conducted a brief assessment of the unfolding operations and moved the position of the IC forward of the original command location, in the parking lot at the front of the building. Also recognizing the magnitude of the incident's casualties, the Chief immediately requested any available rescue-ambulance to respond. He specifically requested 15 additional units beyond those units previously deployed and those currently responding to the initial IC's request for "any available unit." Although the Chief did not formally announce his assumption of command or the new IC location his presence became obvious to the dispatchers and the personnel already engaged in rescue and suppression operations at the scene.

The IC (WWFD Chief) was joined in short order by the department chiefs from the Warwick FD and the Cranston FD at the newly positioned IC area at the front of the building. From this vantage point the command group could better observe and direct the rescue efforts at the entranceway and the fire attack. The chiefs from the mutual aid departments functioned as a command group to support the IC and to direct the assignment of their respective department assets.

Upon the arrival of the Chief from the Coventry FD the IC requested that the Coventry Chief assess and report on the unfolding EMS activities at and near the Cowesett Inn. In this role the Coventry Chief became the EMS liaison to the IC for the remainder of those operations.

Although the IC group did not adopt a traditional IC structure or paradigm, it functioned in a fashion that was, in effect, driven by the unprecedented magnitude of the mutual aid response and the huge coordination challenge presented by the high volume of communications necessary for the multiple responding units. As discussed in the DHS/ODP After-action Report (Annex A, p. A-21) [1], the respective chiefs relayed commands to their dispatchers and arriving units on their respective radio channels, as no common channel was available to effectively handle the volume of radio traffic emanating from the scene.

The resulting fragmentation of vital communications posed substantial challenges to area dispatchers who were trying to satisfy the numerous "any available unit" requests from their respective assets already at the scene. The generalized requests for "any available units" initiated to various dispatch centers by the mutual aid companies produced confusion regarding which units had already responded and which were still available. Since units were being self-deployed, dispatchers had to poll departments to see if they could respond rather than relying on the call-ups driven by the mutual aid system's resource cascade. The communications difficulties also led to Basic Life Support (BLS) patients being transported by Advanced Life Support (ALS) units on a first-come-first-served basis, which is a less effective use of resources. From a command/operations perspective the incident could have been better managed. In spite of this situation, all the critical requirements were achieved with the fire being extinguished in little over an hour and the evacuation of the last casualty in less than two hours from the initiation of the incident.

At approximately 4 am the Command group met at the Cowesett Inn to plan the demobilization of the incident. This effort prioritized the actions necessary to close out the on-scene operations, identified the additional equipment and various staff resources needed to accomplish a wide range of related tasks both at the scene and elsewhere, and insured the necessary notification and coordination with other participating agency personnel. Principal among these activities was the effort to structure the process and staff the victim recovery activities that would conclude the fire ground operations.

The absence of a centralized communications capability and record of the IC operations during this incident precludes a meaningful objective review of those activities. However, the assets needed, both personnel and apparatus, did materialize in a timely fashion. Given the time needed to collect, triage and care for the casualties, these services were capably provided by the initial mutual aid responders.

3.3.3 Fire Attack

The first fire apparatus, WWFD Engine 4 and Tower/Ladder 1, were located about 500 m (0.3 mile) west of the nightclub on Cowesett Avenue and arrived on scene within three minutes of dispatch and approximately 5 ½ minutes into the fire. On arrival Engine 4 reported “heavy fire” conditions at the scene, as flames were visible at multiple locations and heavy volumes of thick black smoke were emanating from various points of the structure. Engine 4 was able to pull into the parking lot and positioned almost directly in front (the north side) of the building, a few meters west of the main entrance, while Tower/Ladder 1 passed the parking lot and turned south on Kulas Road to position on the upgrade, east side of the structure. The location of WWFD Tower/Ladder 1 was tactically compromised by pole mounted power lines extending parallel along Kulas Road between the blazing structure and the apparatus.

Within moments of their arrival, Engine 4’s crew with assistance of Tower/Ladder 1’s personnel and bystanders, had extended a 1 ¾” hand line from the unit and advanced to the main entrance of the club. The fire conditions were deteriorating rapidly. Significant volumes of fire were enveloping the building and heavy smoke was billowing from the main entrance, secondary exits, and knocked out windows in the sunroom and main bar area on either side of the main entrance. At the same time, occupants were trying to escape through that main entrance, with tiers of entrapped victims stacked on top of one another in the doorway. As the crew approached, they utilized a 1 ¾” hand line, served by the unit’s on board water supply, to retard the fire at this principal egress point. This was to provide the entrapped victims a protective water curtain while units assisted individuals. (It has not been determined how many people may have been rescued during this phase, nor when they may have been removed from the front doorway; however, it was reported [2], without confirmation from the fire department, that one person was pulled from near the bottom of the pile as much as an hour after the fire department arrived on the scene.)

Upon its arrival WWFD Engine 2 laid-in, providing two 3” water supply lines from the hydrant across the street at the corner of Cowesett Avenue and Coit Avenue adjacent to the southeast corner of the Cowesett Inn, to support Engine 4’s operations, which had exhausted its on board water supply. Engine 2 was able to enter the parking lot positioning a short distance behind Engine 4. The crew established a supply line to the first arriving unit (WWFD Engine 4) enabling that unit to recharge its previously deployed hand lines once the two supply lines from the hydrant were charged. WWFD personnel were also able to advance additional hand lines and initiate a master stream operation at the front of the structure utilizing Engine 4’s deck gun.

When the WWFD Special Hazards unit arrived it was positioned at the northeast corner of the property facing south on Kulas Road directly behind WWFD Tower/Ladder 1 and raised the unit’s light mast to illuminate the scene. WWFD Engines 3 and 1 were not employed in the suppression operations but were positioned nearby on Cowesett Avenue across the street from the Inn.

WFD Engine 1 laid-in, providing approximately 90 m (300 ft) of 4” supply line from a hydrant on the east side of Kulas Road above the fire ground. They positioned the apparatus facing down-grade (north) in the south bound lane of Kulas Road just above WWFD Tower/Ladder 1 and Special Hazards unit at the east side of the lot. The crew initiated a master stream operation with their deck gun from that position to attack the fire to the interior of the building near the main entrance area.

WFD Ladder 1 was the last apparatus to be engaged in the suppression effort. It backed into the parking lot in front of the structure just to the west of the WWFD initial assignments (Engines 4 and 2). Although equipped with a 4” supply line, Ladder 1 did not have an on board pump capability and attempts to begin master stream operations were initially ineffective due to low water pressure. This operational challenge was overcome by re-routing the supply line to one of the WWFD's engines which then provided the necessary water pressure to establish and maintain an effective master stream

Figure 3-1 shows the layout of the fire ground during the fire attack and suppression activities. The initial attack was mounted by WWFD's first unit, Engine 4, approximately 6 ½ minutes into the fire with the advance of a 1 ¾" line to the main entrance of the structure and the primary victim cache, and continued until the unit's on board water supply was exhausted. While the two, 3" supply lines to the front of the structure were being laid and charged, rescue efforts continued along the building's north face, through both the broken windows and exits. However, these efforts were pursued without the benefit of protective hose lines and were substantially hampered by the rapid fire propagation, radiant heat and heavy volumes of smoke discharge from the structure.

Once the two 3" supply lines to Engine 4 were established approximately 10 minutes after their arrival, an apparatus mounted deck gun/master stream operation was initiated from WWFD's Engine 2 and additional hand lines deployed at the front and to the west side of the structure.

The frontal attack was almost immediately augmented with the arrival of WFD's Engine 1, which had laid its own supply line. Once positioned, Engine 1 began a master stream operation from its deck gun on the east side of the structure and then extended hand lines down the grade to the east side front of the building. These attack lines were most effectively applied to suppress the multiple vehicle fires adjacent to the northeast corner of the structure.

Less than 25 minutes into the incident, the structure was showing fire through the roof in the area of the main bar, which appeared to have substantially self-ventilated or partially collapsed. Shortly thereafter WFD's Ladder 1 was backed into the west side of the parking lot. The unit was provided a 4" supply line from a hydrant located at 198 Narragansett Avenue by Cranston FD's Engine 4. However, due to the extended length of the supply line and the hydrant pressure, this source was not sufficient to produce an effective flow. These efforts were suspended and the supply line was then repositioned to allow WWFD's Engine 4 to initiate pumping operations in support of WFD Ladder 1's elevated master stream operations.

The major section of the main roof collapsed a little more than 45 minutes in to the fire, prompting the IC to initiate an accountability check of the suppression crews. The roll call produced no indication of missing personnel and suppression operations continued.

The sunroom area at the front of the club included a window-wall approximately 9 m (29 ft) long just to the west of the main entrance facing the parking lot. The roofing and structural support for this element of the building's façade collapsed a little more than an hour into the fire, which prompted the IC to initiate another personnel accountability check.

After this second major element of the structure failed, little remained of the building except sections of the exterior walls at the front (primarily in the area of the main entrance which had been the focus of substantial suppression effort). The west and rear walls were heavily damaged, and elements of the nightclub's storage area, food preparation and office areas to the southeast corner of the structure were

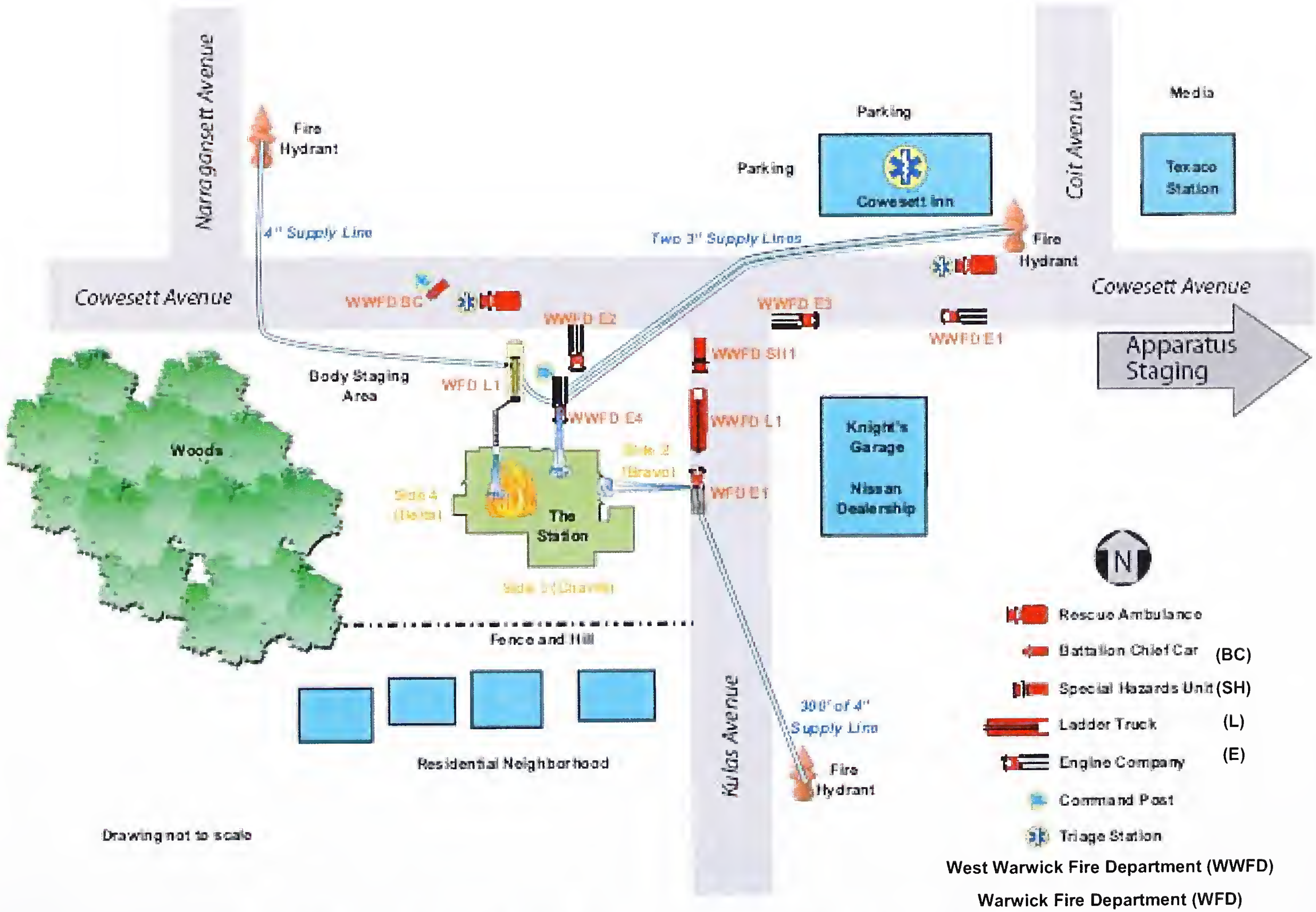


Figure 3-1. Schematic of primary apparatus deployment

effectively destroyed although some components of interior compartment separations still remained standing at that end of the structure.

The fire attack continued with the master stream operations knocking down the residual pockets of major fire in the remaining structure while hand lines were used to address areas that were difficult for the master streams to reach. With the structure now heavily damaged (essentially a total loss) and the fire effectively suppressed, the interior of the structure became accessible for the first time in the operation.

No interior fire suppression attack had been possible at the outset of operations due to the untenable conditions and none was initiated until this final stage of the incident. Once able to get inside, suppression personnel checked the area for possible survivors, extinguished the last of the residual fires and wet down hot spots.

At this point the fire suppression and rescue efforts were essentially terminated and operations at the building transitioned into a victim recovery and identification phase that continued until the last of the 96 fatality remains were removed from the structure and transported to the State Medical Examiner's facilities. The final body recovery efforts were completed by late afternoon on Friday, Feb. 21.

No firefighter fatalities occurred during the extinguishment of this fire. Five firefighters were injured: one with a fractured ankle, and four with smoke inhalation, cuts and bruises.

3.3.4 The Water Supply

The incident area had immediate access to a municipal hydrant system to support fire ground operations. Although positioned short distances away (see Figure 3-1), the incident site had expedient access to three hydrants, all of which were utilized.

The first hydrant was located a few dozen meters northeast of the incident site on Cowesett Avenue near the corner of Coit Avenue and in front of the east side of the Cowesett Inn. That hydrant supported two, 3" supply lines to WWFD's Engine 4 while that team attacked the fire from the front of the building in the parking lot a few meters west of the structure's main entrance.

The two other hydrants both provided 4" supply lines to the units they supported respectively. One, at the southeast corner of the site on the opposite side of the Kulas Road incline at about the crest of the grade, provided WFD Engine 1 supply for its master stream and hand line operations. The other was on the east side of Narragansett Avenue to the north and upgrade of the intersection with Cowesett Avenue some distance from the northwest corner of the site. That hydrant supported the master stream operations of WFD Ladder 1 positioned to the west of the two WWFD engines in the parking lot.

The hydrants' proximity to the incident site's northwest, northeast and southeast corners allowed apparatus to lay-in to the fire ground from all three directions. When supported by the pumping operations of the various engine assignments, the water system's pressure and flow was sufficient to sustain the multiple master streams and the numerous hand lines utilized to extinguish the structure and the various vehicle fires.

3.4 MUTUAL AID

Most emergency services providers, and fire departments in particular, develop and operate with the assistance of mutual aid compacts or agreements with neighboring departments to augment their capability to respond to incidents when their assets are committed or otherwise unable to satisfy the community's emergency response requirements. Such compacts are typically designed to rapidly augment the department's staffing or equipment during an emergency when needs exceed their capabilities.

Mutual aid agreements vary widely in scope and content. Some agreements are designed to provide assets as specifically requested while others provide for the routine deployment of another department's specialized assets such as hazardous materials units, advanced life support (ALS), bomb disposal units, water supply, aerial apparatus or other specialty units when an alarm is initially transmitted. In the latter situation, the mutual aid assets are in effect shared by signatories to the agreements, and are utilized independent of actual jurisdictional or organizational ownership. All agreements benefit the member agencies by providing emergency surge capabilities (staffing, equipment, etc.) from other agencies that would be prohibitively expensive to operate and maintain in each jurisdiction.

While mutual aid arrangements have an obvious practical value, they also have limiting characteristics. Assets which are infrequently used by a department requesting the mutual aid from another may be in use by the department possessing the asset on a regular basis, and therefore unavailable when needed by others. In a wide scope event, there may be more departments in need of specific assets than are available within the member compact. Jurisdictional differences in equipment, tactics and communications systems may also present interoperability challenges to the effective use of mutual aid assets, as was the situation at this incident. Some agreements are relatively small in scope, limited for example, to nearby departments. Others may apply to all the departments in a county -- or as in the case with Rhode Island, cover a multi-state region.

Most agreements center on strategic principles that assure that the specific mutual aid requested will normally come from the nearest jurisdiction with the assets available. Depending on the amount of aid needed (the number, magnitude and/or the diversity of the assets required) the aid is typically moved toward the incident in a fashion that first thins the assets of the area departments nearest the incident and then progressively back-fills or covers those departments providing the initial aid with units from departments further away, providing for successive concentric waves of resource augmentation.

Mutual aid was provided to the West Warwick FD and the other fire departments throughout the state in conjunction with the Southern New England Fire Emergency Assistance Plan (SNEFEAP). The plan was designed to augment each department's staffing and equipment capabilities through an anticipated incident severity progression of up to seven alarms beyond the initial assignments. This is designed to be achieved by providing both assets to the scene and back-fill /coverage for the departments providing emergency fire-EMS assistance to others.

The mutual aid support provided to the respective major operational activities at The Station nightclub fire is summarized briefly in the following sections. These sections provide a general overview of the incident's magnitude and complexity and are not intended to identify or chronicle all of the individual contributions that were made.

3.4.1 The Fire Suppression Operations

The Station nightclub fire required only a relatively modest augmentation of the West Warwick Fire Department's available suppression equipment resources to contain and extinguish. Beyond the WWFD's response, this fire required only two additional apparatus from the Warwick Fire Department to augment the direct fire suppression operations at the scene (WFD Engine 1 and Ladder truck 1). The additional units from WFD that were utilized (one engine and one ladder truck) did not exceed WWFD's equipment complement capabilities; WWFD's own similar assets were deployed to the scene but were not utilized in the suppression effort.

The initial WFD task force group dispatched had been supplemented with an additional engine company, rescue-ambulance and special hazards unit at the election of the responding department. Beyond WFD's substantial response of equipment and personnel, Cranston FD and Coventry FD also provided numerous units and substantial staffing (including approximately 100 firefighters and command officers) to support on-scene operations and to cover WWFD's stations and service area during the incident.

During this stage of operations significant numbers of the officers and staff on the mutual aid units were also deployed to the scene but not involved in direct suppression support. These personnel were primarily employed to provide the critical on-site cadre necessary to effectively initiate and maintain the coordinated casualty collection, triage, pre-hospital victim care and survivor support operations.

3.4.2 The Mass Casualty Incident Operations

In stark contrast to the suppression operation's minimal equipment resource demand on the mutual aid system, the magnitude of the resulting EMS-fire casualty management operation drew upon substantial personnel and equipment resources from throughout in the state. The incident management also benefited from the mutual aid plan's everyday use of fill-in/coverage assignments and direct incident support by and for the EMS units of various departments. This is done in essentially the same fashion as the deployment of the suppression units and other specialized assets.

Initially, the incident site was strewn with numerous victims: many with obvious injuries were sitting on and in the surrounding cars, and some were on guard rails and snow banks, while others stood and milled about or lay on the ground. The immediate availability of shelter from the winter cold was afforded by the proximity of the Cowesett Inn just a few dozen meters across and down the street. Many of the uninjured survivors and walking-wounded migrated there spontaneously to flee the scene and seek/secure assistance. Given its on duty support staff, size, diverse facilities, configuration and cross-street location, the Inn readily became the primary triage and survivor assistance center at the scene.

As this incident's high casualty count became increasingly apparent, the mass casualty incident (MCI) operation began to unfold with dispatchers receiving multiple requests from the scene for "any available rescue" to respond. The casualty collection and care began with the first arriving rescue-ambulance units being besieged by those in need of care or requesting medical assistance for others. A number of these first-in units initially effectively served as field triage and care stations, transferring casualties to other units in and beyond the immediate fire ground congestion on Cowesett Avenue between The Station and the Cowesett Inn.

Initial command of the EMS operations evolved quickly as personnel and equipment became available. As EMS units and company officers arrived they began organizing the chaotic scene. The triage and care efforts that were initially attended by the first arriving EMS providers wherever the units were positioned on-scene began to center on the Inn and its immediate area. For much of the incident's duration, at least three distinct triage areas were operating simultaneously: one near The Station on Cowesett initiated by an officer and crew from Hopkins Hill FD from Coventry, one on the outside of the Inn at the front door established by a Cranston FD officer and crew, and another inside the Inn under the direction of a WFD officer.

As additional chief officers and crews from Warwick, Cranston and Coventry fire departments began to arrive, the management of the EMS operations evolved significantly. The needs and activities of the respective triage sections were afforded greater command cognizance through the use of an EMS liaison to the IC, a role filled by the Coventry FD Chief.

A Cranston FD deputy chief assumed the role of transportation coordinator and began staging units away from the immediate area of the Inn at a parking lot of a nearby restaurant. This action was initiated to reduce the congestion at the site and to better coordinate the loading and transfer of victims to regional hospitals. The effective coordination of both incoming unit staging and on-scene activities was significantly compromised due to non-interoperable radio equipment between command elements and responding units, as mentioned earlier [1]. The communications challenges also materially hampered direct coordination with regional hospitals. As a result, the transportation officer was, more often than not, unable to communicate directly with the hospitals to ascertain their status and capabilities -- and therefore unable to direct units to the most appropriate medical facilities.

Less than two hours after the initial alarm, the MCI management effort had effectively organized multiple field triage and care locations as well as the in-door operations at the Cowesett Inn and the last of the casualties were transported. The wide scale ground transportation EMS evacuation of 186 casualties had been accomplished using nearly 40 fire department-based emergency medical services units, 20 private sector ambulances from a variety of commercial providers, and buses used to shelter and transport those with only minor injuries. More than 200 people may have been injured in the incident, most of whom were transported to medical facilities throughout the state by EMS providers and private vehicles.

3.4.3 The Law Enforcement Scene Security & Traffic Management Operations

Beyond their immediate response and assistance at the scene, the West Warwick Police Department (WWPD), the Warwick Police Department, the Coventry Police Department and other local agencies including the Rhode Island State Police personnel played key roles in managing and supporting the incident security, access and traffic management efforts necessary to effectively access, stage, deploy and permit egress by the significant numbers of rescue/ambulances (about 60 units) and all the other fire apparatus and emergency services units that responded. Their collective efforts assured the volume of EMS units had effective access to the scene and its adjacent staging areas. They also assured that the traffic management effort provided for the safe exit of emergency vehicles once they were loaded with victims and enroute to area hospitals.

3.4.4 The Mass Fatality Recovery and Victim Identification Operations

The impact and consequence of such a significant number of fire casualties (both injured and killed) extended beyond the fire service organizations involved to also challenge the area's local law enforcement agencies, the State Police, the State Fire Marshal's Office, the State Medical Examiner's Office and other regulatory authorities. There were extraordinary informational, tactical and technical challenges requiring the coordination and contribution of virtually every agency involved. These included identifying uninjured survivors, those who had been EMS triaged and transported and to where, those who might still be missing, and those who were among the dead

These operations generally required two concurrent efforts; one to physically recover and identify the remains on site, and the other -- accomplished off-site at facilities conducive to conducting confidential interviews -- was to collect victim identification profiles from friends and relatives of those still unaccounted for.

The victim profiles included physical descriptions of the person such as sex, height, weight, hair and eye color etc., and any available information about what they had been wearing when last seen (such as clothing items and jewelry). This information was used to assist with subsequent identification efforts, including forensic examinations by the State Medical Examiner.

Both of these activities were accomplished with a regard for the privacy and dignity of the victims and their survivors. During the recovery of the physical remains, efforts were made to avoid additional trauma to the deceased and to collect personal effects that might aid in the victim's identification. These actions were accomplished while shielding the area from the view of bystanders. The collection of victim identification profiles was also handled discreetly, to the extent possible given the circumstances. Interviews were conducted in private and the information collected was treated as confidential.

The victim identification processes, both investigatory and forensic, continued through the weekend and until the last fatality was positively identified on Tuesday evening, Feb. 25, 2003. Completion of the victim recovery and identification operation effectively brought a close to the response efforts, with the exception of the on-going fire investigation.

3.4.5 Post-fire Investigation Operations

Major fires, especially those producing a significant number of injuries and/or fatalities, often involve concurrent investigations by various local and state law enforcement agencies and other regulatory authorities, as occurred in this case. By law, in most jurisdictions, fire losses in general -- and particularly those resulting in serious injuries and/or deaths -- are investigated to determine at the very least, the location of the origin of each fire and its cause (natural, accidental, criminal, etc.). Depending on a variety of other factors, they also may be the subject of other inquiries, reviews, or hearings by a range of regulatory/technical authorities. The sooner that relevant information regarding witnesses/persons involved and specific facts can be collected, the more effective the initial incident information management effort and subsequent investigations are likely to be. Law enforcement agencies typically play the key role in this aspect of overall incident management security and in supporting the public's information needs.

The RI State Fire Marshal was on the scene of this multiple fatality fire within an hour of the IC's request for his assistance. Even though the origin and cause of this fire was known (actually captured on video-tape) the State Fire Marshal's Office conducted an investigation to document the loss, and to determine the parties responsible for the catastrophic loss of life and injury. These efforts were conducted in conjunction with local authorities, primarily WWPD and WPD although other authorities (including the RI State Police) participated substantially.

Owing to the magnitude of the incident, the State Attorney General's Office oversaw and directed various aspects of the inquiry. The Warwick PD also played a key role by establishing and staffing an office dedicated to assembling investigative reports and related information.

Post-incident investigation is part of the emergency response function. The subsequent investigative efforts are normally necessary to determine the origin and cause of the fire and to ascertain if the circumstances of the incident warrant the filing of criminal charges, the issuance of notice of regulatory violations, and legal actions (such as condemnation orders) to protect the public safety and to enforce laws and regulations. This typically involves local and state agencies working in collaboration with each other, as was the case in the investigation of The Station nightclub fire.

A number of Federal agencies responded after the fact to The Station nightclub fire. At the request of the State's Attorney General, the Bureau of Alcohol, Tobacco, and Firearms (ATF) provided direct technical assistance to the AG's investigation. The U.S. Occupational Safety and Health Administration conducted its own investigation due to its jurisdiction over worker safety and health [3]. The Office of Domestic Preparedness in the Department of Homeland Security was interested in how the community responded to this mass casualty event [1]. The National Institute of Occupational Safety and Health was not involved because there were no firefighter deaths.

3.5 OBSERVATIONS

The use of standard Incident Command structures and practices facilitated the concurrent fire suppression and mass casualty incident management operations. The early involvement of the EMS teams within the overall IC effort allowed the chief officers directing the EMS operation to focus on their casualty care and management challenges and to enable the fire suppression command forces to direct victim rescue and extinguishment efforts.

As is common in wide-area mutual aid responses, various responding agencies/units were unable to establish or maintain effective voice communications with IC. The Incident Commander's ability to effectively apply the available resources is critically dependent upon wireless voice communications with the responding units. The need for effective communication systems and equipment (e.g., interoperable with multiple common channels and the ability to handle a large amount of traffic) at large-scale events cannot be overstated.

The arrival time of WWFD's first due units (Engine 4 & Ladder 1) of the initial response assignment was within the four minute objective specified in NFPA Standard 1710 [5]. The model standard further suggests that the remainder of the first full alarm assignment should arrive within eight minutes. The achievement of the latter objective could not be confirmed from the information available to this investigation.

WWFD's fire apparatus staffing of the first full alarm assignment was half of the firefighter staffing recommended by NFPA Standard 1710, which suggests a minimum of four personnel on both engine and truck companies. Had WWFD apparatus staffing been consistent with the model standard at least ten additional firefighters would have been available to more expeditiously establish water supply to the suppression units, establish master stream operations from the first arriving ladder/truck company, and support victim rescue and casualty care operations.

3.6 REFERENCES FOR CHAPTER 3

[1] "Rhode Island -- The Station Club Fire After-Action Report," Office of Domestic Preparedness, Department of Homeland Security, October 2004.

[2] Crowley, C.F., The Station Nightclub Disaster - A survivor's story: Saved by a pileup; *Providence Journal*. Providence, R.I.: Mar 10, 2003. pg. A.01

[3] Occupational Safety and Health Administration Citation and Notification of Penalty, dated August 19, 2003 based on inspection # 304991086.

[4] *NFPA 1500, Standard on Fire Department Occupational Safety and Health Program,* National Fire Protection Association, Quincy, MA, 2002.

[5] *NFPA 1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, National Fire Protection Association, Quincy, MA, 2001.

Chapter 4 MATERIALS TESTING AND SUPPORTING EXPERIMENTS

4.1 INTRODUCTION

Combustible interior finishes, scenery, or decorations have played an unfortunate but significant role in fires that have occurred in places of assembly over the last 100 years. Often resulting in hundreds of fatalities, examples of these fires include the Iroquois Theatre (602 died, Chicago, IL, 1903), the Rhythm Club (207 fatalities, Natchez MS, 1940), and the Cocoanut Grove (492 died, Boston, MA, 1942) [1]. In each of these incidents, fire-related material properties, including ignitability, heat release rate, and rapid flame spread contributed significantly to fire growth that resulted in a tragic loss of life. In an effort to minimize the repetition of this type of fire, standard test methods for assessing the rate of flame spread, heat release rate, and ignitibility have been developed.

Standard tests can generate critical fire-related material property data that can be a valuable resource for fire protection engineers, code officials, and code enforcement personnel. In the U.S., flammability and fire spread properties of materials are often evaluated using UL 94 –*Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances* [2] and ASTM E-84 – *Standard Test Method for Surface Burning Characteristics of Building Materials* [3]. The heat release rate properties of materials can be assessed using ASTM E-1354 – *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter* [4]. Both the spontaneous ignition temperature (SIT) and flash ignition temperature (FIT) for plastics can be determined using ASTM D 1929 - *Standard Test Method for Determining Ignition Temperatures of Plastics* [5].

Standard tests have a limited ability to predict performance in real fire scenarios and no single standard tests should be used as the sole criterion to assess the total fire hazard. Under carefully controlled laboratory conditions, standard tests do allow comparisons such as, Will material "A" ignite more quickly than material "B"? or, Will material "A" contribute to more rapid flame spread than material "B"? Standard tests do allow the performance of different materials to be rated or compared, but the relationship between standard test performance and actual fire performance can be much more complicated. For example, while a standard test may provide a comparative measure of flame spread, it is difficult for the same standard test to predict the overall fire hazard because the standard test does not incorporate or measure important fire behavior properties including melting, ease of ignition, heat release rate, and products of combustion. Additional properties need to be included for a complete fire-hazard or fire-risk assessment of the materials or assemblies under fire actual conditions.

4.1.1 Standard Tests for Flammability and Fire Spread – UL 94 and E-84

UL 94 includes six different tests to compare the relative burning characteristics of different materials, or assessing any change in the burning characteristics prior to, or during, use. These tests include (1) Horizontal Burning Test –HB, (2) 20 mm Vertical Burning Test – V-0, V-1, or V-2, (3) 125 mm Vertical Burning Test – 5VA or 5VB, (4) Radiant Panel Flames Spread Test, (5) Thin Material Vertical Burning Test – VTM-0, VTM-1, or VTM-2, and (6) Horizontal Burning Foamed Material Test – HBF, HF-1, or HF-2. These test methods typically involve exposing small samples (less than 500 mm x 150 mm) to a flame or radiant panel for a specified period of time, then removing the heat source, and observing whether the sample continues to flame or glow. A burning rate with units of mm/min can be calculated from the time required by the flame to burn a specific distance. Each test method includes criteria for classifying or rating the performance of each material.

For example, an HF-1 rating could be achieved by a 150 mm x 40 mm sample of polyurethane foam if after exposure to a small flame source for 60 s (a) no more than four of five samples continued to flame for more than 2 s after the flame was removed and no more than one sample continued to flame for more than 10 s, (b) the foam did not continue to glow for more than 30 s after the flame was removed, and (c) the cotton indicator that was positioned below the test sample was not ignited by flaming particles or drops.

While UL 94 does utilize both horizontal and vertical sample orientations, the impact of corner geometry, ventilation effects, and prolonged exposure to high thermal flux are not included in the test conditions. Ignition temperature, mass loss rate, and heat release rate data are also not recorded.

The E-84 test method was developed with the anticipation that a large test would provide a more realistic environment for surface burning behavior of building materials. E-84 involves a much larger test specimen than UL 94, up to 0.610 m x 7.3 m, which is mounted on the ceiling of a 0.45 m wide x 0.32 m high x 7.6 m long "tunnel" apparatus. A natural gas fired burner, 88 kW, is positioned at one end of the test sample and the flames from the burner impinge on an approximately 3.25 m^2 area of the sample. The specimen is exposed to the flames and hot gases of the burner for a 10 minute test period. The hot gases and combustion products flow along the unburned portion of the sample and are exhausted at the other end of the apparatus. The extension of the visible flames is recorded as a function of time and is used to determine a flame spread index, which is based upon the extent of burning that occurs with a red oak plank. Red oak is assigned a value of 100, and the flame spread index of other materials are normalized accordingly. For example, Douglas fir plywood, fire retardant treated Douglas fire plywood, and type X gypsum board are 91, 17, and 9, respectively.

Loose-fill insulation, plastics, and wall coverings can be tested by using different sample mountings and support screens. The large specimen does allow for the development of physical and structural failure modes, such as cracking and buckling, which may not occur on smaller specimens. The openness of the tunnel design does allow for testing of composite assemblies, panels, and boards. Although plastics can be tested in the apparatus, thermoplastic materials can drip or fall to the floor of the apparatus and result in low values for flame spread index that do not relate to their true fire hazard potential. The test configuration is limited to a horizontal ceiling orientation. Vertical or corner configurations, different flame exposure periods, and different heat fluxes are not included in the test method.

4.1.2 Standard Tests for Heat Release Rate Properties of Materials – E-1354

The E-1354 test method utilizes a cone calorimeter to collect data on heat release rate, mass loss rate, optical density of smoke, and gas concentrations in combustion products. The cone calorimeter exposes relatively small samples (10 cm x 10 cm) to a uniform thermal flux. The thermal flux can be varied from 5 kW/m^2 to 100 kW/m^2 in either a horizontal or vertical sample orientation. An electric spark is used to ignite the combustible gases near the surface of the sample. The sample is positioned on a load cell to track mass loss rate throughout the burn. Additional instruments allow the optical density of the smoke and gas concentrations to be monitored continuously. While the cone calorimeter can provide heat release rate as a function of thermal flux, the impact of ventilation, corner geometries, and composite assemblies are difficult to characterize.

4.1.3 Standard Test for Determining Ignition Temperature of Plastics – D 1929

The D-1929 test method utilizes a hot air furnace to determine the ignition temperatures for small samples of plastic materials. A specimen of a material, in pellet, powder, sheet, or foam form, and up to 3 g in mass or 20 mm x 20 mm x 50 mm in size is inserted into a pre-heated tube furnace. Air flows from the bottom up and out through the top of the vertically oriented tube at a velocity of 25 mm/s. After insertion, the sample remains inside the furnace for up to 10 minutes. At the end of 10 minutes, depending on whether ignition has or has not occurred, the temperature of the furnace is lowered or raised and repeated at the new temperature with a new specimen. The lowest air temperature at which ignition occurred is recorded as the ignition temperature. The Flash Ignition Temperature determination uses a pilot flame at the top of the furnace while the Spontaneous Ignition Temperature determination does not utilize a pilot flame. This test method is limited to a temperature of 400 °C, which is much lower than typical gas temperatures in the upper layer of a room fire (600 °C). The exposure time is limited to 10 minutes and the air flow is limited to a single velocity.

4.2 MATERIAL PROPERTIES FOR FIRE MODELS

Computational fire models incorporate specific material properties in order to calculate fire development and growth for a given fire incident. These material properties, such as thermal conductivity, heat capacity, density, and heat of combustion are utilized by the model to predict if and when a component will ignite and how much energy or heat will be released as the component burns. The ignition and subsequent release of energy causes the fire to grow and spread throughout a structure.

For common building materials including gypsum or pine paneling, these materials can be found in various handbooks [6,7,8] or in the combustion/fire literature [9,10,11] (Table 4-1). For less common building materials, such as flexible polyurethane foam, one can estimate a set of thermal properties from similar materials or one can characterize the properties by conducting tests on representative samples of the material. Since the quality of the model predictions is directly related to how accurately the material properties have been characterized, testing representative material samples provides more accurate properties. The properties in Table 4-1 were either measured in this investigation or taken from the literature.

The type and composition of the materials that were identified as being present inside the nightclub were characterized generically as flexible polyurethane foam, ceiling tiles, wood paneling, carpet, and an industrial pyrotechnic device. This materials testing conducted by NIST and described in this chapter did not include any materials actually recovered from the nightclub. NIST was not able to determine whether the foam in the nightclub was (a) fire retardant, (b) non-fire retardant, or (c) a combination of fire retardant and non-fire retardant foams.

Four test series were conducted and are described in this chapter or the appendices:

1) properties of polyurethane foam;

2) cone calorimeter heat release measurements of several polyurethane foams, plywood, carpet, and ceiling tile;

3) heat flux and temperature measurements of pyrotechnic devices impinging on surfaces; and

4) fire growth measurements in real-scale mockups of the platform, main floor, and alcove.

Data from each of these test series provided insight into the material properties, fire spread, heat flux, and fire growth of the different materials. The properties of the polyurethane foam that were measured included the density, ignition temperature, and heat of vaporization, all of which are required to accurately simulate fire spread. The cone calorimeter measurements established an appropriate range of heat release rates for those materials tested. (Note that both fire retardant and non-fire retardant foams ignited and burned when exposed to an external thermal flux in the cone calorimeter.) The experiments that involved discharging pyrotechnic devices against a foam-covered wall verified that non-fire retarded polyurethane foam could be ignited by a shower of sparks. (The fire retardant foam did not ignite in a similar test.) The real-scale mockups of the platform, main floor, and alcove provided data to evaluate the performance of the computer fire model. The information from all four test series led to an improved set of input data for the combustion model used in predicting the behavior of the fire (presented in Chapter 5), and allowed a better understanding of the parameters that affected the performance of the computer simulation of the entire nightclub.

Table 4.1 Material Properties of Common Building Materials and Selected Plastics [4,5,6]

Material	Thermal conductivity W/m-°C	Density kg/m^3	Heat capacity kJ/kg-°C	Heat of combustion MJ/kg	Piloted ignition heat flux limit, kW/m^2	Ignition temperature °C	Heat of vapor-ization kJ/kg	Flame spread index[a]
Douglas Fir	0.11	420	2.72					70-100
Fiber Insulating Board	0.048	240						
Fiber Board Medium Density		749		7 - 12 12 - 13		167		
Gypsum	0.48	1440	0.84	3				10-15
Hardboard					27			< 200
Pine white yellow	 0.112 0.147	 430 640	 2.8					 72-215 130-195
Plywood Panelling					29			< 200
Polystyrene Foam		32.9		17 - 21 36 - 41				
Polyurethane Foam[b]	0.034	22[b]	1.4	21 - 28[b]		370[b]	1000 - 1600[b]	

[a] based upon ASTM E84 [3]

[b] data from NIST investigation

4.3 POLYURETHANE FOAM

4.3.1 Background

Polyurethane refers to a large category of materials including surface coatings, elastomers, and foams, rigid or flexible, and thermoplastic or thermosetting [12,13]. While large quantities of polyurethanes are used to manufacture adhesives and protective coatings, the foam type of polyurethane is widely used in the production of upholstered furniture, bedding, sponges, toys, wearing apparel, and medical dressings. Rigid urethane foams are used for insulation in building constructions. Flexible polyurethane foams are used in packaging materials and acoustical insulation panels.

The urethane linkage, which all polyurethanes have in common, involves the reaction of an isocyanate group with a hydroxyl-containing group. Common hydroxyl-bearing groups include polyether alcohols, polyester alcohols, carboxylic acids, and amines. If the hydroxyl-bearing group incorporates multiple ether groups, then the resulting polyurethane will have a number of ether linkages and is typically referred to as a polyether polyurethane. If the hydroxyl-bearing group incorporates multiple ester groups, then the resulting polyurethane will have a number of ester linkages and is termed as a polyester polyurethane foam. A more detailed description of urethane formation chemistry is in Appendix H.

Both polyether and polyester formulations of polyurethane can be used as packaging materials. The polyurethane foam which is offered for packaging typically does not include any fire retardant additives or incorporate any fire retardant compounds into the urethane structure. As a packaging material, the polyurethane foam (ether and ester) is commercially available in a range of sizes including 1.22 m (4 ft) x 2.44 m (8 ft) sheets. The gray colored foam can be obtained in several geometries including solid blocks, uniform thickness sheets, and convoluted or "egg-crate" sheets.

4.3.2 Locations in Nightclub

In The Station nightclub, polyurethane foam had been installed on the rear wall, platform wall, and in the alcove as a sound attenuation material (Figure 4.1). The foam was installed on the vertical surface of the platform wall from the raised floor of the platform to the raised ceiling. The ceiling over the dance floor, raised platform, and area between the dance floor and the sun room had been raised to 3.8 m (above the dance floor). The raised ceiling was fabricated out of gypsum board and a light rack had been suspended approximately 12 cm below the gypsum board. The vertical surface on the east side (side nearest kitchen) was also faced with gypsum board. The vertical surface on the north side (side nearest the sun room) was covered with wood paneling. The rear wall featured a vertical section and a sloped section. The vertical wall formed the rear wall of the nightclub and was vertical for approximately the first 2.5 m above the dance floor. At 2.5 m above the dance floor, the "ceiling" sloped and followed the angle of the roof. The sloped ceiling extended from the rear wall over the raised dining area to the raised gypsum ceiling. Wood paneling covered the lower portion, 0.8 m high, of the rear wall. The upper portion of the vertical wall and the sloped ceiling were covered with foam.

A roll of gray convoluted foam was recovered by other investigators from the basement of the burned out nightclub one day after the fire and turned over to the West Warwick Police Department as evidence. That foam did not appear to have been painted or to have been mounted on any surface. Samples from this recovered foam were tested, upon the request of the state of Rhode Island, by the Bureau of Alcohol, Tobacco, and Firearms (ATF) in a cone calorimeter at the ATF Fire Laboratory in Maryland [24]. NIST had no access to the material examined by the ATF Fire Laboratory, and was not able to conduct a chemical analysis to determine if the foam contained fire retardants. (Note: The ignition behavior of the NIST non-fire retardant foam, described in Section 4.5.2, was consistent with the behavior exhibited by the foam on the walls of the nightclub as documented by the WPRI-TV video.)

Photographs of the nightclub interior do not clearly demonstrate whether staples, nails, organic adhesive, or some combination of all three were used to mount the foam on the wall. The foam appeared to have been mounted over the top of the previous wall material, which, depending on the location was either wood paneling or gypsum board. In some areas, portions of the alcove in particular, the foam was installed over rigid polystyrene foam thermal insulation laid between the wood studs. The foam was installed in either full 1.22 m x 2.44 m sheets or was trimmed to fit the geometry.

The photographs of the nightclub interior do clearly show gaps where two sheets of foam meet. Gaps between the foam and the wall can also be observed at various locations, typically at external corners of the alcove. While the gray color of the foam can be observed in some photos of various bands that had performed at The Station, later photos show a darker color, indicating that the foam may have been sprayed with a black paint. The surface of the foam also had a glittery appearance that may have been a result of the wet paint being dusted with glitter or sparkle dust. Some of the glitter would have become partially embedded in the wet paint and would have provided the more sparkling appearance that was observed in some of the video of the nightclub interior.

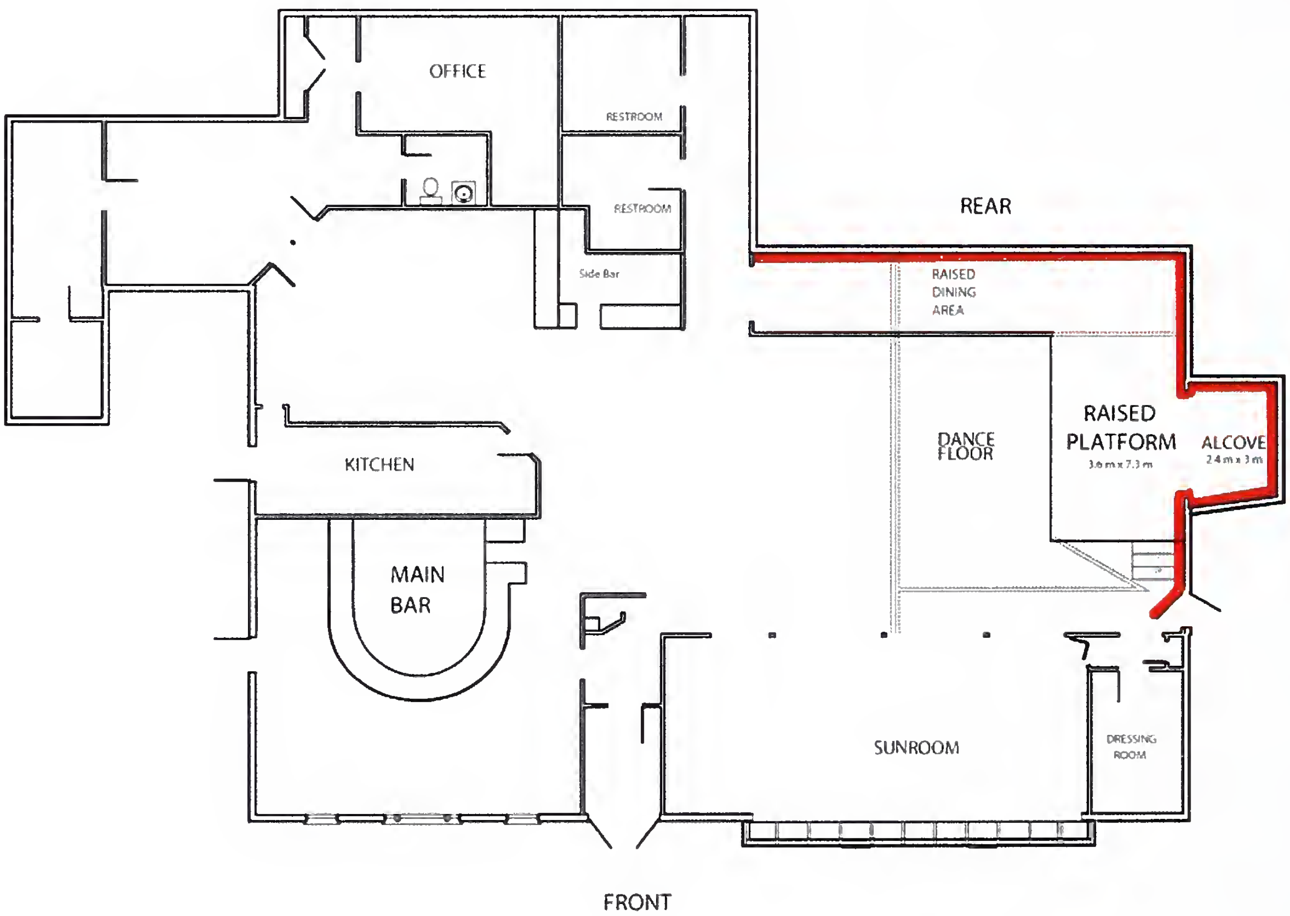


Figure 4-1. Portion of Nightclub with Polyurethane Foam Mounted on Wall (shaded red section).

4.3.3 NIST Foam Samples

After experiencing some difficulty, NIST was able to locate a source of non-fire retardant polyether polyurethane foam. Recent consolidations within the polyurethane foam manufacturing industry appear to have reduced the range of polyurethane foam products available to the public. The non-fire retardant polyurethane foam (ether) was purchased in two lots from a single distributor. Unfortunately, the distributor was not able to identify the manufacturer of the foam. Foam distributors typically purchase foam from a number of different sources based on price and availability. Foam arrives at distributor's warehouse in tractor-trailer sized lots. While bulk shipment may contain source information, stock is broken down into smaller units and source information is typically not maintained on each individual piece of foam. When foam arrives at a warehouse, new stock is intermingled with old stock.

The foam was purchased in two lots as 1.22 m x 2.44 m sheets (flat or in rolls). The rear surface of each sheet was flat. The front side was convoluted, with a series of peaks and depressions that resembled the surface of a continuous egg crate. Lot A was nominally 40 mm thick measured from the back to the peak; lot B was nominally 30 mm thick. Peak-to-peak spacing, and valley to sheet back dimensions are described in Appendix D.

NIST also purchased a number of 1.22 m (4 ft) x 2.44 m (8 ft) sheets of fire retardant polyester polyurethane foam from a commercial supplier in single lot. It is possible that the distributor had intermingled foam from different sources within a single purchase. Unfortunately, as with the purchase of the non-retardant polyether foam, the distributor was not able to identify the manufacturer of the foam for the same reasons. The fire retardant foam was measured at 0.03 m (1.5 in) and 0.010 m (0.4 in) at its thickest and thinnest dimensions, respectively (See Appendix D).

4.3.4 Heat of Vaporization and Ignition Temperature of Non-flame retarded Polyurethane Foam

Polyurethane foams can be produced in numerous ways with different properties, and because the behavior of the polyurethane foam in the fire was critical to the incident, measurements were made on the NIST-purchased materials to confirm literature values, fill gaps in the data, or narrow uncertainties.

The heat of vaporization is a measure of the amount of energy that is necessary to convert a material from a condensed to a vapor phase. Differential scanning calorimeter(DSC) and thermal gravimetric analysis (TGA) techniques were used by NIST to calculate the heat of vaporization for samples of non-fire retarded, flexible polyether polyurethane foam (lot B). These instruments yielded a range of heats of vaporization between 1000 and 1600 kJ/kg.

The ignition temperature was determined by Southwest Research Institute using ASTM D 1929. As described in Appendix D, the piloted ignition temperature of non-fire retarded flexible polyurethane foam (lot B) was found to be 370 °C +/- 5 °C.

4.3.5 Heat Release Rate of Polyurethane Foams

The cone calorimeter was used to determine the heat release rate of the NIST-purchased polyurethane foams. The test protocol detailed in ASTM E 1354 [14] was used for these experiments. Samples which measured 0.1 m x 0.1 m were cut from the larger sheets. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 °C) room for at least two weeks. Then each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. A test plus two replicates of each sample (total of three tests) were conducted with an external heat flux from 20 kW/m^2 to 70 kW/m^2. In all tests, the convoluted side was exposed to the thermal flux.

Data from these tests (23 in all) are tabulated in Table 4-2. (Additional data and plots of the heat release rate for each sample versus time are in Appendix D.) Focusing on the last column of the table, one can see that the non-flame retarded NIST samples have a peak heat release rate of around 600 kW/m^2 when exposed to an incident radiant flux of 35 kW/m^2. This compares to a peak heat release rate of 453 kW/m^2 for the flame retarded NIST sample at the same external flux, and less than 300 kW/m^2 for the sample tested by ATF. A plot of the peak heat release rate as a function of incident radiation is shown in Fig. 4-2a, comparing the NIST results to the ATF measurements. As expected, the peak heat release rate increases about linearly with imposed heat flux.

The time to sustained ignition is another measure of the fire hazard posed by a material. The times to ignition are shown in the third column in Table 4.2. Both lots A and B of the NIST non-fire retarded polyurethane foam needed 6 to 7 seconds for sustained ignition when exposed to 35 kW/m^2 of radiant heat. The fire retarded NIST sample resisted ignition for 13 seconds, and the ATF sample ignited in 3 seconds at a slightly higher irradiance level (40 kW/m^2). Figure 4-2b is a plot of the time to ignition (expressed as $1/t^{1/2}$) as a function of incident flux, comparing the NIST non-fire retarded polyurethane (lot B) to the cone calorimeter measurements made by ATF on their foam [24].

Table 4.2 Peak HRR, time to sustained Ignition, and time to Peak HRR

polyurethane foam sample ID	External Radiant Flux, kW/m^2	Time to Sustained Ignition, Average,* seconds	Time to Peak Heat Release, Average,* seconds	Peak Heat Release Rate, Average,* kW/m^2
NIST				
PUF-FR	35	13	36	453
PUF-NFR-A	35	7	30	605
PUF-NFR-B	20	14	45	450
	35	6	30	586
	40	4	29	820
	60	3	24	1154
	70	3	21	970
ATF [24]				
Polyether PUF	20	9	37	260
Polyether PUF	40	3	31	297
Polyether PUF	60	1	26	415

* Average values include all individual test runs at each specific external thermal flux. Data from individual test runs are provided in Appendix A.

The time to ignition in the cone calorimeter is governed by the ignition temperature, the imposed radiant flux, and the effective thermal inertia, $k\rho c$, of the material, where k is the thermal conductivity, ρ is the density, and c is the specific heat averaged over the heating period. As explained in Appendix E, the time to ignition is inversely related to the square of the imposed radiant flux and directly related to the effective thermal inertia. From the measured ignition temperature[#] and ignition delay at 35 kW/m^2, $k\rho c$ is estimated to be about 0.075 $(kW/m^2\text{-}^\circ C)^2\text{-s}$ for the NIST (lot B) non-fire retarded polyurethane foam.

[#] Measured here using ASTM D 1929. The ignition temperature can also be inferred from the limiting heat flux necessary for piloted ignition in the cone calorimeter.

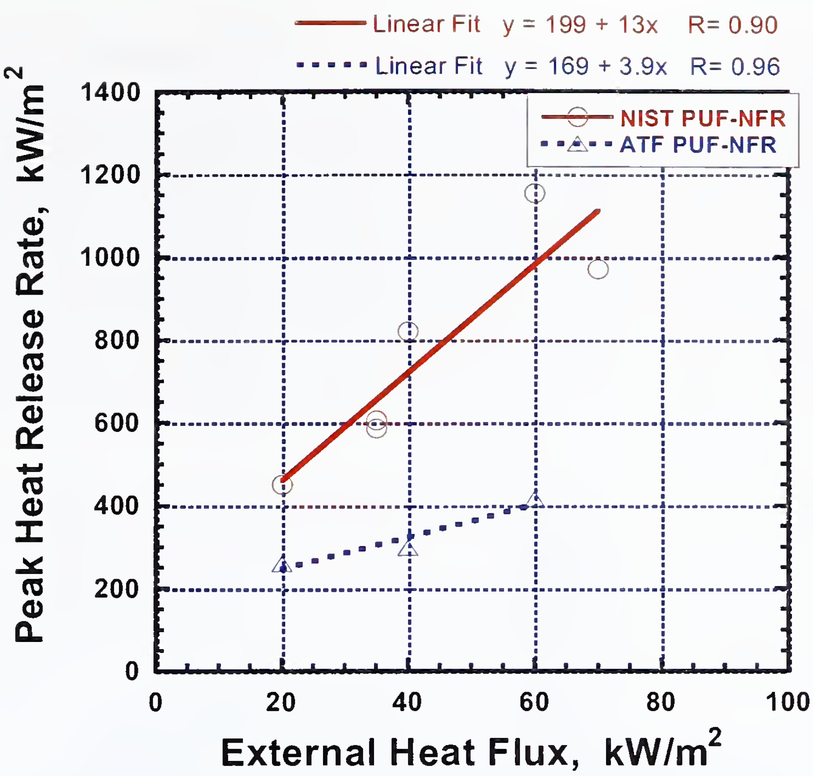


Figure 4-2a. Peak heat release rate versus external heat flux for different polyurethane foams tested at NIST and ATF.

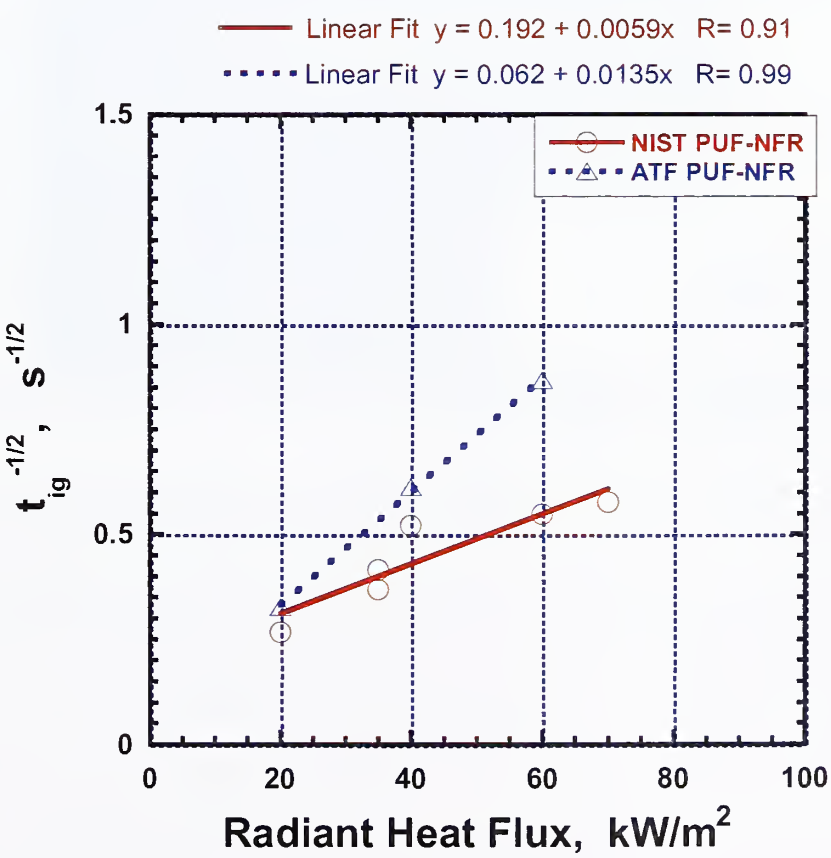


Figure 4-2b. Time to sustained ignition versus external heat flux for different polyurethane foams tested at NIST and ATF.

The precise reasons why the polyether foam tested by ATF differed from the behavior of the foams tested by NIST are not clear. (NIST did not have access to the foam from the fire scene tested by ATF.) However, the shorter time necessary for ignition of the ATF foam suggests that the effective value of kρc was less. It is possible that the behaviors were influenced by the different molecular structure, additives, or manufacturing processes. It is also not clear under what conditions the foam had been stored in the basement of the nightclub or whether it had always been stored in the basement, nor what impact aging or water from fire fighting operations may have had on the foam. Using the properties of either foam, the fire is predicted to spread rapidly, with the foam acting as an ignition source for the wood layer underneath. The contribution from the foam to the total heat release in the fire was much less than from the wood, once the wood was ignited by the burning foam.

4.4 CONE CALORIMETER MEASUREMENTS OF FINISH MATERIALS

Cone calorimeter experiments were conducted on four other common finish materials similar to those in the nightclub. Two external heat fluxes were examined to account for the changing conditions experienced by the materials in the actual fire. All of the cone calorimeter tests conducted on the materials representative of those in the nightclub (polyurethane foams, wood paneling, carpet flooring, and ceiling tiles) and the external fluxes that were imposed on the samples are summarized in Table 4.3. The complete data set (time to ignition, peak heat release rate, time to peak heat release rate, total heat release rate, specimen total mass loss, average mass loss rate, average effective heat of combustion, average smoke extinction area, average carbon dioxide yield, and average carbon monoxide yield) can be found in Appendix D for each of the 38 tests.

Table 4.3 Cone Calorimeter Tests

Material	External Flux kW/m^2	Sample Number	Test ID	Manufacturer
Poly(ether) Polyurethane Foam, gray, convoluted, **non-fire retardant**	35	3	PUF-NFR-A	A
Poly(ether) Polyurethane Foam, gray, convoluted, **non-fire retardant**	20, 35, 40, 60, and 70	20	PUF-NFR-B	B
Poly(ester) Polyurethane Foam, gray, convoluted, **fire retardant**	35	3	PUF-FR	C
Wood Paneling, 5 mm thick, plywood substrate, birch finish	35 and 70	6	WP	D
Carpet Flooring, 6.2 mm thick, polyester short nap, 100% filament olefin, ave. tufted face wt 39 oz, twist tough bind 14.00, beige color	35 and 70	6	CF	E
Ceiling Tile type 942B 610 mm x 1219 mm x 16 mm (24 in x 48 in x 0.62 in)	35 and 70	6	CT	F

4.4.1 Acoustical Ceiling Tiles

A suspended or dropped ceiling had been installed in the nightclub except for in the sunroom, the platform area, and the dance floor areas (Figure 4-3). Each 0.61 m (2 ft) x 1.22 m (4 ft) x .016 m (0.625 in) panel had been installed or dropped into a metal grid support system. Photographs of the nightclub interior clearly demonstrate that the ceiling tiles had been painted black. It was not clear from the photographs whether the paint had been applied by brush, roller, or spray can. The surface of the tiles also had a glittery appearance that may have been a result of the wet paint being dusted with glitter.

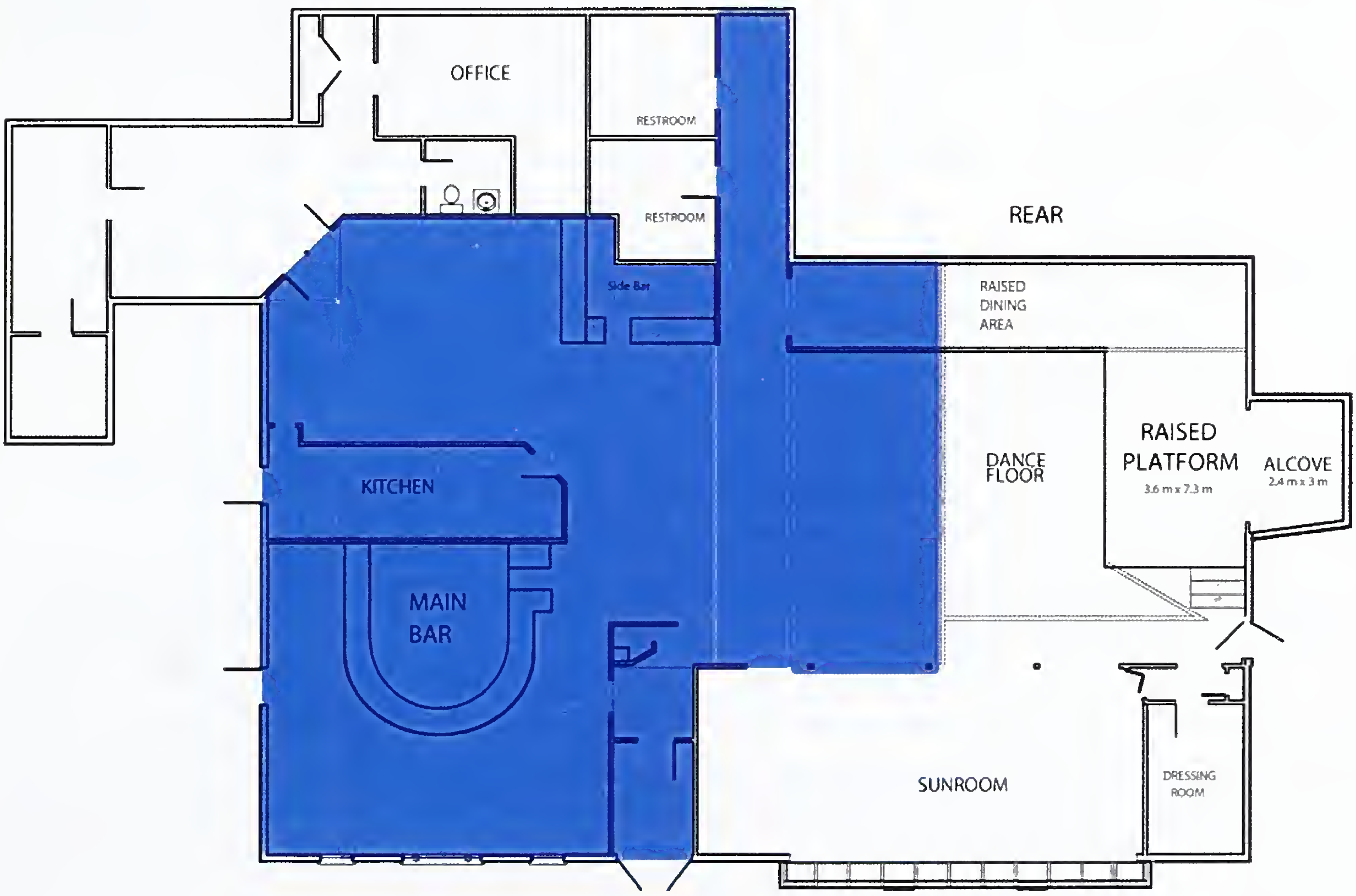


Figure 4-3. Portion of Nightclub with Acoustical Tile Ceiling (shaded blue section).

Labeling found on a surviving acoustical tile indicated that that the tile was a mineral fiber type of material, a 942 (residential coding) or 755 (commercial coding). Samples of 942B acoustical tiles were purchased from a local supplier for these cone calorimeter tests. The front side of each panel (see Appendix D) exhibited a factory-applied coat of white vinyl-latex paint while the rear side of each panel was unpainted. Samples that measured 0.1 m x 0.1 m were cut from the larger panels. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least two weeks. Then each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, the painted side was exposed to the thermal flux.

When exposed to 35 kW/m^2 of external heat flux, the ceiling tiles did not ignite. Ignition and peak heat release rate values (average) are tabulated in Table 4.4. Each test was terminated after 3 minutes of exposure when none of the three samples ignited. As the thermal flux was increased to 70 kW/m^2, ignition did occur and the samples reached their peak heat release rate in approximately 20 seconds. The ceiling tiles demonstrated an average peak heat release rate of 57 kW/m^2. Individual test data and plots of the heat release rate for each sample versus time are in Appendix D.

Table 4.4 Cone Calorimeter Results for Ceiling Tile, Wood Panels, & Carpet Flooring

Sample ID	External Thermal Flux, kW/m^2	Time to Sustained Ignition, seconds	Time to Peak Heat Release Rate, seconds	Peak Heat Release Rate kW/m^2
Ceiling Tile (CT)	35	Did not ignite		
	70	8	20	57
Wood Paneling (WP)	35	41	129	437
	70	15	85	526
Carpet Flooring (CF)	35	54	192	627
	70	20	78	1371

4.4.2 Wood Paneling

Wood paneling had been installed in the nightclub around the platform area, around the sunroom, back bar area, and entry way (Figure 4-4). Interior photographs of the nightclub did not provide sufficient information to identify the specific brand or type of paneling.

A veneer type paneling which utilizes a plywood substrate was selected as being representative of the fuel load contributed by the paneling. The wood paneling was purchased from a local retailer in 1.22 m (4 ft) x 2.44 m (8 ft) sheets. The 0.0003 m (0.0125 in) birch veneer was laminated to a 0.006 m (0.25 in) thick three-ply Luan mahogany backer layer. The front side of each panel (Appendix D) had a glossy coat of finish while the rear side of each panel was unfinished plywood. Samples that measured 0.1 m x 0.1 m were cut from the larger panels. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least two weeks. Then, each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, the veneer side was exposed to the thermal flux.

When irradiated with 35 kW/m^2 of external heat, the wood paneling reached its average peak heat release rate, 440 kW/m^2 , in approximately 130 seconds. At the lower thermal flux, each sample required about 40 seconds to achieve sustained ignition. At the higher flux, 70 kW/m^2, the wood panel samples required much less time to sustain ignition, resulted in a higher average peak heat release rate of 530 kW/m^2, and required substantially less time, 85 seconds, to achieve the peak value. Individual test data and plots of the heat release rate for each sample versus time are in Appendix D.

The heat release curves exhibited a two peak shape, with the second peak much greater than the first peak. Each wood panel sample charred significantly as it burned, and the char represented a greater fraction of the total available fuel than that which was burned early in the test. In the higher thermal flux exposure, the additional flux caused more of the fuel to be burned early in the test, so the two peaks were closer in value.

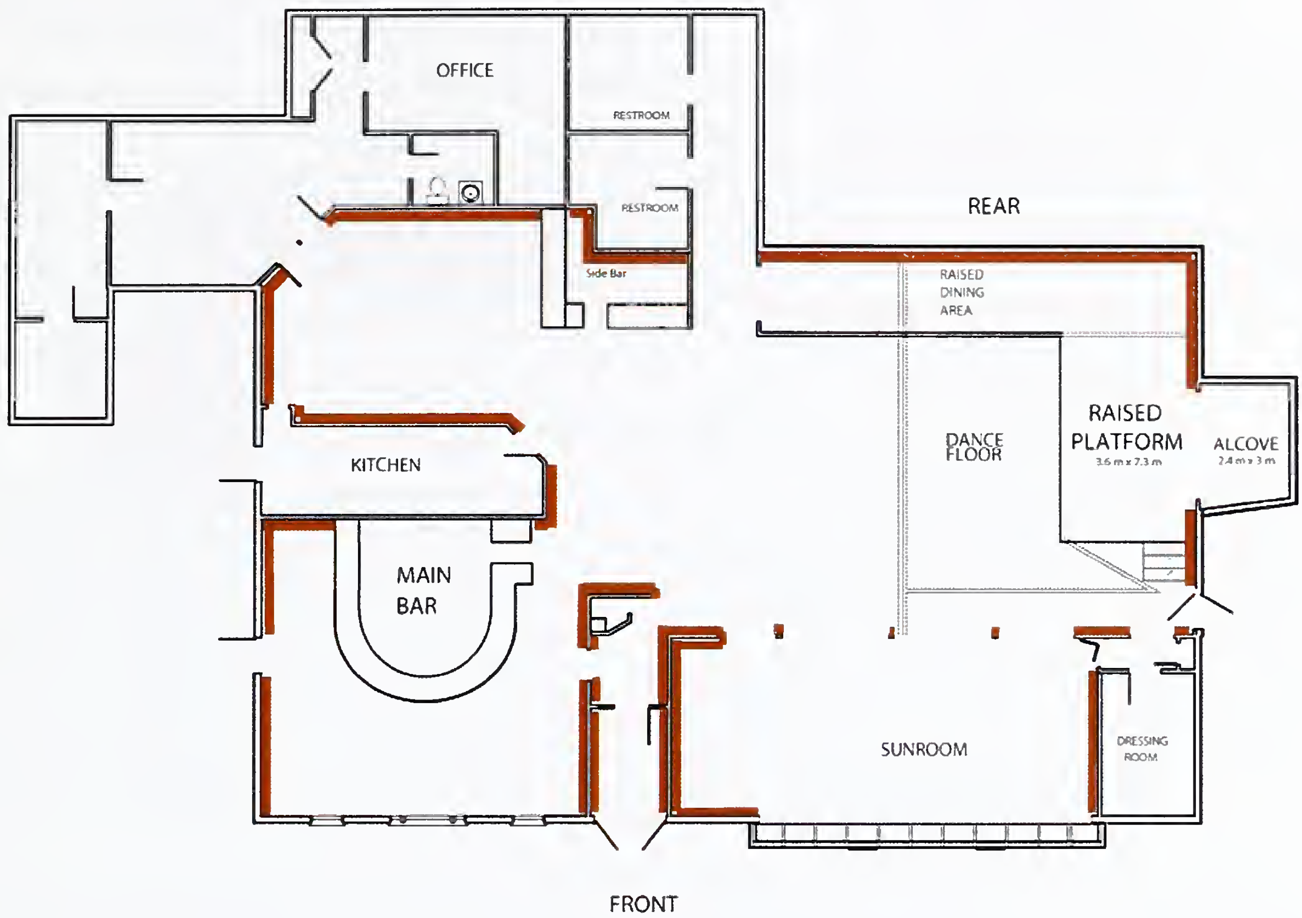


Figure 4- 4. Portion of Nightclub with Wood Paneling (brown shaded sections).

4.4.3 Carpet Flooring

Carpet flooring had been installed in the nightclub on the elevated section along the rear wall and around the platform area. (Figure 4-5). Interior photographs of the nightclub did not provide sufficient information to identify the specific brand or type of carpeting.

A closed-loop olefin carpet with a binding layer was selected as representing the fuel load contributed by the carpeting. The carpet was purchased from a local supplier in a 3.2 m (12 ft) wide x 15.7 m (50 ft) long continuous roll. The 0.006 m (0.25 in) nylon pile was embedded in a 0.002 m (0.1 in) thick binding layer. Samples that measured 0.1 m x 0.1 m were cut from the roll. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least two weeks. Then each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, the olefin pile side was exposed to the thermal flux.

When exposed to 35 kW/m^2 of external heat flux, the average peak heat release rate for the three carpet samples was 627 kW/m^2. The carpet required about 54 seconds, on average, to achieve sustained ignition, and approximately 190 seconds to reach its peak heat release rate (Table 4.4). hen exposed to the higher external heat flux of 70 kW/m^2, the carpeting reached its peak heat release rate in about half the time. Peak heat release rates for all three carpet samples averaged 1370 kW/m^2. Individual test data and plots of the heat release rate for each sample versus time are in Appendix D.

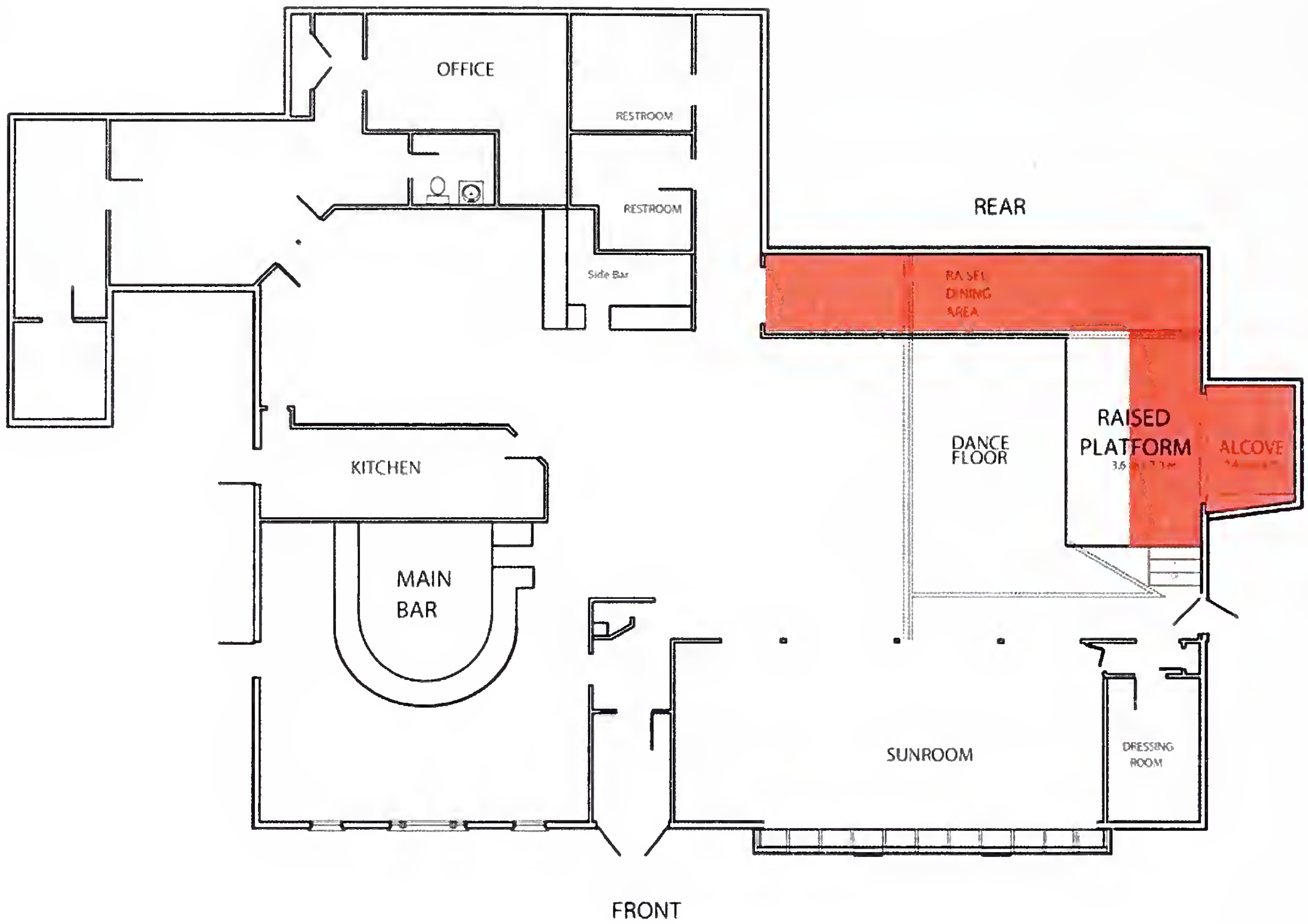


Figure 4-5. Portion of Nightclub with Carpeting.

For the lower flux exposure, the heat release curve exhibited a relatively brief step at around 200 kW/m^2 and then increased gradually to a single broad peak. As the carpet initially began to burn, some of the energy released was conducted into the olefin pile, but instead of producing a char, the polymer melted and formed a more uniform density fuel. As the burning continued, it increased at a relatively steady rate, reached its peak and decreased at a more rapid rate. At the higher flux exposure, the additional energy from the internal heating caused the melting to occur more rapidly, so the initial step seen at the lower flux was not observed.

4.4.4 Fuel Load Properties – Ignitability, Mass, and Location

The contribution of assorted fuels to fire spread and total heat release rate can be very different. The cone calorimeter test data demonstrated that the polyurethane foam, both the fire retardant and non-fire retardant formulations, could ignite in less than 15 seconds of exposure to 20 kW/m^2 of external heat flux. Once ignited, the polyurethane foam reached peak heat release rates ranging from 450 kW/m^2 to1150 kW/m^2 in less than 60 seconds. Both the wood paneling and carpet flooring required from 80 seconds to 200 seconds to reach peak heat release values which ranged from 440 kW/m^2 to 1370 kW/m^2.

The polyurethane foam was a low density material and was quick to ignite, but the mass of the foam was consumed in a relatively short period of time. The foam would have contributed to a quick initial fire growth, but typically would not have had sufficient mass to carry the fire past the initial stages. Wood and the carpet flooring had greater mass and were a larger source of energy than the foam, although the wood and carpet required longer times to ignite. Once ignited, both the wood and carpet would provide a substantial amount of the energy released during a fire. The ceiling tiles would have released relatively little energy compared to the other fuel components.

The contribution of a specific fuel is dependent on the relative amounts of the fuel and how quickly the fuel becomes involved in the fire. Wood is often found in flooring, wall paneling, and structural members such as studs, joists and rafters. Carpeting is typically used only as a floor covering. In a wood frame structure, the wood component of the fuel load may provide the bulk of the energy released. The location of the fuel can also impact when and how rapidly a specific fuel becomes a contributor to the heat release rate. For instance, wood paneling near the ceiling ordinarily would become involved more quickly than wood flooring.

4.5 PYROTECHNIC DEVICE TEST SERIES

A series of full scale experiments was conducted to document the thermal characteristics of a discharging pyrotechnic device like those that were ignited in the nightclub on Feb. 20, 2003. At the beginning of the show, four separate pyrotechnic devices, or gerbs, were discharged on the platform in front of the alcove. Two gerbs, which had been positioned on the floor of the platform, discharged vertically along the centerline of the alcove opening (Figure 4-10). Two additional pyrotechnic gerbs, which were located near the other two gerbs on the platform floor, sprayed white "sparks" at a 45 degree angle to both the left and right sides of the alcove. The WPRI-TV video of the nightclub interior showed that glowing particles or "sparks" ignited the foam on both sides of the alcove in approximately 10 seconds.

The throw, or distance the hot particles traveled, the period of "spark" discharge, and the white appearance of hot particles, were consistent with a pyrotechnic device called a Silver 15 x 15 Stage Gerb. Forty silver 15 x 15 gerbs were purchased from a commercial manufacturer of stage pyrotechnics. Appendix F provides a detailed description of the gerbs.

For the NIST tests, each gerb or pair of gerbs was discharged either along or against a gypsum board wall or a foam covered gypsum board wall. The wall was painted black to enhance the contrast with the white sparks, and a grid of 0.3 m (1 ft) squares was painted on it. Gerbs were also discharged against the wall in a plane perpendicular to the wall (Figure 4-11). Heat flux gauges and thermocouples were embedded in the gypsum wall. The instrumentation was positioned so that the spark discharge was centered over the flux gauges and thermocouples. Examples of typical data, heat flux and gas temperature, are plotted versus time in Appendix F, and each discharge was video taped using a standard mini-DV digital video camera and an infrared camera.

4.5.1 Gypsum Wall Board

The gerbs were ignited electrically. Each discharge was recorded using a standard video camera and an infrared camera. The infrared camera utilized a barium-strontium-titanate (BST) solid state detector with a spectral response of 8 μm to 14 μm. The IR camera was included in these experiments to provide a qualitative image of the hot gas plume as well as the spray of the white sparks.

The visible images show that each gerb discharged a spray of white sparks for at least 14.5 seconds, but no more than 16 seconds. While most of the sparks were thrown less than 2.74 m (9 ft), a limited number of sparks traveled in excess of 4.6 m (15 ft) from the tip of the gerb. For the gerbs that were positioned at 45°, the infrared images show a central core of hot gases, a plume of warm gases that does not travel as far as the hot metallic particles. The buoyant hot gases developed a vertical trajectory within 1.2 m (4 ft) of the gerb tip. For the gerbs that were positioned vertically, the infrared images again

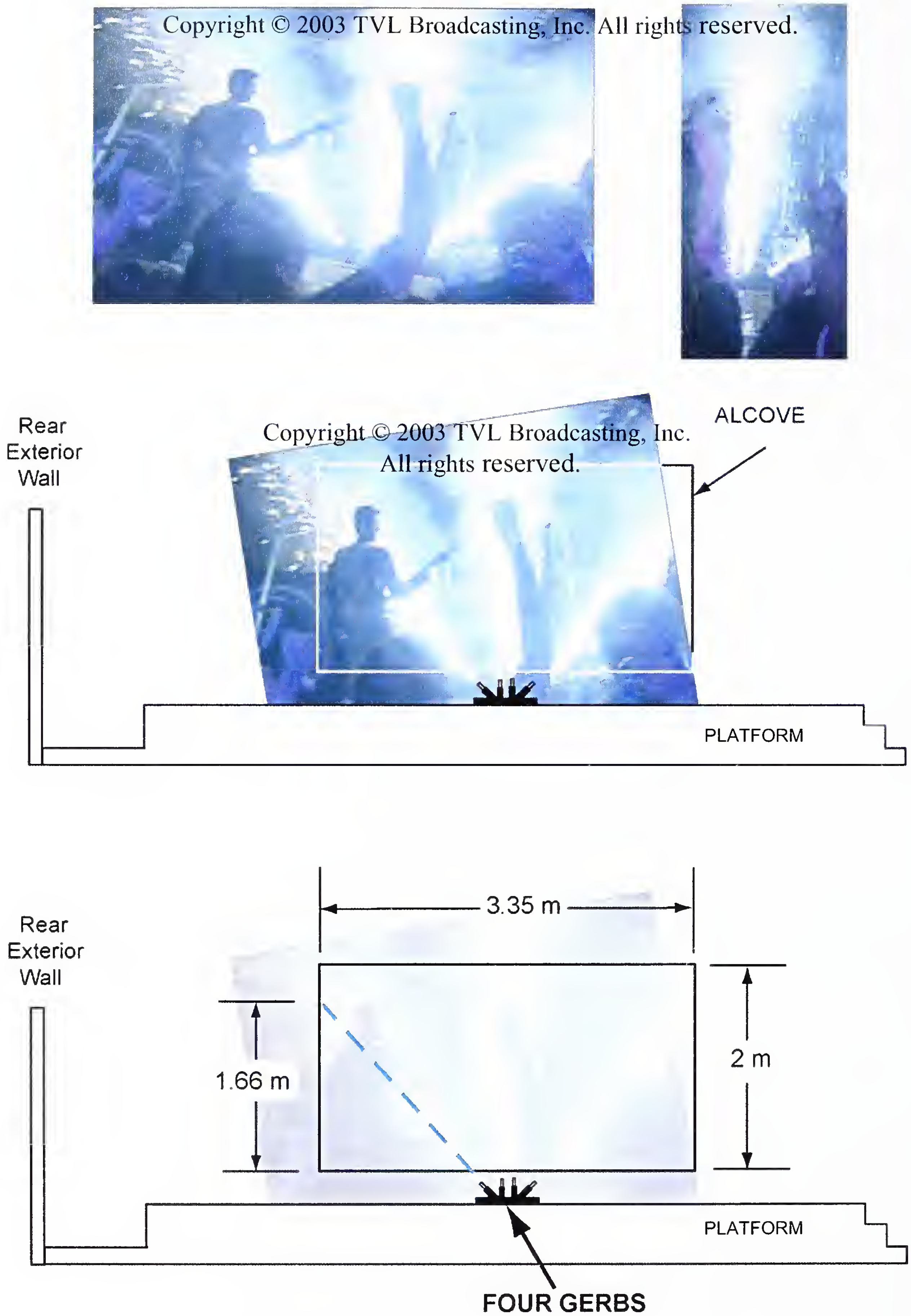


Figure 4-10. Pyrotechnics (15 x 15 gerbs) positioned on nightclub platform. Video image copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

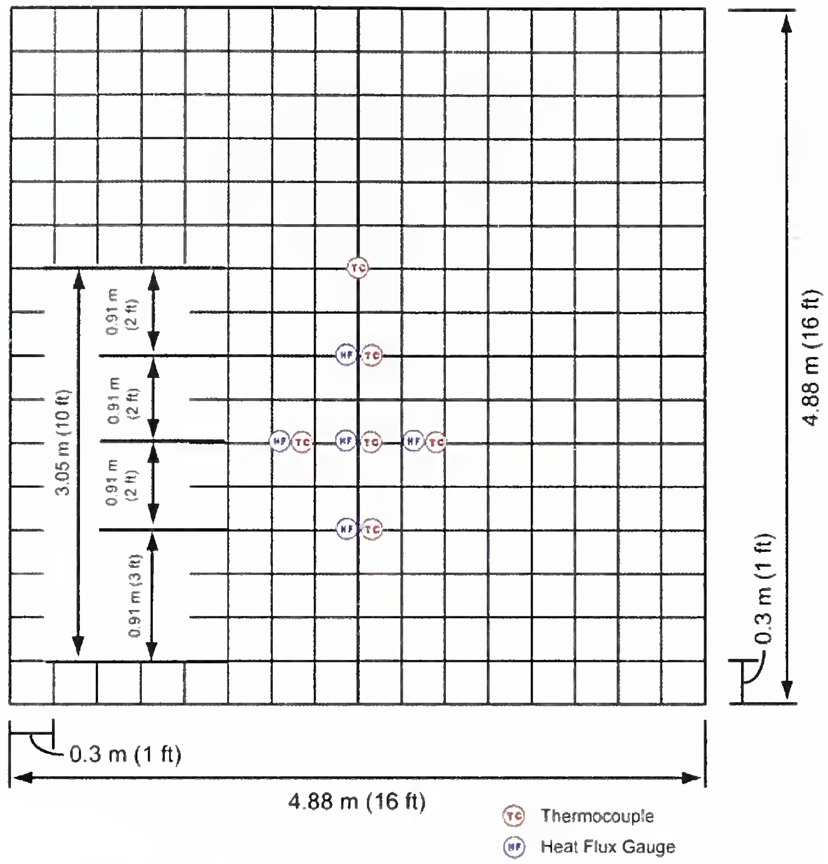
Figure 4-11. Single Gerb at 45 degrees and in a Plane Perpendicular to Wall.

demonstrate a central core of hot gases; in this vertical configuration, the plume of combustion gases is aligned with the trajectory of the hot sparks. The measured heat fluxes from the gerbs impinging on the wall were less than 2.5 W/m^2. Each total heat flux gauge monitored the heat flux over a fixed volume that was defined by the view angle of the gauge. The heat flux monitored by a gauge might result from multiple glowing particles, hot gases propelling the sparks, and/or the air entrained by the gerb discharge.

4.5.2 Foam Covered Wall

The video recorded in the nightclub demonstrates that there were four gerbs positioned in front of the alcove. The two vertical gerbs were spaced about 0.1 m (4 in) apart and the two 45 degree gerbs were each positioned about 0.25 m (10 in) outside the vertical gerbs. This arrangement placed the tip of the 45 degree gerbs approximately 1.21 m (4 ft) from each of the side walls of the alcove. The spray of hot sparks would have impinged on a foam covered wall from about that distance.

In order to simulate this arrangement, a single gerb which was angled at 45 degrees was discharged against (and in a plane perpendicular to) the wall from a distance of 1.22 m (4 ft). A single 1.22 m (4 ft) by 2.44 m (8 ft) sheet of non-fire retardant polyurethane foam (PUF-NFR-B) was stapled to the gypsum board wall. A single gerb was positioned at a 45 degree angle so that the tip of the gerb was 1.22 m (4 ft) from the wall surface. The tip of the gerb was located 0.3 m (1ft) above the floor. While temperature data were collected during the gerb discharge, the heat flux gauges were removed to prevent damage from dripping and burning plastic.



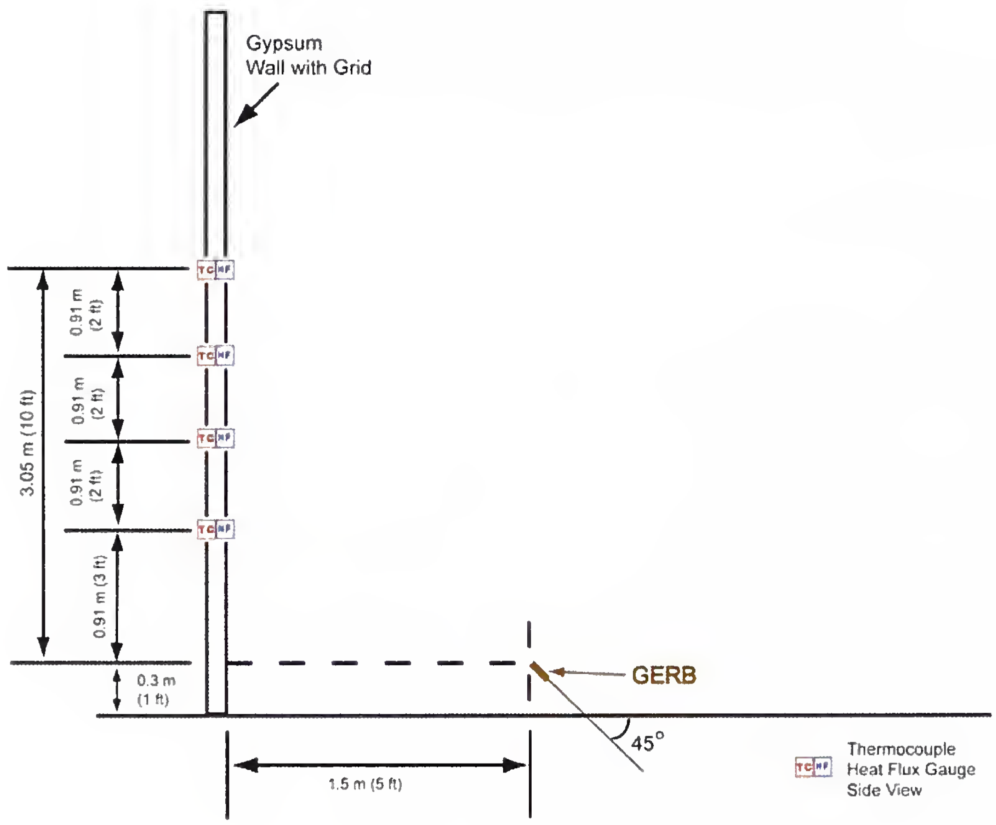


Figure 4-12. Instrumentation Diagram for a Single Gerb at 45 degrees and in a Plane Perpendicular to Wall.

Still images were captured from the video recorded by the standard video and IR camera. For gerbs that were positioned at 45 degrees in a plane parallel to the wall, pairs of visible and infrared images are shown for times from 0 seconds to 30 seconds in Figure 4-13a through 4-13h. The visible images demonstrate that the gerb discharged a spray of white sparks for 15 seconds. The spray of hot sparks impacted the wall between 0.91 m (3 ft) and 1.5 m (5 ft) above the floor. Within 2 seconds after ignition, a thermal pattern (white area in IR image) developed on the wall. This area of increased temperature was oval in shape with a horizontal width of 0.3 m (1 ft) and a vertical dimension of 0.61 m (2ft). A similarly sized and positioned thermal pattern was also seen at 5 seconds into the discharge. The edges of the thermal pattern appeared fuzzy or diffuse. At 10 seconds after ignition, this thermal pattern had sharper edges and a black "haloing" appeared around the pattern. This haloing or shadowing has been observed under laboratory conditions in the presence of a significant thermal gradient. BST detectors measure relative levels of infrared radiation and are AC-coupled. The AC-coupling can cause a "black halo" or shadowing effect that increases as the relative radiation difference between an object and its surroundings increases unless a DC restoration process is included in the signal output circuitry. This would be consistent with the foam burning before t = 10 seconds. Although not clearly seen in the standard video camera, flames were observed on the right hand side of the hot spark pattern at 9 seconds. By 15 seconds a well defined and hot thermal plume was observed in the IR image. Gas temperatures are plotted versus time in Appendix F, Figs. F-16a and F-16b.

The alcove in the nightclub was 2.0 m (6.5 ft) tall and the gerbs were positioned vertically at the center of the alcove opening. In the NIST tests, similar gerbs easily reached that height, as did the plume of hot gases. It can be seen from the WPRI video, however, that the pair of vertically-directed gerbs on the platform of the nightclub did not ignite the foam at the top of the alcove.

The width of the alcove in the nightclub was 3.0 m (10 ft) and the end of each gerbs was offset from the center of the opening by about one foot. The NIST tests demonstrated that a 15 x 15 gerb which was angled at 45 degrees and discharged against (and in a plane perpendicular to) a wall from a distance of 1.22 m (4 ft) could ignite a sheet of polyurethane foam in approximately 10 seconds. This is similar to the ignition sequence observed in the WPRI video.

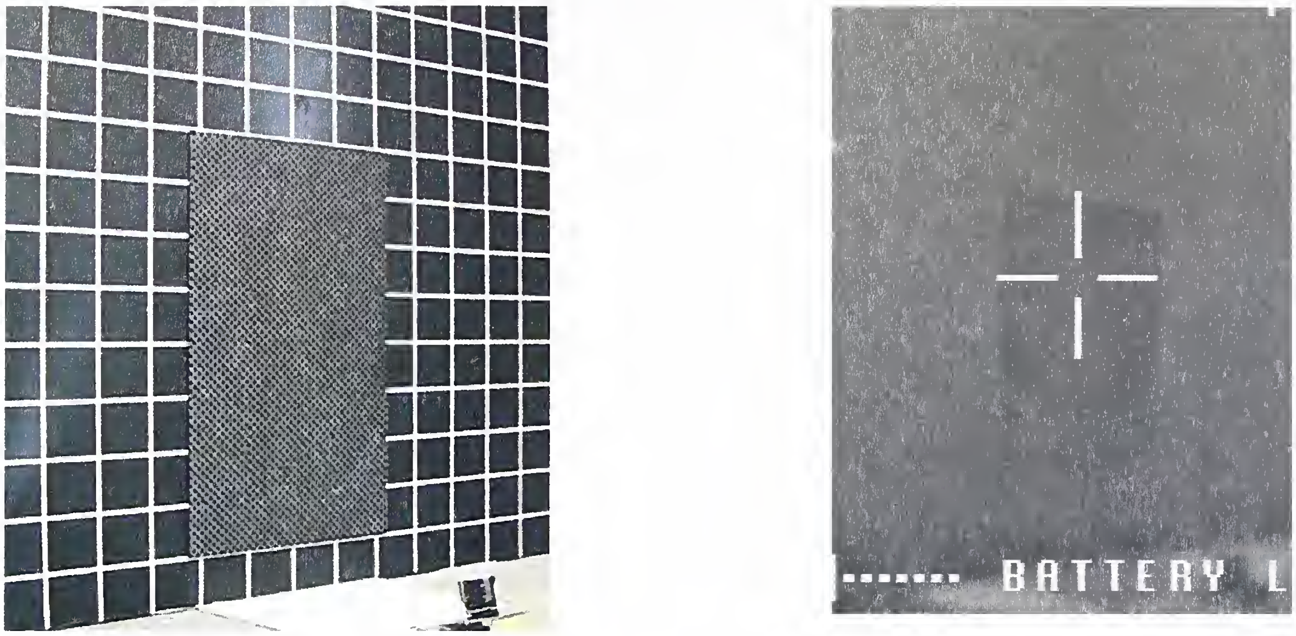


Figure 4-13a. Standard and Infrared Video Images of Non-fire Retarded Polyurethane Foam on Gypsum Board Wall just before ignition at t = 0 seconds.

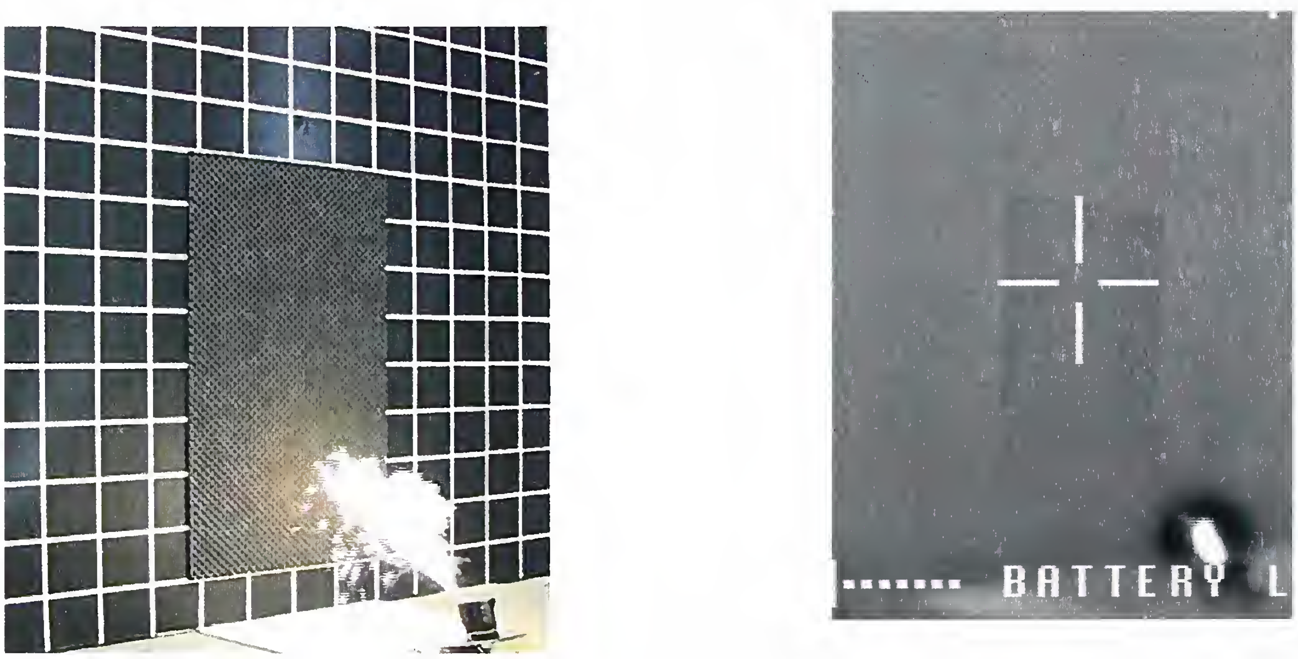


Figure 4-13b. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 0.5 seconds.

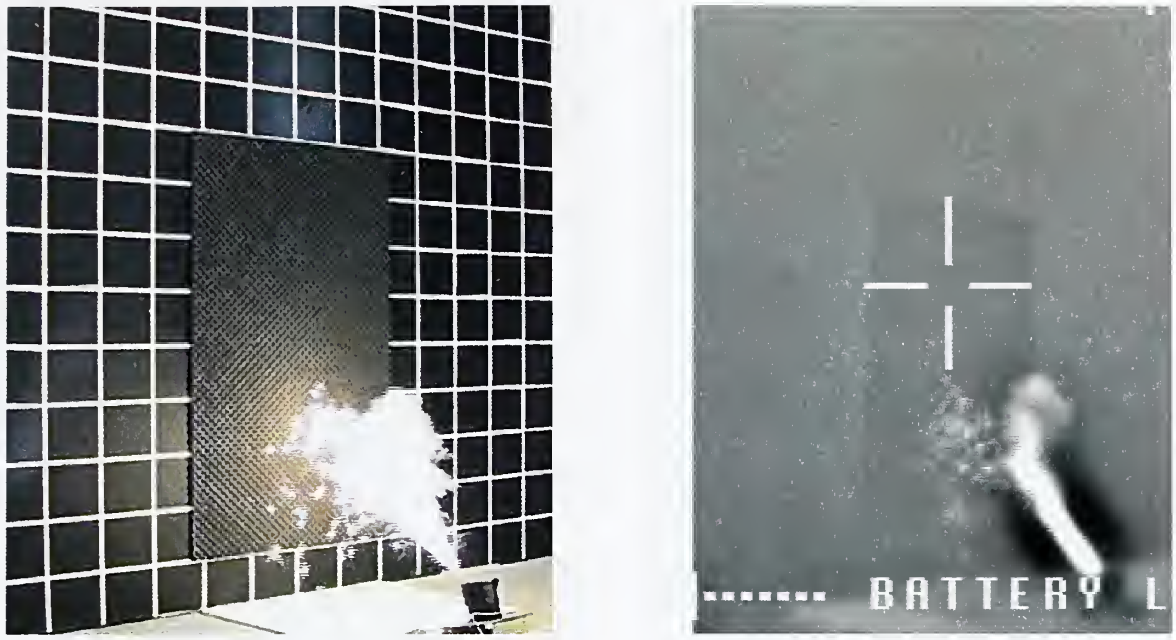


Figure 4-13c. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 1 second.

Figure4-13d. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 2 seconds.

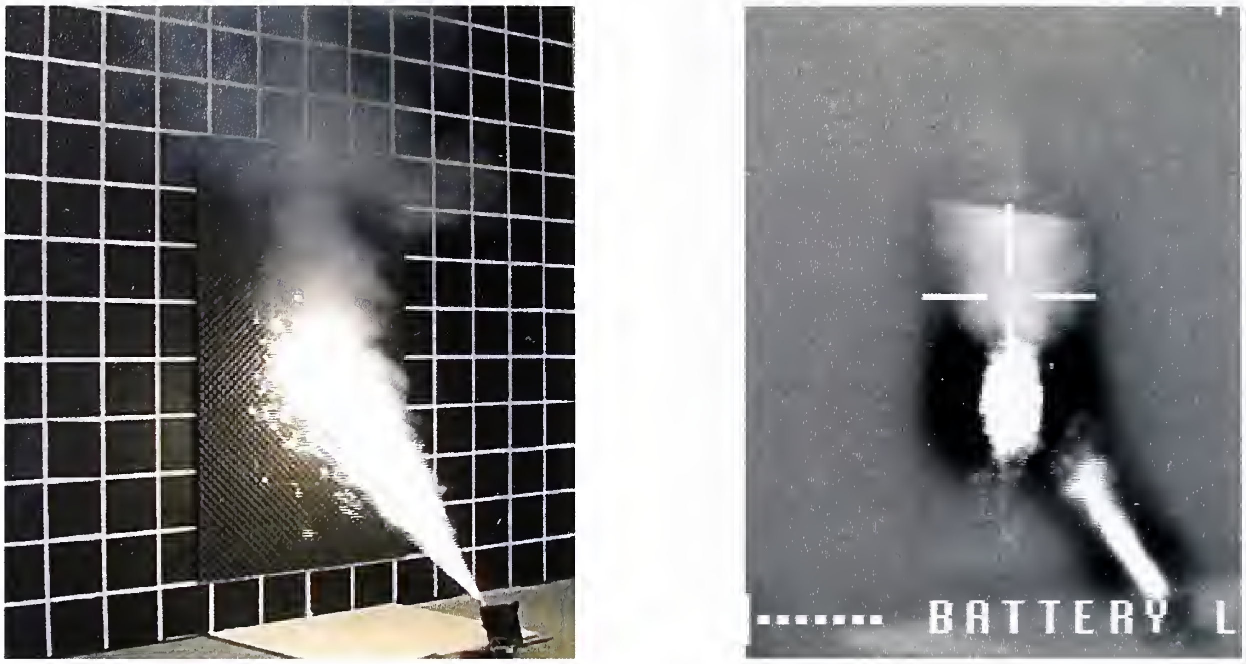


Figure 4-13e. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 5 seconds.

Figure 4-13f. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 10seconds.

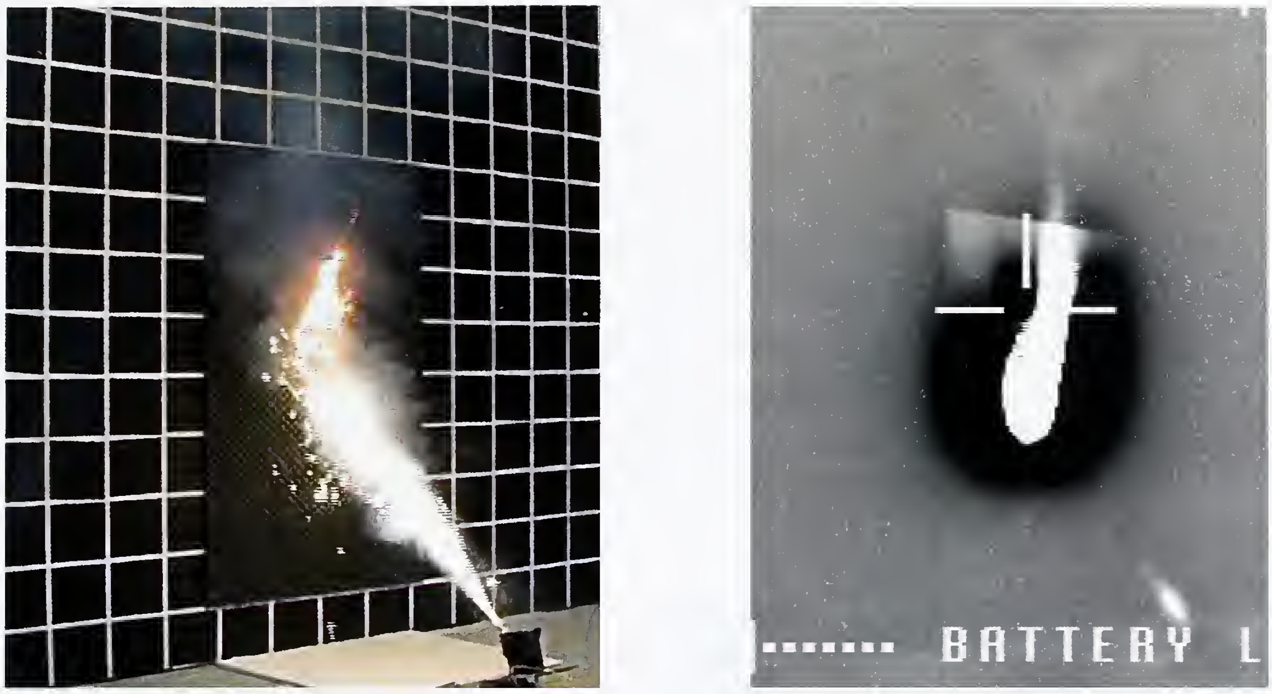


Figure 4-13g. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 15 seconds.

Figure 4-13h. Standard and Infrared Video Images of Gerb Discharge onto a Non-fire Retarded Polyurethane Foam Sheet on Gypsum Board Wall at t = 30 seconds.

4.5.3 Impingement of Gerbs on Wood Paneling

A test using an arrangement similar to the one above was conducted using a bare wood panel to determine if the wood could be ignited by a 15 x 15 gerb. A 1.22 m (4 ft) x 2.44 m (8 ft) panel of 6.4 mm (1/4 in) plywood with a birch veneer was mounted vertically 1.22 m (4 ft) from a gerb angled at 45 degrees from the floor. The plywood panel had been cut in two with the exposed surface of the upper portion offset about 1 - 2 mm back from the front surface of the lower portion, forming a small lip 1.22 m from the floor. The purpose of the lip was to capture hot sparks in an attempt to increase the likelihood that the gerb could cause ignition of the wood.

Figure 4-14a shows the sparks from the gerb impinging on the wood panel about half way through the test. No ignition was observed. The hot sparks did create small black marks and craters in the finish of the panel, as can be seen in Figure 4-14b.

Figure 4-14a. Gerb impinging on wood panel.

Figure 4-14b. Damage to wood panel following impingement by sparks from gerb. Lip on panel surface can be seen as line below mounting screws.

4.5.4 Impingement of Gerbs on Fire Retarded Polyurethane Foam

A test using the arrangement similar to the one above was conducted with a piece of the fire retardant polyurethane (PUF-FR) attached to the wood panel to determine if the foam could be ignited by a 15 x 15 gerb. A 1.22 m (4 ft) x 2.44 m (8 ft) panel of 4.6 mm (0.18 in) thick plywood with a birch veneer was mounted vertically with a 0.71 m (28 in) high x 0.97 m (38 in) wide piece of foam centered on the panel as shown in Figure 4-15a. The foam was positioned 1.22 m (4 ft) from the gerb discharge tip. The gerb was angled 45 degrees above horizontal as in the previous experiments. The foam had been cut in two with the exposed surface of the upper portion offset from the front surface of the lower portion, forming a small gap and lip along the horizontal centerline of the foam. The purpose of the gap was to capture hot sparks in an attempt to increase the likelihood that the gerb could cause ignition of the foam.

Figure 4-15a shows the sparks from the gerb impinging on the foam. No ignition was observed. The hot sparks did cause "pitting" in the foam. The pits are area where the sparks melted or burned away small amounts of foam, but the process did not propagate. Examples of the pitting can be seen in Figure 4-15b.

The experiment was repeated with a new piece of foam. The lower piece of foam overlapped the upper piece of foam, creating a small ledge as shown in Figure 4-15c. The positioning of the gerb was the same. The results were similar to the previous experiment; i.e., no ignition, just minor scorching and small holes in the foam from some of the sparks (see Figures 4-15c and 4-15d). The temperatures in the plume as a function of time are plotted in Appendix F, Figs. F-24 and F-25.

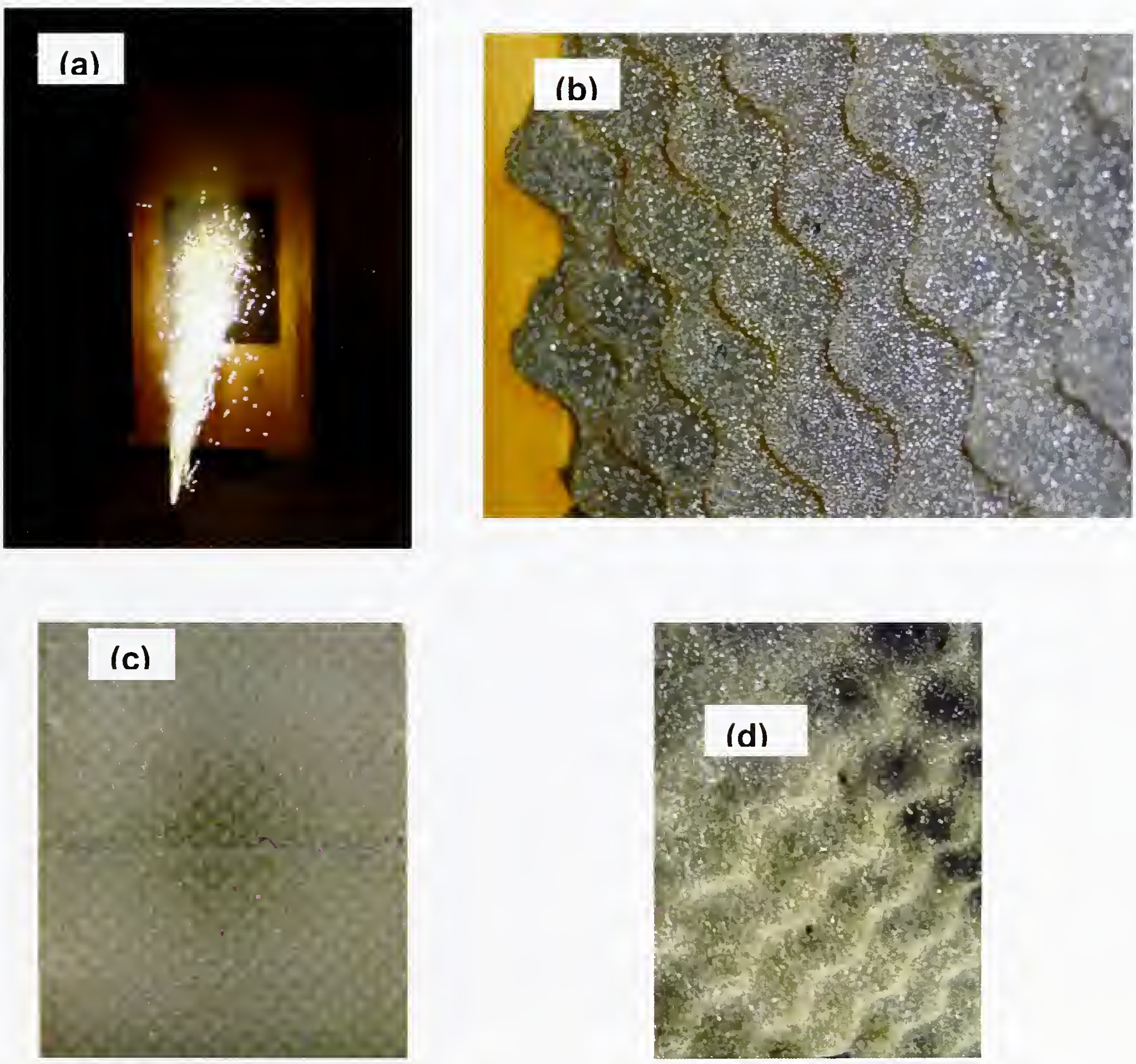


Figure 4-15. Gerb impinging fire retardant polyurethane foam (a); evidence of pitting (b); horizontal ledge at mid-plane to catch sparks, and evidence of scorching in second sample (c); and close-up of scorched area (d).

4.6 FIRE GROWTH MEASUREMENTS IN REAL-SCALE PLATFORM AREA MOCKUP

Real-scale platform area mockup experiments were conducted to characterize the fire growth and spread in the early stage of the fire. Approximately 20 % of the nightclub was reconstructed in real scale with polyurethane foam covered walls, a drummer's alcove, a raised platform, carpeting, and wood paneling. Figure 4-16 shows the dimensions of the mock-up floor plan and compares the test compartment to a floor plan of the nightclub. Data collected on fire spread (gas temperatures, heat fluxes, and gas concentrations) allow the performance of the computer fire model to be assessed. The degree to which the computer fire model is able to mimic the fire growth for this real-scale mockup is indicative of the quality of the simulation of the fire in The Station presented in Chapter 5, within the limitations of uncertain materials and imprecise dimensions for the actual nightclub.

Two real-scale tests were conducted: one without automatic sprinklers, and one with automatic sprinklers. By designing the real-scale mockup experiments carefully, in terms of controlling factors such as fuel and ventilation, the mockup tests provided a means to determine the benefit of automatic sprinklers in a fire similar to what occurred in The Station, and to gain insight as to conditions in the nightclub during the early fire growth and spread, in particular the levels of CO and HCN since these cannot be predicted by the computer fire model.

4.6.1 Test Configuration

The physical mock-up was recreated in the NIST Large Fire Laboratory. The overall floor dimensions of the test room were 10.8 m by 7.0 m, and the ceiling height was 3.8 m. A single opening, 0.91 m wide and 2.0 m high was located in the wall opposite the alcove. An isometric view of the test compartment is shown in Figure 4-17. In order to allow the combustion gases to be exhausted into an instrumented hood, the full-scale mock-up experiments were conducted with the platform section oriented to the east of the dance floor. In the actual nightclub, the platform section was **west** of the dance floor. In order to be consistent, the mock-up data will be presented using the orientation of the actual nightclub.

The test area was constructed with a structural steel frame, lined with two layers of 12 mm thick calcium silicate board, and covered with 12 mm thick gypsum board. The walls of the alcove and the raised floor area had 5.2 mm thick plywood paneling installed over the gypsum board. The paneling had a flame spread index of 200 or less per ASTM E-84 [15], according to the manufacturer. The plywood paneling extended 3.6 m from the raised floor along the rear wall of the test area.. The rear wall was adjacent to the platform on the right as one stands on the platform facing the audience (stage-right). A non-fire retarded, ether-based, polyurethane foam (PUF-NFR-B) was glued over the paneling in the alcove and along the walls on both sides of the alcove opening and to the rear wall, as shown in Figure 4-18. The polyether polyurethane foam was from the second lot of PUF-NFR-B foam tested and described earlier in this chapter. The flat side of the foam was mounted next to the plywood and the convoluted side was left exposed. The foam was installed from the top of the wall down to 1.35 m above the floor. It was also applied to the ceiling of the alcove and extended for 2.4 m from the raised floor along the rear wall.

4.6.2 Instrumentation

The test room was equipped with thermocouples, video cameras, heat flux gauges, bi-directional probes, and gas extraction probes to measure carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), and hydrogen cyanide (HCN). In addition, fixed temperature and rate-of-rise heat detectors were installed, as

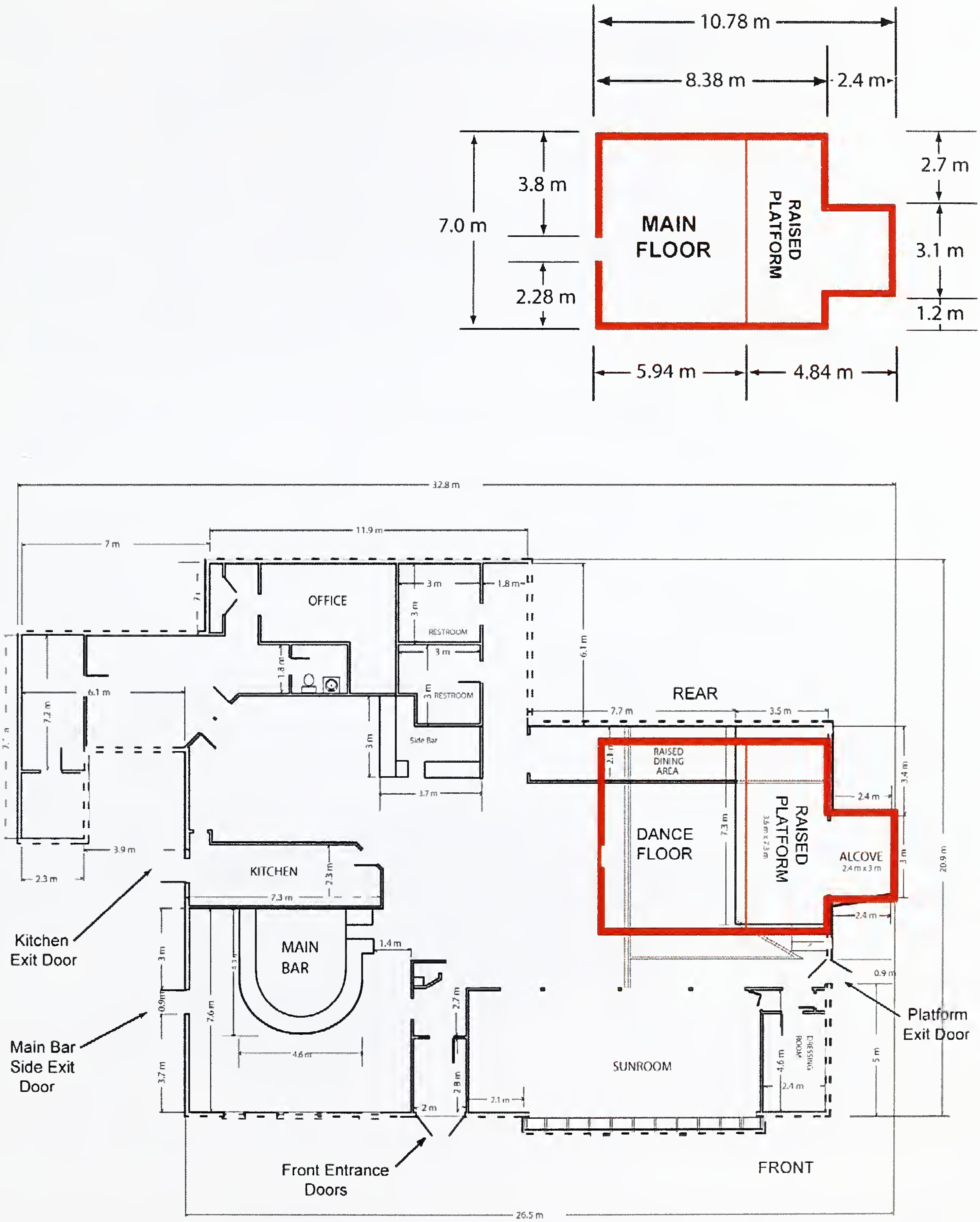


Figure 4-16. Real-Scale Mockup Floor Plan versus Station Nightclub Floor Plan.

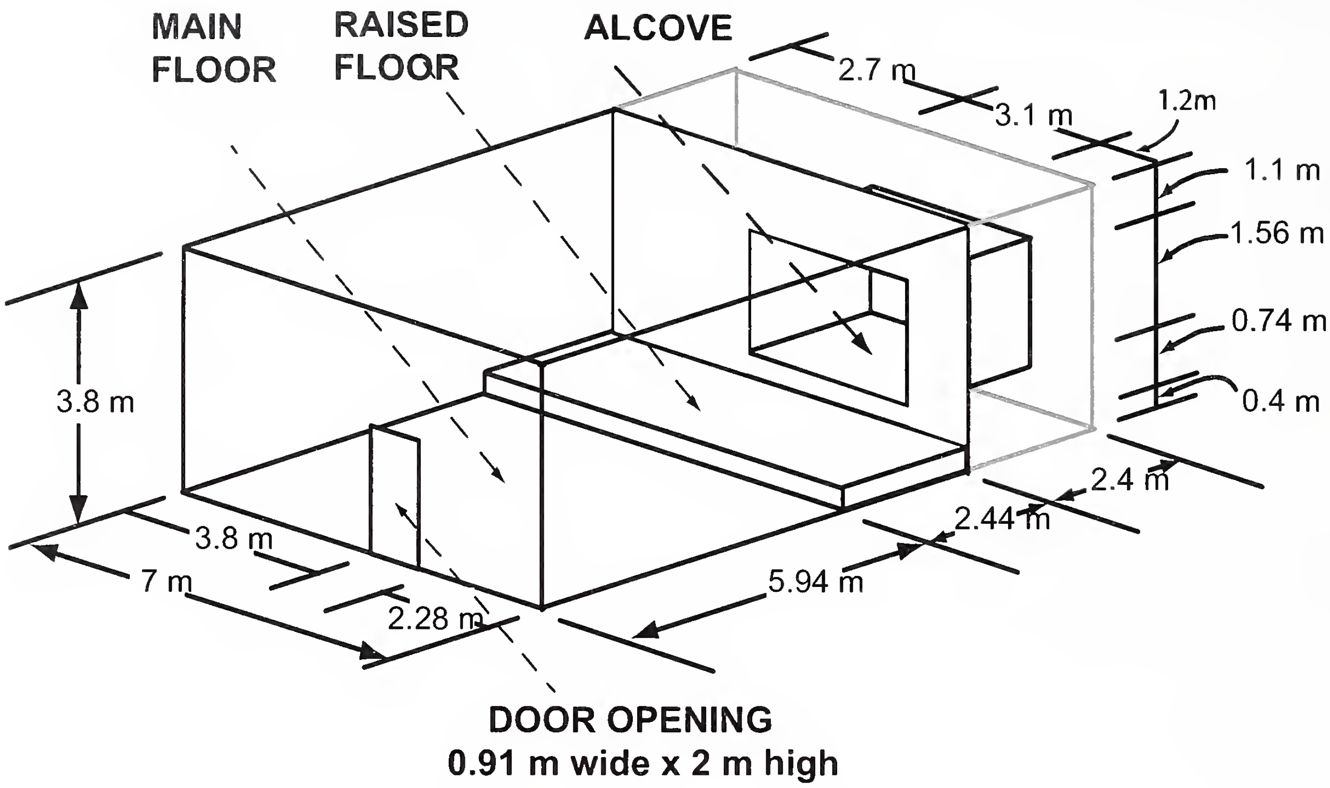


Figure 4-17. Isometric view of the test compartment.

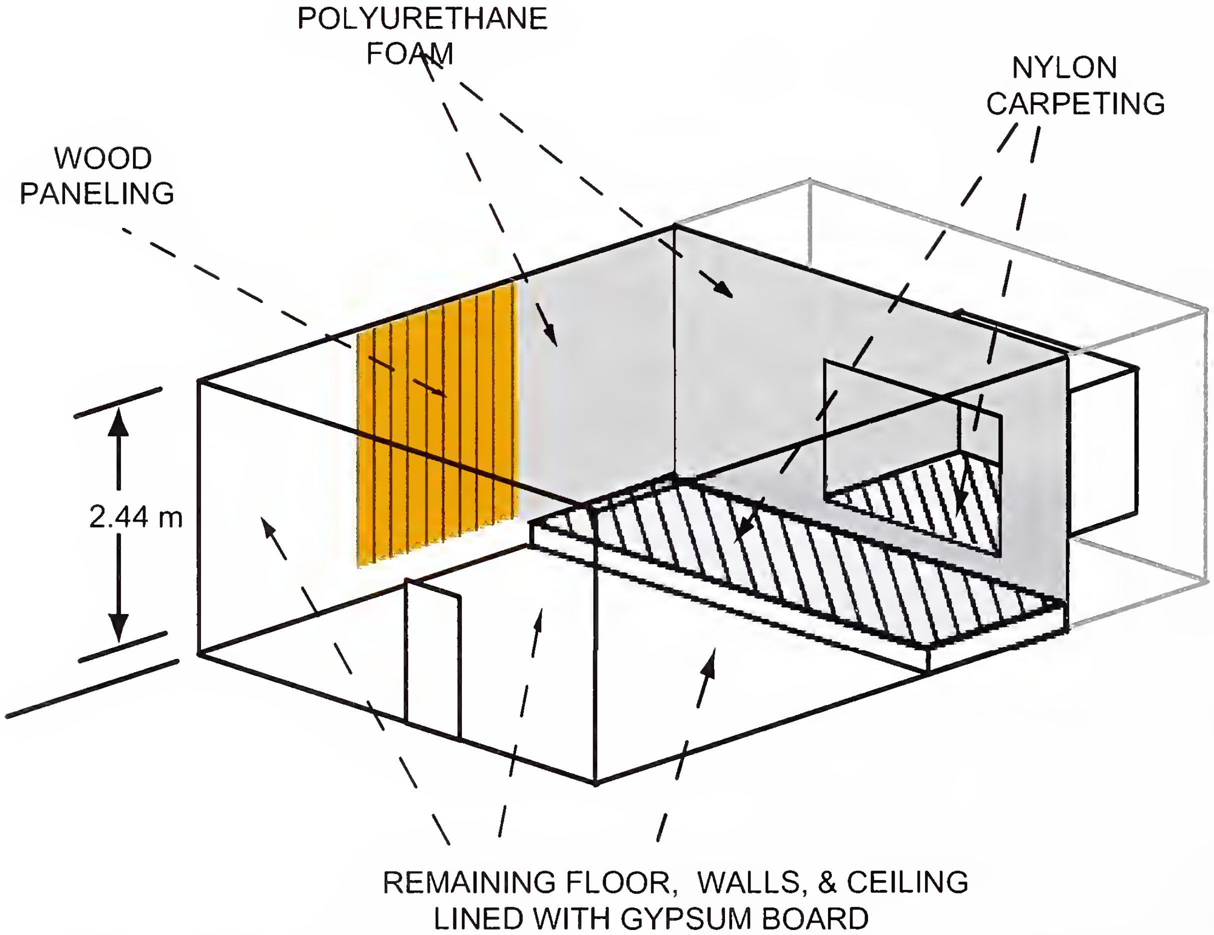


Figure 4-18. Floor plan showing the test area and the fuel locations.

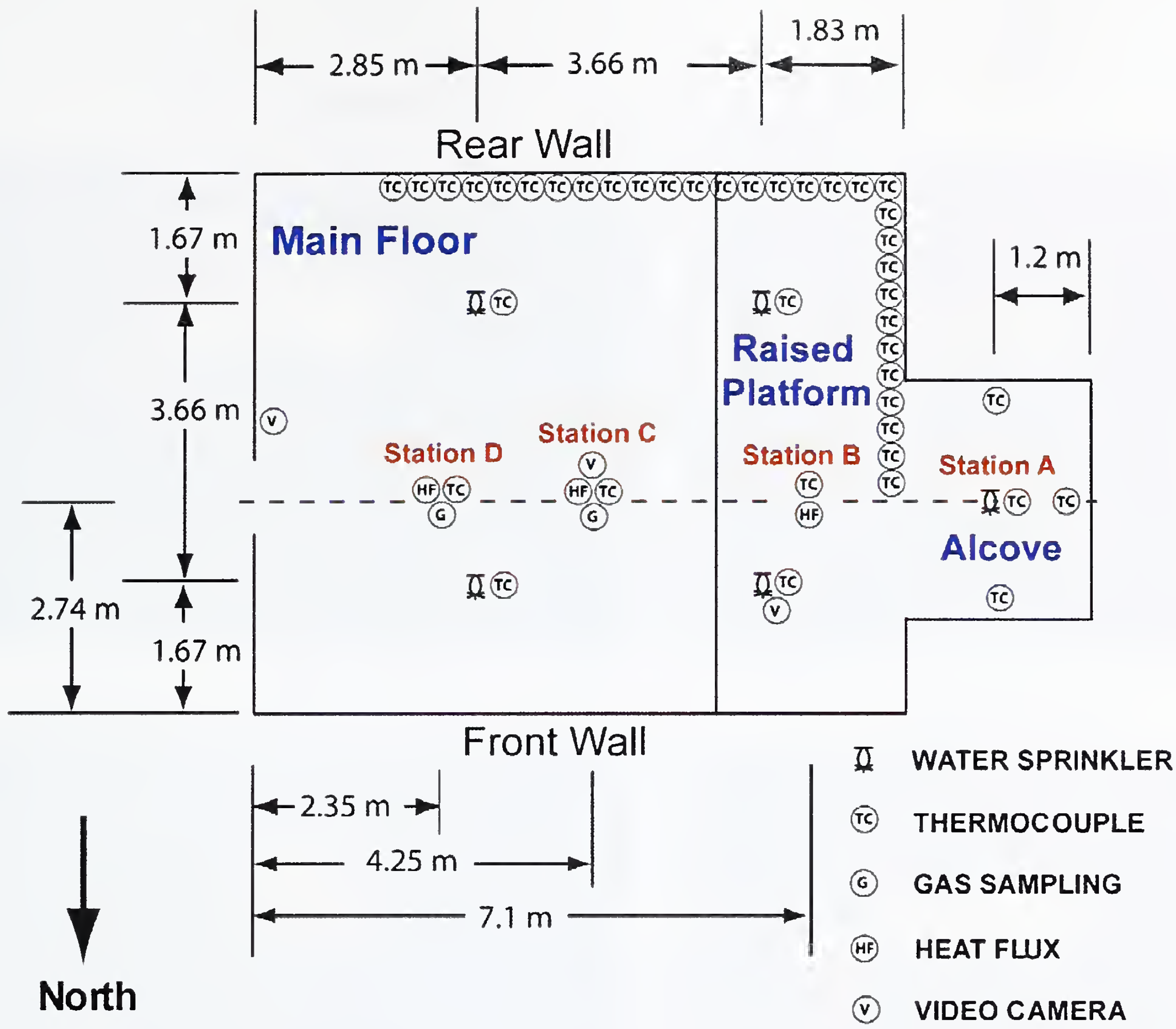


Figure 4-19. Schematic floor plan with instrumentation positions.

were sprinklers. In the unsprinklered experiment, standard response pendent sprinklers were installed without a water supply. The sprinklers were attached to a 150 mm (6 in) length of 19 mm (0.75 in) pipe that was filled with water and pressurized with air. In the sprinklered experiments, all sprinklers were connected to a single water supply. The sprinkler was monitored for time to activation with a pressure sensor that was attached to the short length of pipe. The only difference between the sprinklers installed in the unsprinklered experiment and the sprinklered experiment was the thermal element. In the sprinklered experiment, quick response sprinklers were used. Figure 4-19 is a schematic floor plan of the instrumentation positions.

4.6.3 Experimental Procedure

Prior to ignition, each of the analyzers was zeroed and calibrated and the data acquisition system and videos were started to collect background data. Data for 194 channels were recorded at 1 second intervals. Ignition of the foam was initiated simultaneously with electric matches at two locations on the outer corners of the alcove, 1.66 m above the raised floor area. The fire gases that emerged from the open door on the south end of the test room were captured in the hood of the oxygen depletion calorimeter. The data were reduced and plotted versus time for each of the channels.

The succession of video frames on the left of Fig. 4-20 show how rapidly the fire spreads during the first 50 seconds, compared to how quickly the fire is controlled with sprinklers in the frames along the right. The first sprinkler activates on the right of the platform 24 seconds after ignition. By 30 seconds the sprinkler above the platform on the left and the sprinkler in the alcove have activated.

Figure 4-20. Still frames taken from video of full-scale mock-up experiments. Time after ignition is indicated in lower left of each frame. Left column: unsprinklered; right column: sprinklered (first head activates at 24 seconds)

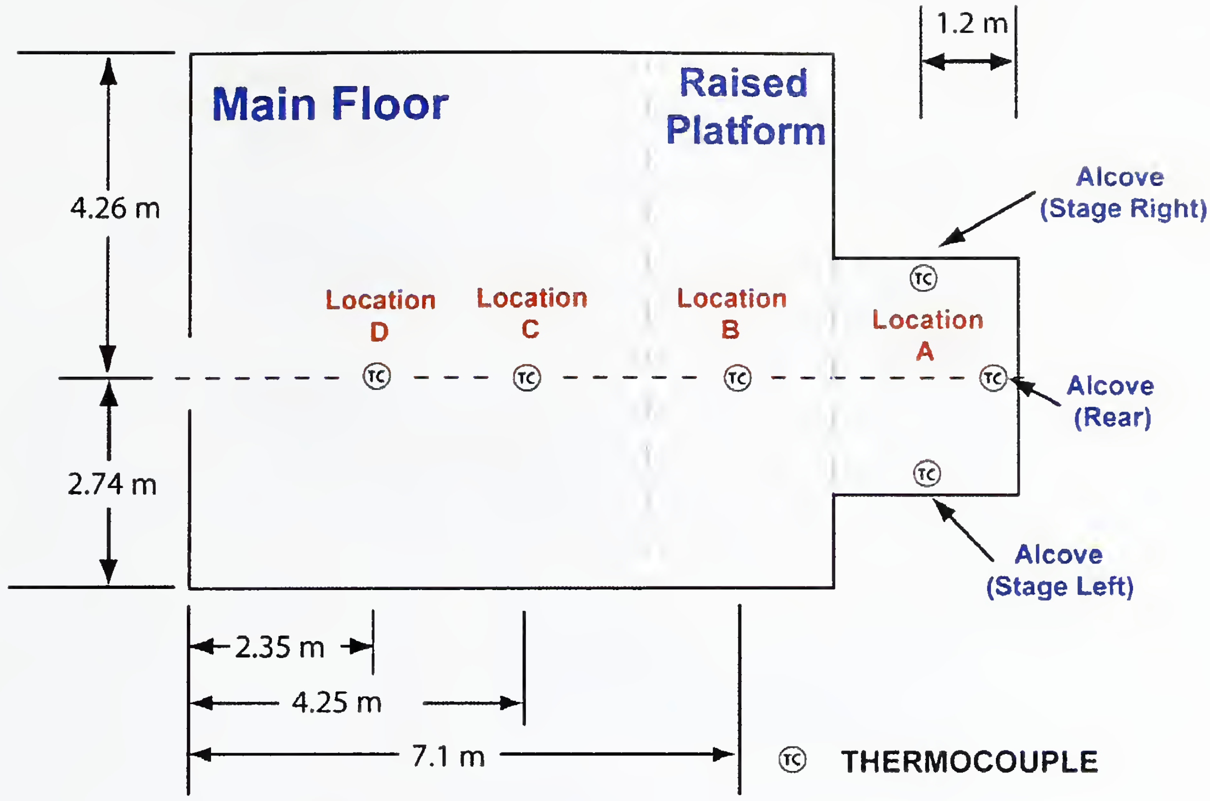


Figure 4-21. Schematic floor plan with thermocouple positions.

4.6.4 Temperature

The temperatures were measured with 0.51 mm nominal diameter bare bead, type K thermocouples, distributed as shown in Fig. 4-21. The standard uncertainty in temperature of the wire itself is ± 2.2 °C at 277 °C and increases to ± 9.5 °C at 871 °C as determined by the wire manufacturer [16]. The uncertainty of the temperature in the environment surrounding the thermocouple is known to be much greater than that of the wire[17][18]. Temperatures were not corrected for radiation since the radiant environment was dynamic and the local velocity needed for such a correction was not measured. Radiation tends to increase thermocouple temperatures in cooler regions of the fire room and to decrease thermocouple temperatures in hotter regions.

The thermocouple array over the platform floor area had a thermocouple located at 0.025 m, 0.30 m, 0.61 m, 0.91 m, 1.22 m, 1.52 m, 1.83 m, 2.13 m, 2.44 m, 2.74 m, 3.05 m, 3.35 m, 3.66 m below the ceiling. For the platform floor thermocouple array, the thermocouple that was located 3.66 m below the ceiling, was positioned on the platform floor. The two thermocouple arrays on the main floor also had a thermocouple located at 3.66 m below the ceiling, but in each case, the thermocouple was positioned 0.15 m above the main floor. Vertical thermocouple arrays were installed in the center of each wall of the alcove. Each array had a thermocouple located at 0.30 m, 0.61 m, 0.91 m, 1.22 m, 1.52 m, and 1.83 m below the ceiling of the alcove. A horizontal thermocouple array was installed 0.30 m below the ceiling. The array began at the centerline of the alcove opening and continued north along the rear wall, and then followed the platform wall west for 6.1 m. The thermocouples were spaced approximately 0.30 m apart. In addition, thermocouples were located adjacent to the sprinklers.

Selected temperatures versus time are plotted in Fig. 4-22 through Fig. 4-24 for the unsprinklered experiment. Results for the sprinklered experiment, at the same locations in the test room, are provided in Fig. 4-25 through Fig. 4-27. Additional temperature plots are presented in Appendix G.

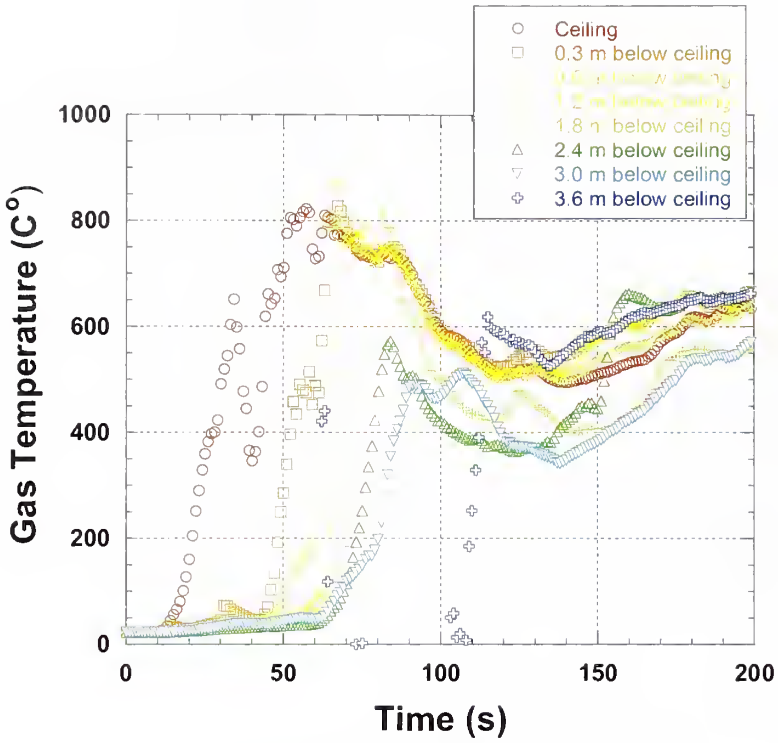


Figure 4-22. Temperatures versus Time for Unsprinklered Mockup Test. Thermocouples positioned on Platform (Location B) from ceiling to platform floor.

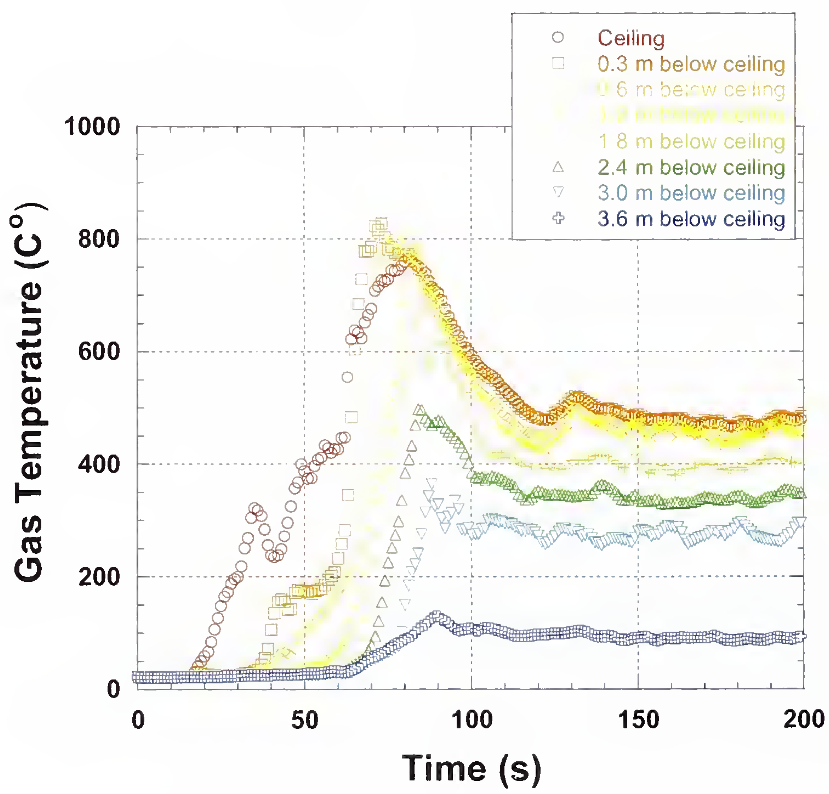


Figure 4-23. Temperatures versus Time for Unsprinklered Mockup Test. Thermocouples positioned on Main Floor (Location C) from ceiling to floor.

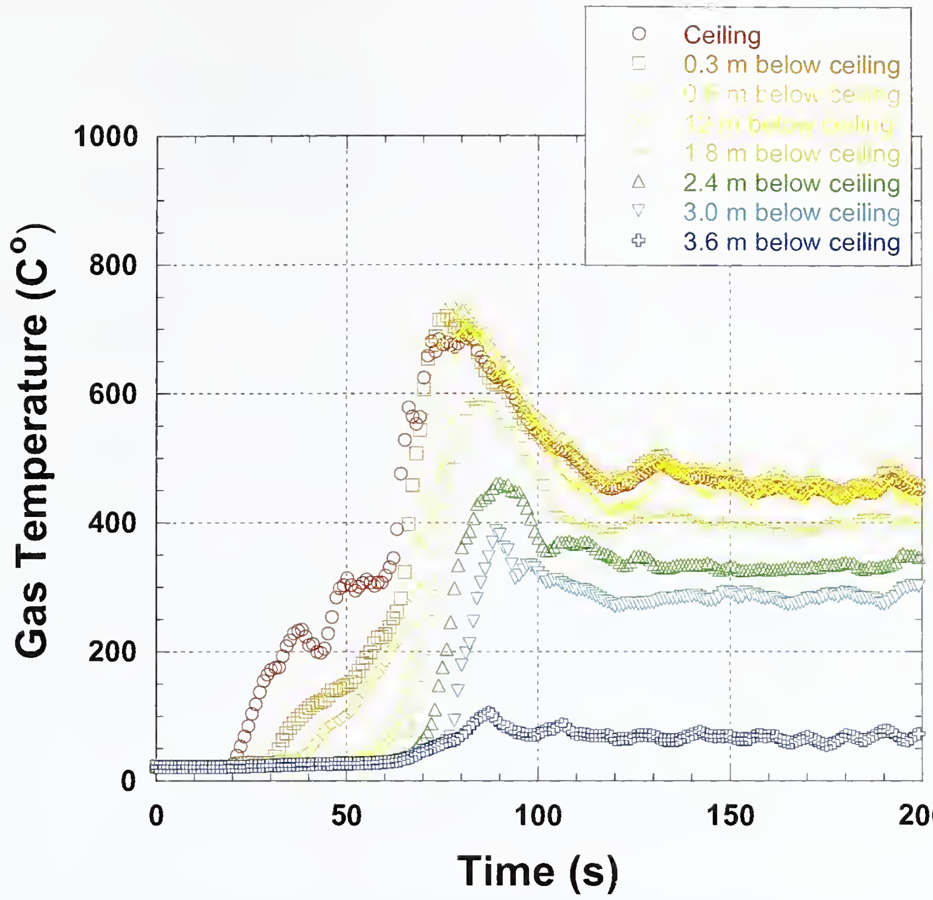


Figure 4-24. Temperatures versus Time for Unsprinklered Mockup Test. Thermocouples positioned on Main Floor (Location D) from ceiling to floor.

For the unsprinklered case, the temperature at the ceiling measured at location B (Fig. 4-22) began to increase within 10 seconds of ignition and continued to increase to over 800 °C in approximately 50 seconds. In less than 60 seconds, the temperature exceeded 50 °C at 1.4 m (4.5 ft) above the floor (2.4 m below the ceiling). The hot gases began to form an upper layer and the layer began to descend; in just over 110 seconds, the temperature at the floor of the platform had increased to over 600 °C.

The thermocouple array at location C was installed 6.7 m from the foam covered platform wall, 3 m further away from the platform wall than the thermocouples at location B. The temperatures required about 15 seconds longer to begin increasing than those measured at location B, and required approximately 70 seconds to reach peak temperatures of 800 °C. From Fig, 4-23 one can see that the temperatures at 3.6 m below the ceiling did not begin to increase until 60 seconds after ignition and then the temperatures reached peak values of approximately 100 °C in 90 s. The temperatures at location C exceeded 50 °C at the 1.4 m (4.5 ft) above the floor (2.4 m below the ceiling) elevation in less than 70 seconds.

The thermocouple array at location D was installed 8.5 m from the foam covered platform wall, an additional 1.8 m further away from the platform wall than the thermocouples at location C. The temperatures began to rise in about 20 seconds (see Fig. 4-24), and required approximately 80 seconds to reach peak temperatures of 700 °C. The temperatures at 3.6 m below the ceiling did not begin to increase until 70 seconds after ignition and reached peak values of approximately 100 °C in 90 s. The temperatures near the floor at location D were about the same as the values recorded at the floor on the platform, Location C.

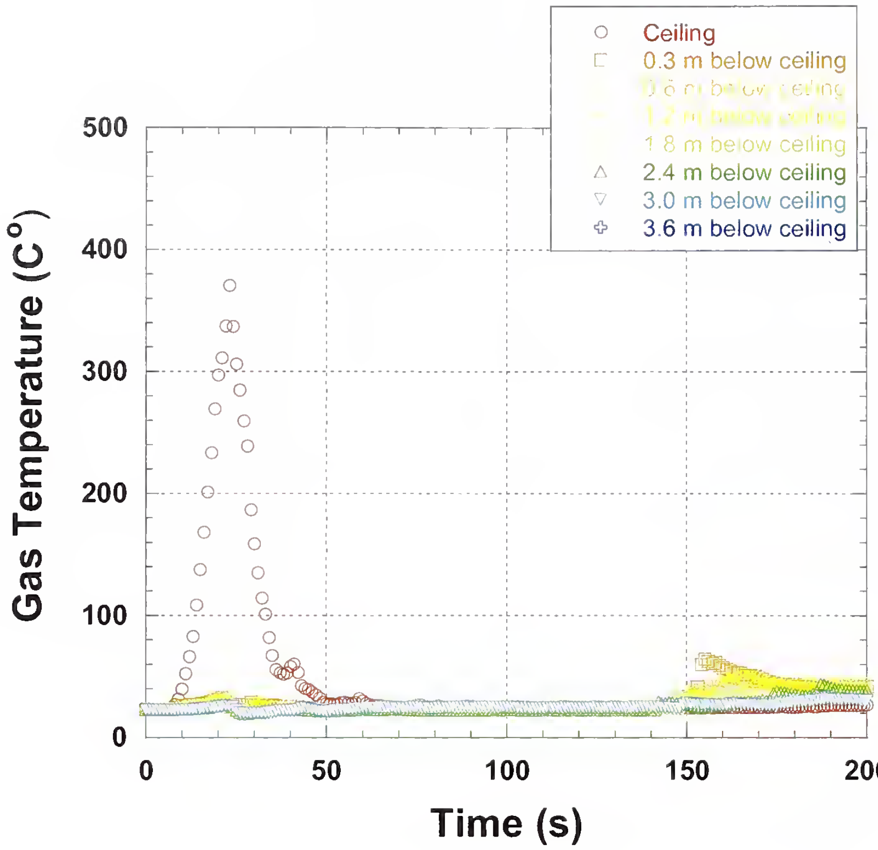


Figure 4-25. Temperatures versus Time for Sprinklered Mockup Test. Thermocouples positioned on Platform (Location B) from ceiling to platform floor.

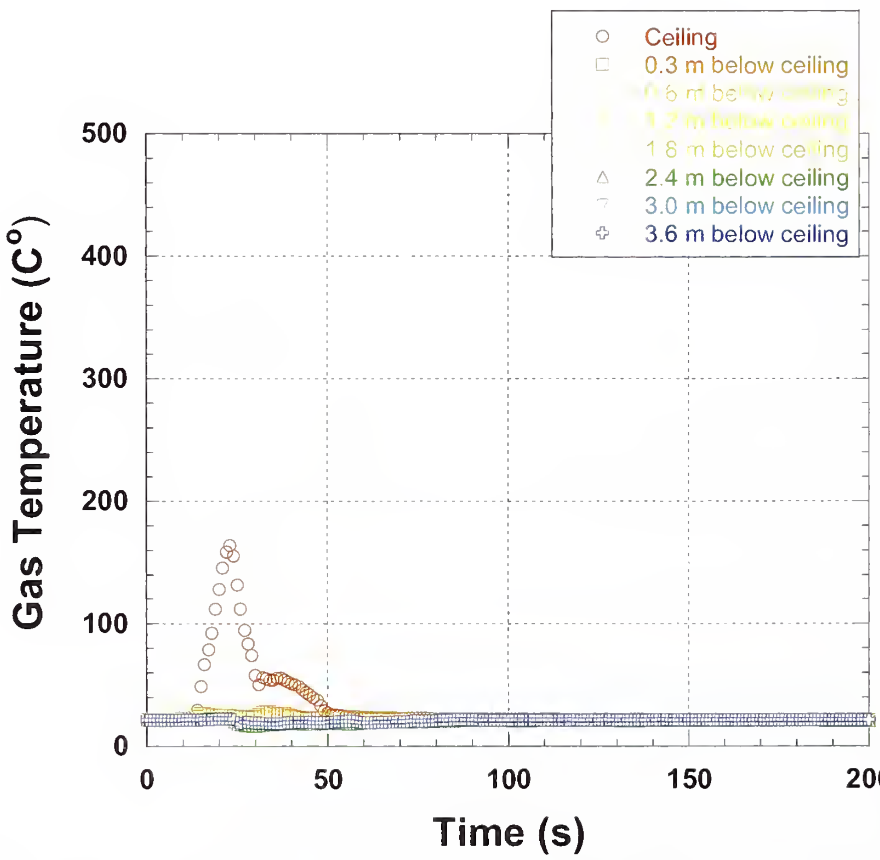


Figure 4- 26. Temperatures versus Time for Sprinklered Mockup Test. Thermocouples positioned on Main Floor (Location C) from ceiling to floor.

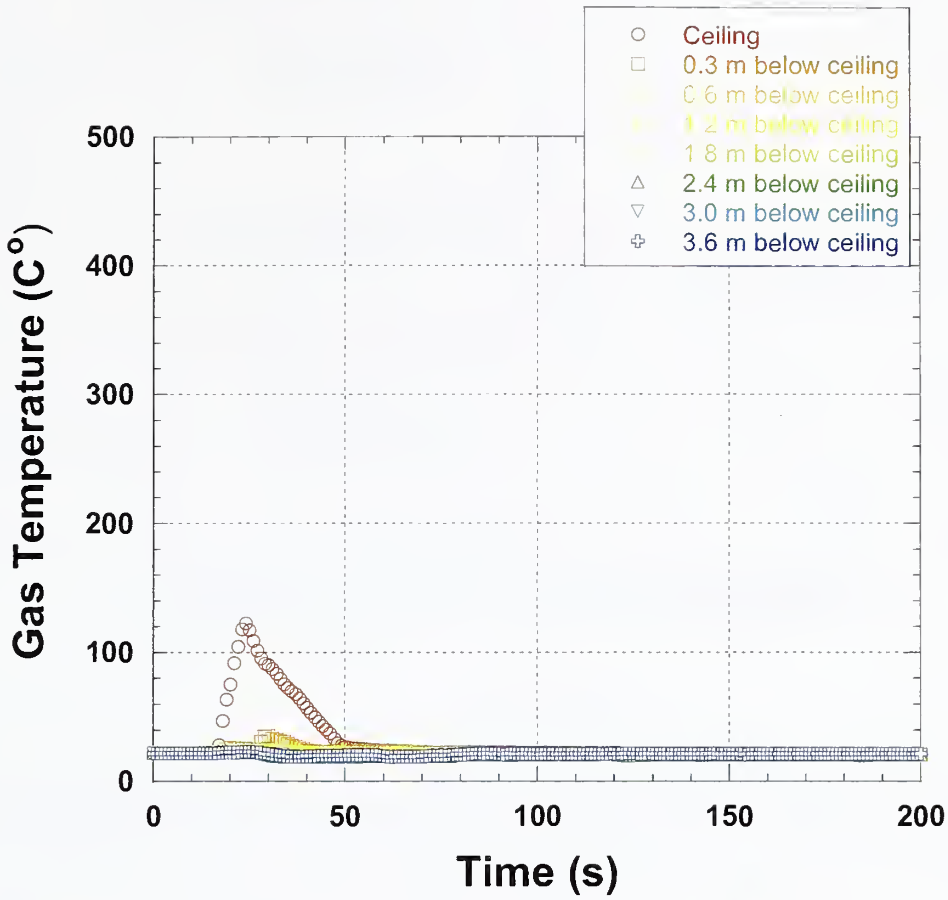


Figure 4-27. Temperatures versus Time for Sprinklered Mockup Test. Thermocouples positioned on Main Floor (Location D) from ceiling to floor.

For the sprinklered test burn, the ceiling thermocouple at location B (on the platform) recorded a peak temperature of 380 °C about 20 seconds after ignition, as can be seen in Fig. 4-25. When the sprinkler activated, the ceiling temperature quickly decreased, dropping to about 20 °C within 40 seconds of ignition. The activation of the sprinklers caused the other thermocouples at lower elevations to record near ambient temperatures throughout the test burn.

At location C (Fig. 4-26), the ceiling temperatures reached a peak temperature of 170 °C in about 20 seconds and declined to near ambient temperatures within 60 seconds. For location D (Fig. 4-27), the ceiling temperatures reached a peak temperature of 130 °C in about 20 seconds and declined to near ambient temperatures within 60 seconds. Thermocouples at lower elevations for both locations appeared to remain at near ambient temperatures throughout the test.

The comparison between the temperatures at the ceiling and 1.4 m above the floor for the sprinklered and unsprinklered experimental data is striking, as demonstrated in Fig. 4-28a for location C and Fig. 4-28b for location D. At 25 seconds, the temperatures at the ceiling were about 175 °C at location C and 125 °C at location D for both experiments, indicative of the fire being properly replicated up to the point when the sprinkler activated. During the next 25 seconds the temperatures throughout the compartment returned to close to ambient conditions in the sprinklered compartment. This compared to a continuing rapid rise in temperatures for the unsprinklered compartment, which reached ceiling temperatures in excess of 300 °C at 50 seconds, and peaks of 700 °C plus in the following 25 seconds. Peak temperatures of 400 °C to 500 °C were reached 1.4 m above the floor for the unsprinklered test; temperatures did not rise at all for the sprinklered compartment at this location.

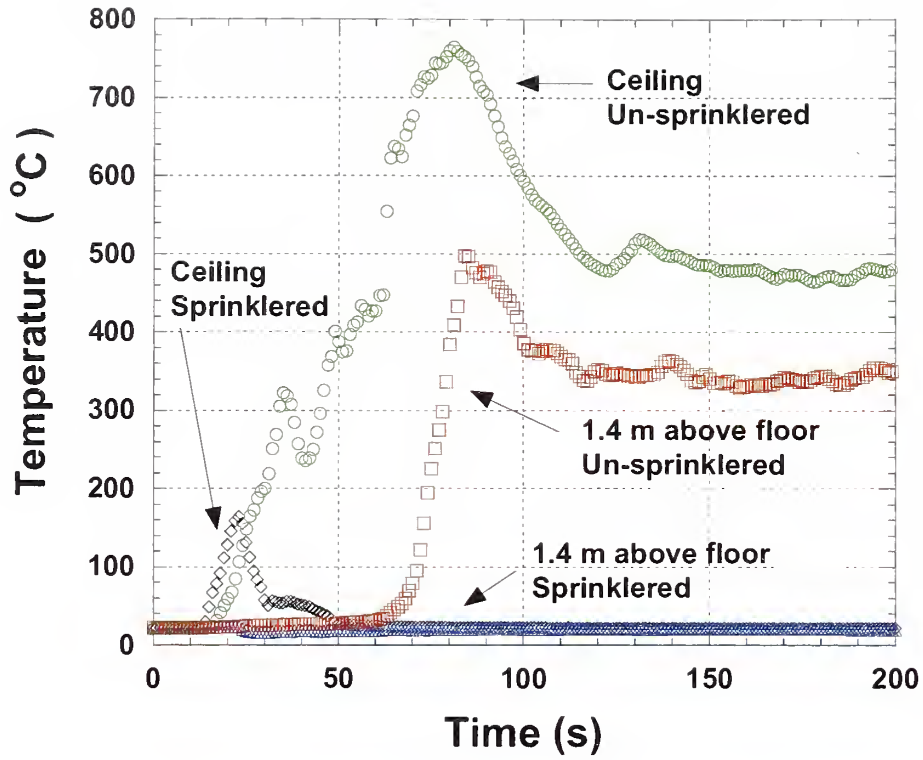


Figure 4-28a. Temperatures versus Time for Unsprinklered and Sprinklered Mockup Test. Thermocouples positioned on Main Floor (Location C) at ceiling and 1.4 m (4.5 ft) above floor.

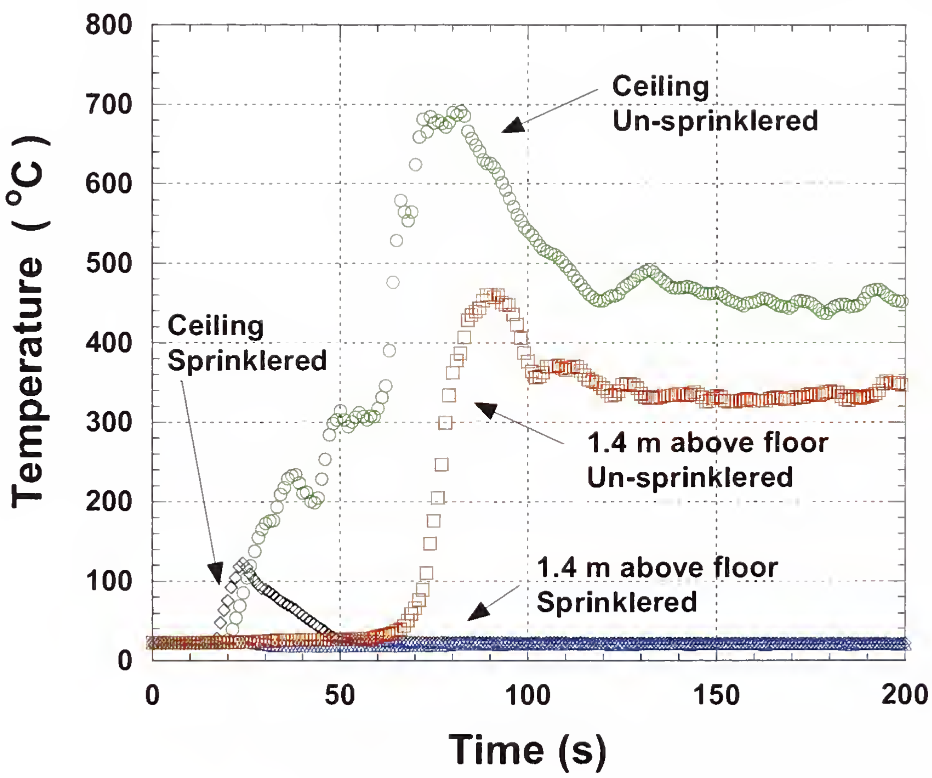


Figure 4-28b. Temperatures versus Time for Unsprinklered and Sprinklered Mockup Test. Thermocouples positioned on Main Floor (Location D) at ceiling and 1.4 m (4.5 ft) above floor.

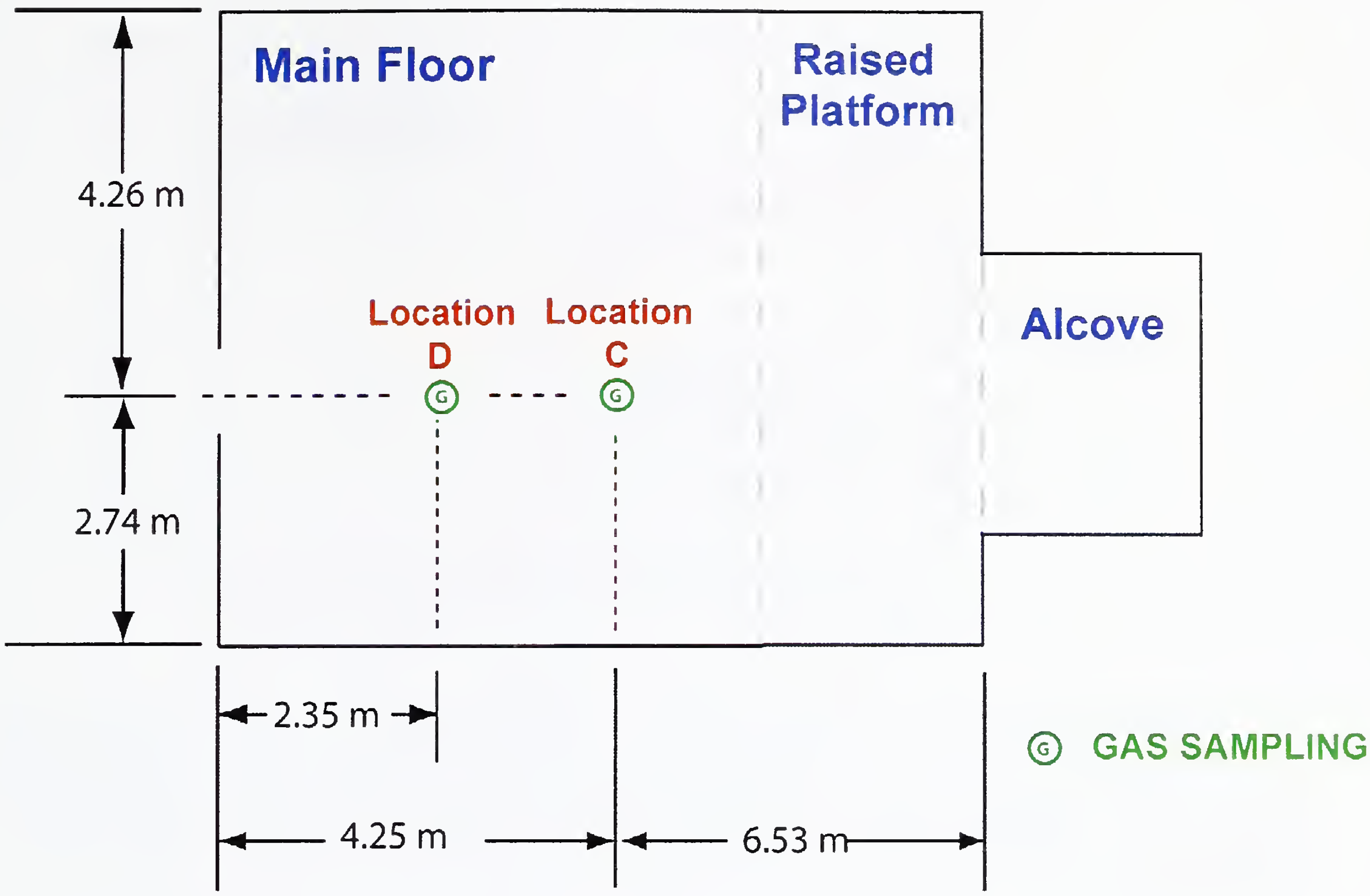


Figure 4-29. Schematic floor plan with gas sampling locations.

4.6.5 Oxygen Depletion and Gas Volume Fractions

For fires burning in the open under the laboratory hood, the chemical power measured by the oxygen depletion calorimeter is equal to the heat release rate from the fire as a function of time. However, for a fire within a room, the effluent from the enclosure is a mixed average of the upper layer gases, and does not represent the instantaneous heat release rate of the fire. With this limitation in mind, oxygen depletion rate was measured using the NIST 10 MW hood. The measurement system was calibrated with a gas burner placed directly under the hood (not in the enclosure) with heat release rates as high as 5 MW and an expanded uncertainty (95 % confidence level) of 11 % for fires larger than 400 kW. Bryant et al. [19] provide details on the operation and uncertainty in measurements associated with the oxygen depletion calorimeter.

There was a significant time delay between ignition of the foam in the full-scale mock-up and the first indication in the oxygen depletion calorimeter that heat was being released by the fire. The fire gases generated inside the test room did not exit the door way and enter the calorimeter until about 70 seconds later, and by the time they were detected, the combustion products had mixed with fresh air in the room. The result was that the measured heat release represented an average over time. The measured peak for the unsprinklered test was 4.3 MW. A steady heat release rate of about 3.4 MW was reached after about 150 seconds. The sprinklered experiments yielded no heat release rate measurements since the sprinklers quickly suppressed the fire after 25 seconds, a time shorter than the time lag discussed above.

Gas sample extraction probes 1.4 m above the floor were used to measure CO, CO_2, O_2 and HCN at the two locations shown in Fig, 4-29. The gases were pulled through 9.4 mm ID tubing to chemical analyzers

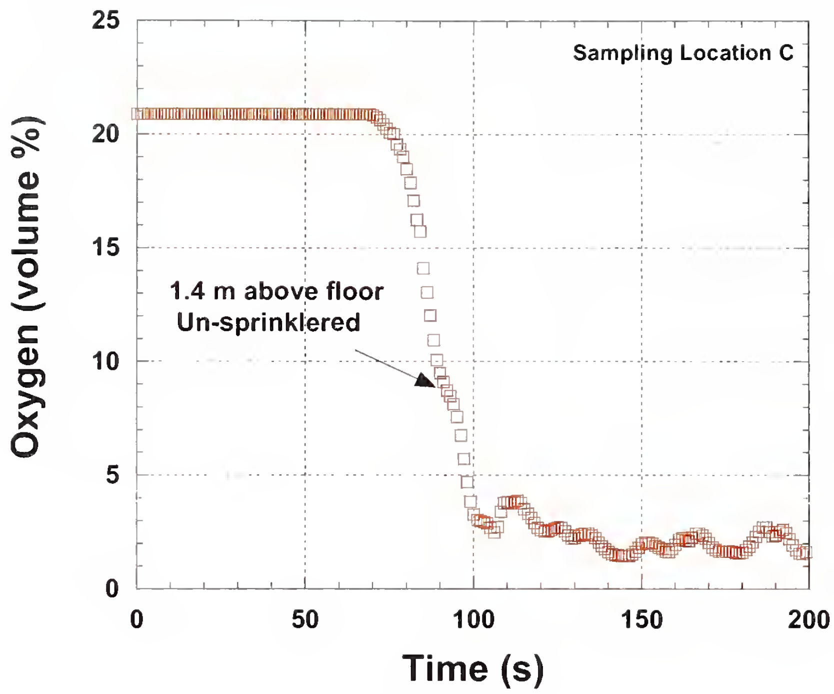


Figure 4- 30. Oxygen Volume Fraction vs Time for Unsprinklered and Sprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location C) at 1.4 m (4.5 ft) above floor.

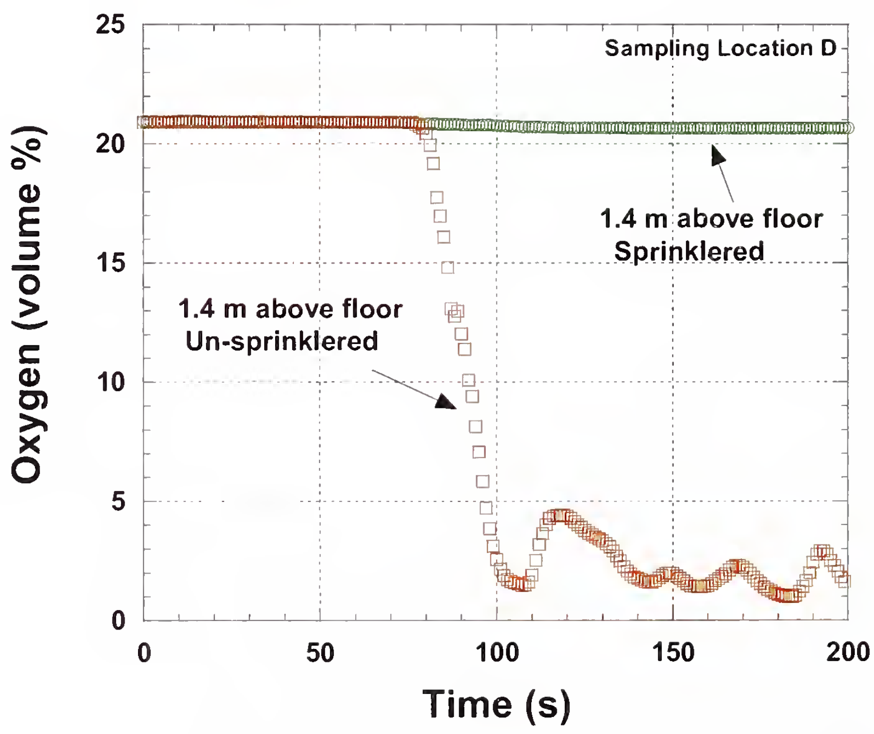


Figure 4-31. Oxygen Volume Fraction vs Time for Unsprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location D) at 1.4 m (4.5 ft) above floor.

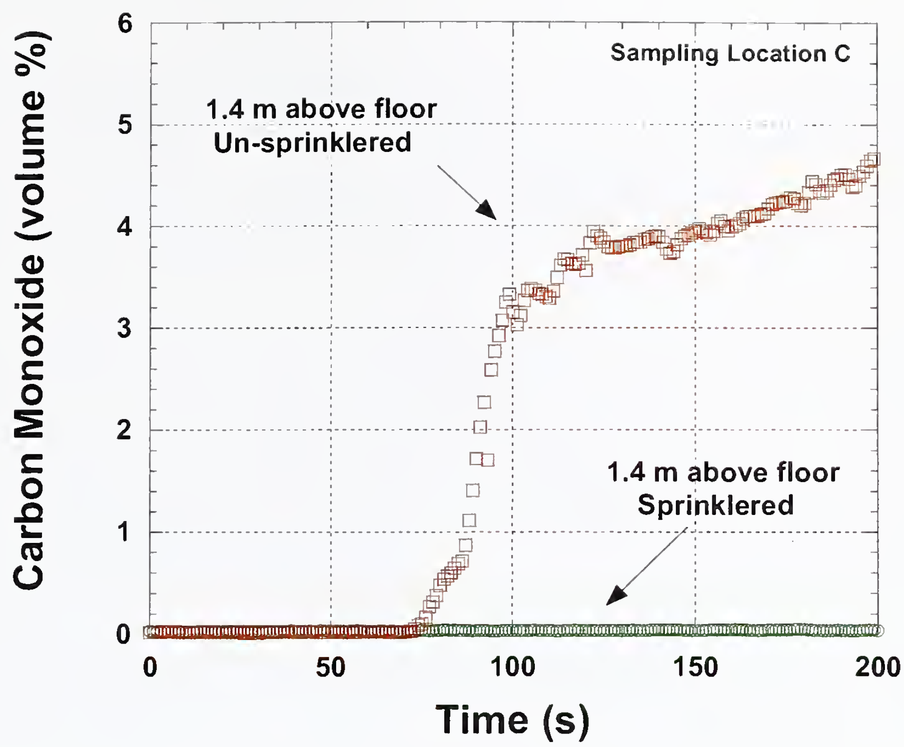


Figure 4-32. Carbon Monoxide Volume Fraction vs Time for Unsprinklered and Sprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location C) at 1.4 m (4.5 ft) above floor.

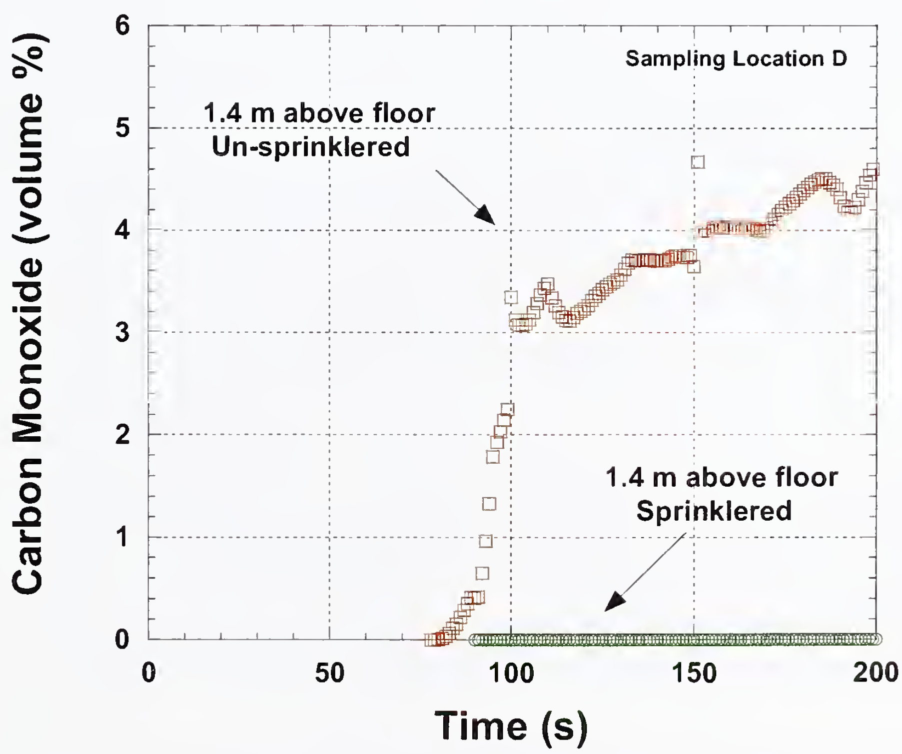


Figure 4-33. Carbon Monoxide Volume Fraction vs Time for Unsprinklered and Sprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location D) at 1.4 m (4.5 ft) above floor.

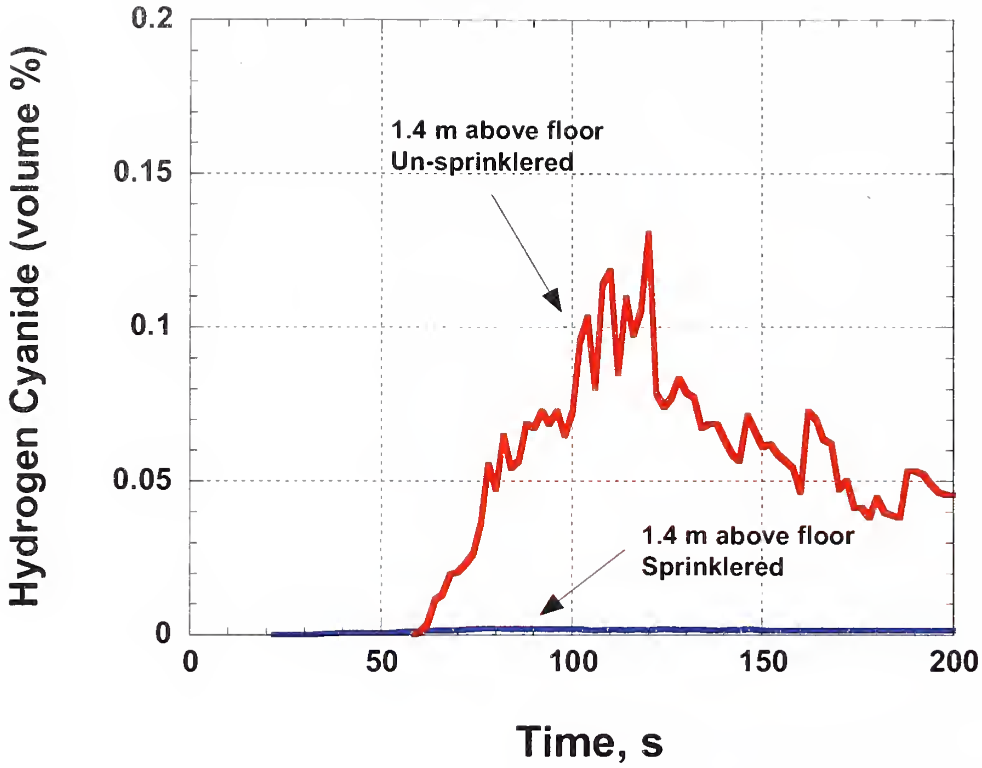


Figure 4-34. Hydrogen Cyanide Volume Fraction vs Time for Unsprinklered and Sprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location C) at 1.4 m (4.5 ft) above floor.

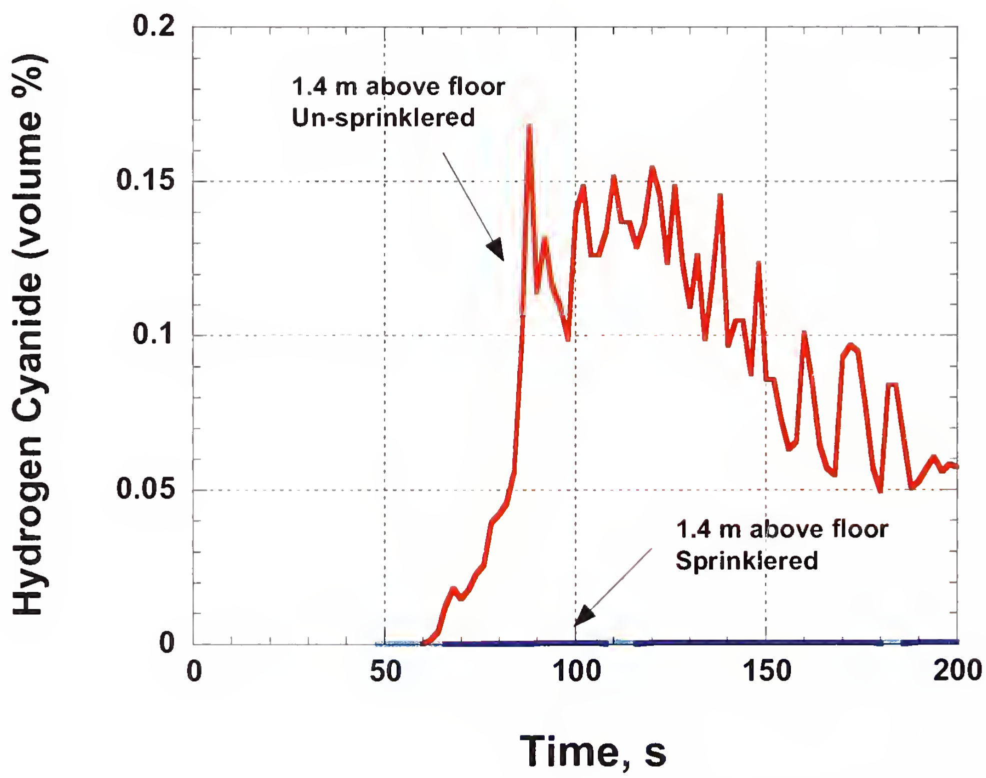


Figure 4-35. Hydrogen Cyanide Volume Fraction vs Time for Unsprinklered and Sprinklered Mockup Test. Gas Sampling probe positioned on Main Floor (Location D) at 1.4 m (4.5 ft) above floor.

after passing through moisture and particulate filters. Carbon monoxide and CO_2 volume fractions were monitored using non-dispersive infrared gas analyzers while the oxygen volume fractions were measured using paramagnetic analyzers. Hydrogen cyanide concentrations were monitored using impingers and real-time gas analyzers with cyanide combination electrodes. Each impinger utilized 0.1 M KOH as the trapping solution and samples were analyzed according to NIOSH Method 7904 [20].

During the sampling process, the gas sample for the oxygen, carbon monoxide, and carbon dioxide analysis was drawn through a cold trap which removed the water vapor. The oxygen, carbon monoxide, and carbon dioxide concentrations were recorded by each analyzer on a dry basis, and later corrected for the water removed by assuming that for every mole of carbon dioxide or carbon monoxide generated, one mole of water was also generated. By adding the water vapor back into the gas sample, the concentrations of oxygen, carbon monoxide, and carbon dioxide decreased. The hydrogen cyanide sample gas utilized a different sampling train and did not pass through a cold trap.

Gas volume fractions versus time are plotted for the unsprinklered and sprinklered tests in Figures 4-30 through 4-35 for O_2, CO and HCN. (Additional gas volume fractions measurements are discussed in Appendix G.) At both locations C and D, oxygen volume fractions did not begin to drop at the 1.4 m elevation until 70 seconds to 80 seconds after ignition for the unsprinklered mock-up experiments. At both locations, the oxygen volume fractions descended to less than 4 % in less than 100 seconds, then fluctuated between 1 % and 4 % . During the sprinklered test burns, the oxygen mole fraction at location D did not appear to drop much below ambient oxygen levels. (A malfunctioning oxygen analyzer prevented the oxygen concentrations from being monitored at location D during the sprinklered burns.)

At both locations C and D, volume fractions of carbon monoxide at the 1.4 m elevation did not begin to increase until 70 seconds to 80 seconds after ignition for the unsprinklered mock-up experiments, but then increased to 3 % in the next 20 seconds to 30 seconds and reached 4.5 % by 200 seconds after ignition. During the sprinklered test burns, the carbon monoxide concentration at neither location C nor location D appeared to increase much above ambient levels.

The volume fractions of hydrogen cyanide at the 1.4 m elevation began to increase 60 seconds after ignition for the unsprinklered mockup experiments. At location C, the HCN reached its peak value of 0.13 % in 120 seconds. The HCN increased slightly faster at location D, where it reached a peak volume fraction of 0.17 % in about 90 s. During the sprinklered test burns, the hydrogen cyanide concentration at locations C and D were barely above the measurable limit.

4.6.6 Heat Flux and Heat Detectors

Three elliptical radiometers were installed in the ceiling of the test cell viewing downward at location B, C, and D (Fig. 4-36). In addition to the radiometer at location B, a total heat flux gauge with an upward view was installed flush with the platform floor. At locations C and D, two additional total heat flux gauges were installed 1.5 m above the floor. One total heat flux gauge was position to have an upward view, while the other gauge had a view of the alcove. The heat flux sensors were water cooled Schmidt-Boelter type transducers.

For the unsprinklered compartment test, the output of the thermal radiation and total heat fluxes for the radiometer and heat flux gauges at locations C and D are shown in Fig. 4-37 and Fig 4-38. At location C, peak fluxes in excess of 50 kW/m^2 were reached about 70 seconds after ignition. Peak fluxes at location D were about 20 % lower than location C. At 100 seconds after ignition, radiation and heat flux at

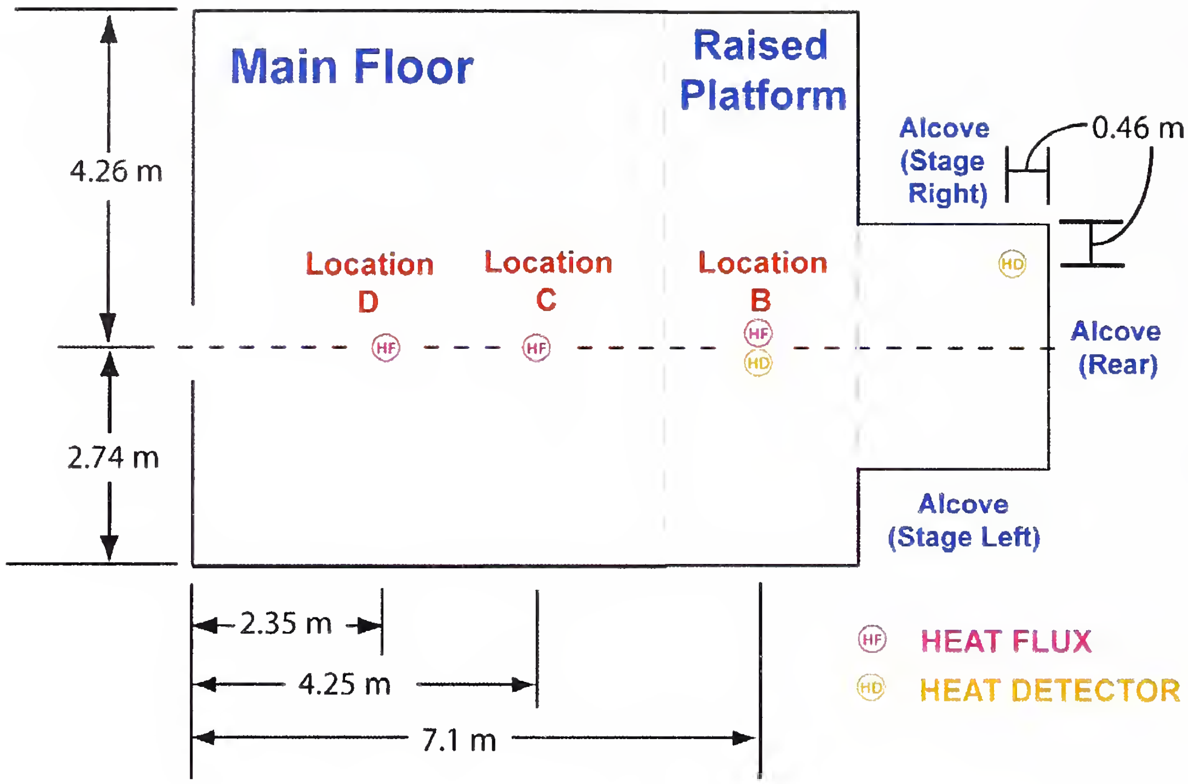


Figure 4-36. Schematic floor plan with heat flux and heat detector locations.

location C and the heat flux at location D decreased significantly to 20 kW/m^2 and appeared to remain relatively constant at both locations. The radiometer in the ceiling at location D dropped to 10 kW/m^2 before becoming relatively steady. (Additional plots of heat flux are shown and discussed in App. G.)

In the sprinklered test at locations C and D, neither radiation nor total heat flux reached levels much above the background. Only on the platform at location B was there a slight increase in radiation and total heat flux, starting around 20 seconds after ignition.

Two types of heat detectors were also installed: fixed temperature models with an activation temperature of 93 °C, and a rate of rise/fixed temperature model which activated when the rate of temperature increase exceeded about 7 °C /min or when the temperature reached 93 °C. One pair of detectors was installed on the ceiling, adjacent to the thermocouple array on the raised floor, and the second pair of heat detectors was installed on the ceiling in the north-east corner of the alcove.

The responses of rate of rise heat detectors and fixed temperature detectors are plotted in Fig. 4-39 and Fig. 4-40, respectively. For both unsprinklered and sprinklered test burns, each of the rate of rise detectors activated in less than 20 seconds. Only in the unsprinklered experiments did the fixed temperature detectors activate. The fixed temperature detector in the alcove activated in about 20 seconds while the fixed temperature detector above the platform required almost 40 seconds to respond.

4.6.7 Sprinkler Activation

Five sprinkler heads were installed on a nominal 3.66 m spacing. One sprinkler was installed centered in the alcove, two were installed over the platform, and two over the main floor area. (See Figure 4-41.) The

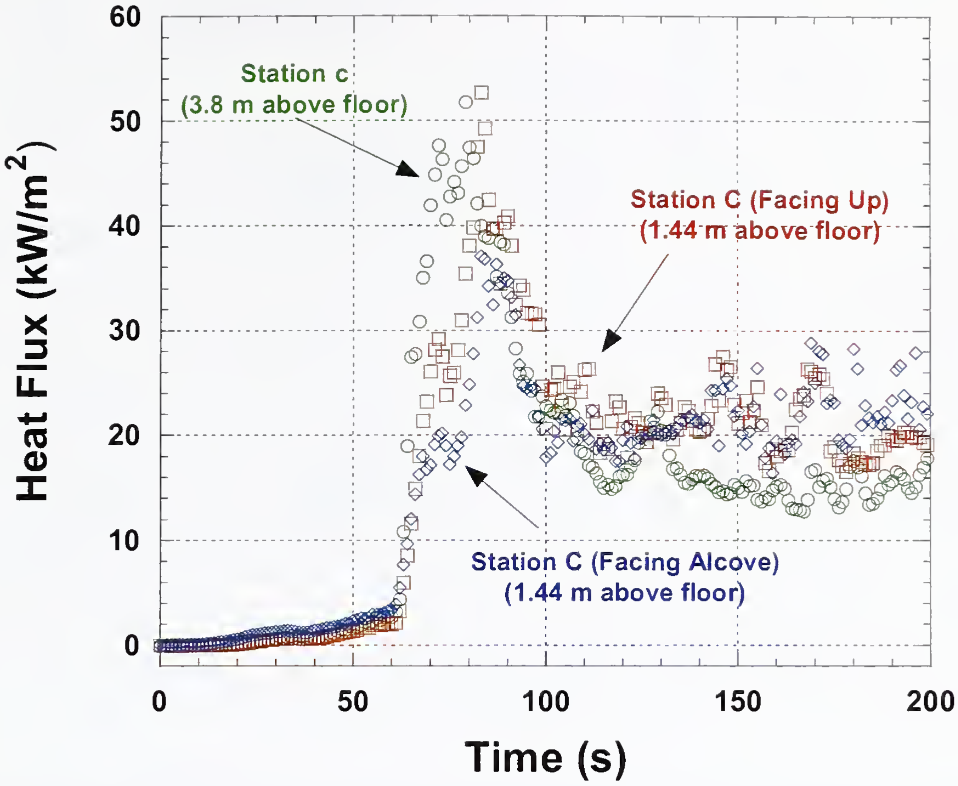


Figure 4- 37. Heat Fluxes versus time for unsprinklered mockup test. Radiometer positioned flush with ceiling (3.8 m above floor); heat flux gauges facing up (1.44 m above floor), and facing alcove (1.44 m above floor) at sampling location C.

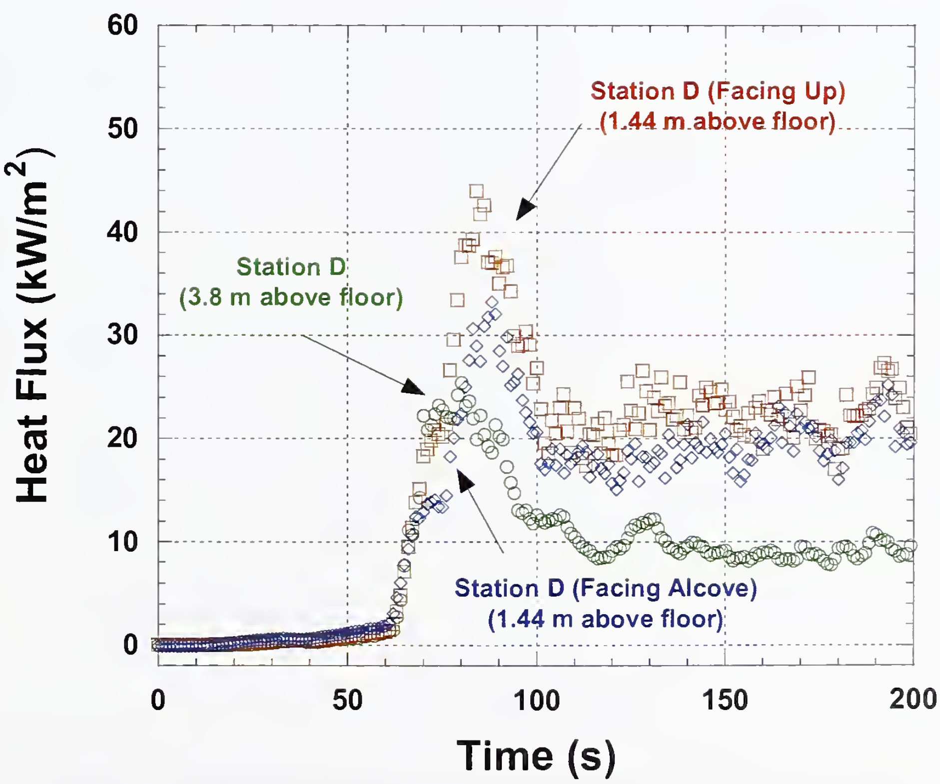


Figure 4- 38. Heat fluxes versus time for unsprinklered mockup test. Radiometer positioned flush with ceiling (3.8 m above floor); heat flux gauges facing up (1.44 m above floor), and facing alcove (1.44 m above floor) at sampling location D.

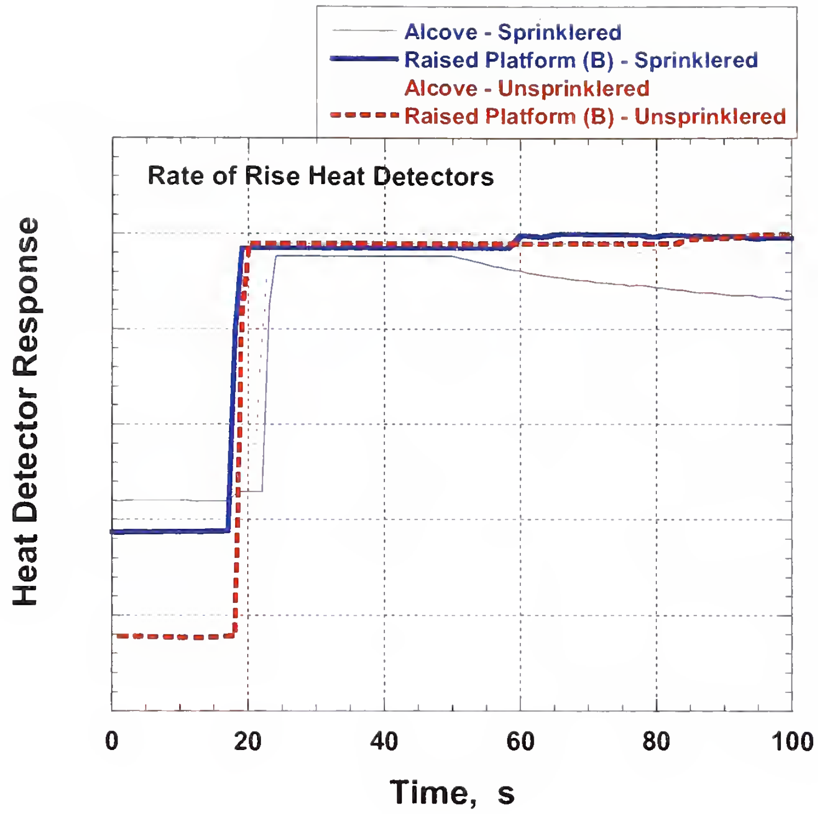


Figure 4- 39. Response of Rate of Rise Heat Detectors versus Time for Unsprinklered and Sprinklered Mockup. Detectors located in Alcove and at Location B.

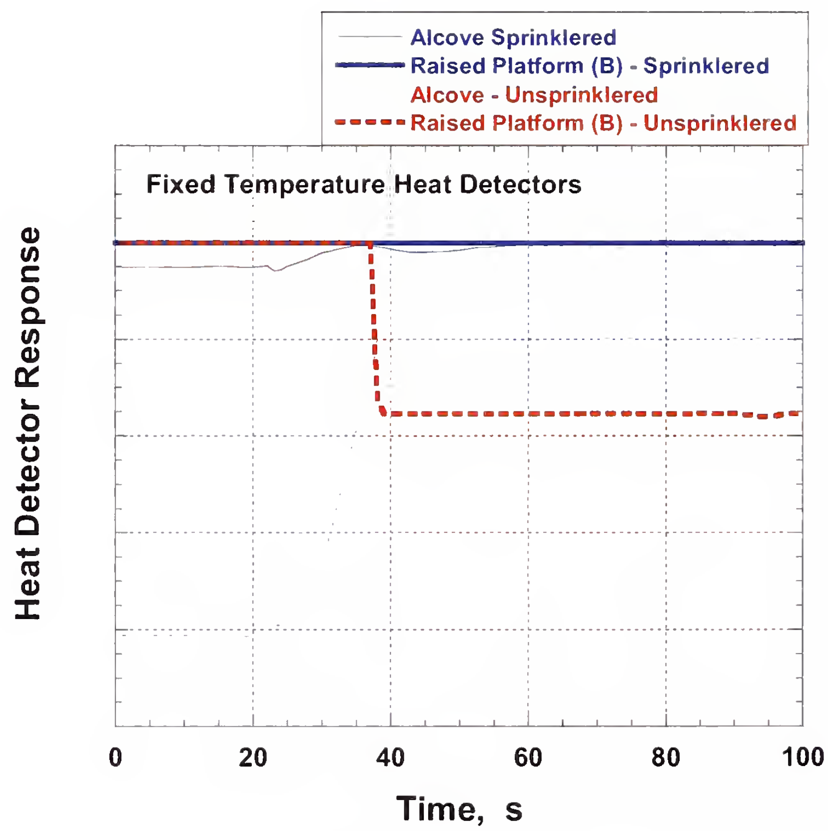


Figure 4- 40. Response of Fixed Temperature Heat Detectors versus Time for Unsprinklered and Sprinklered Mockup. Detectors located in Alcove and at Location B.

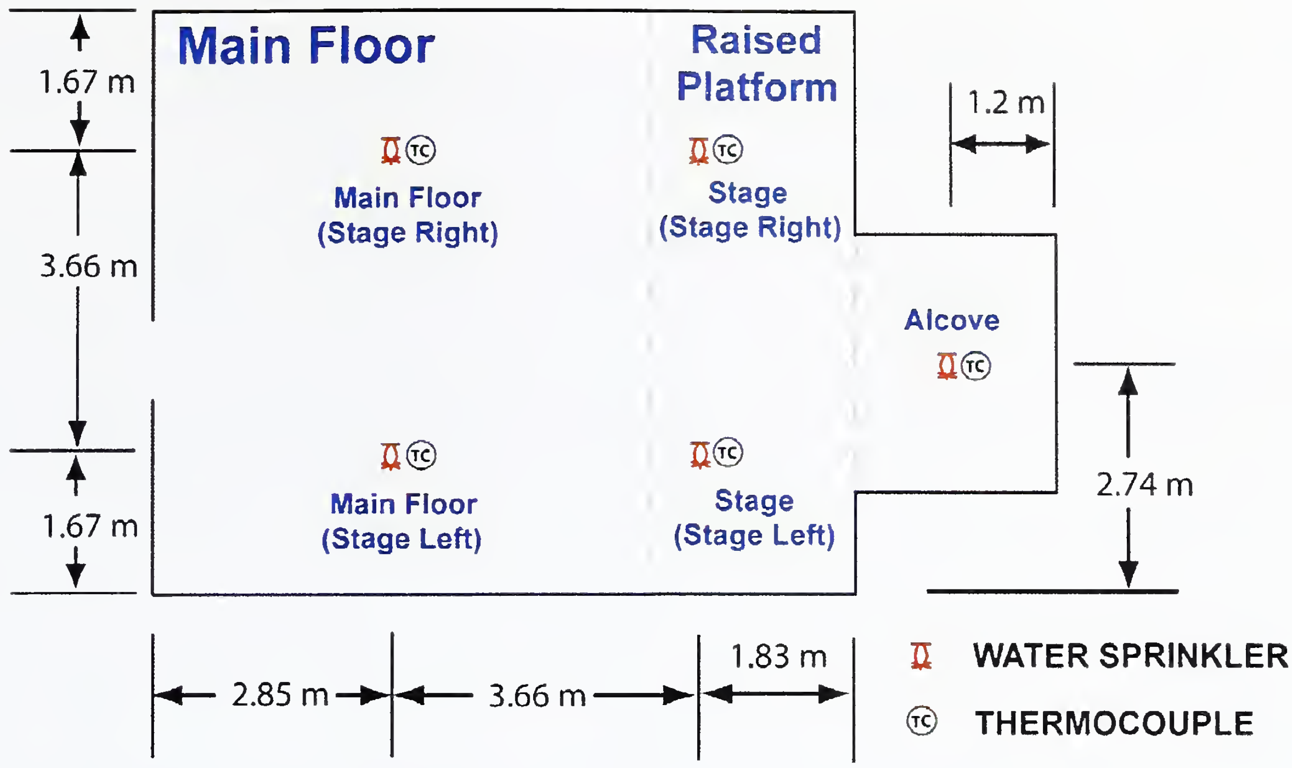


Figure 4- 41. Schematic Diagram of Sprinkler and Sprinkler Thermocouple Locations.

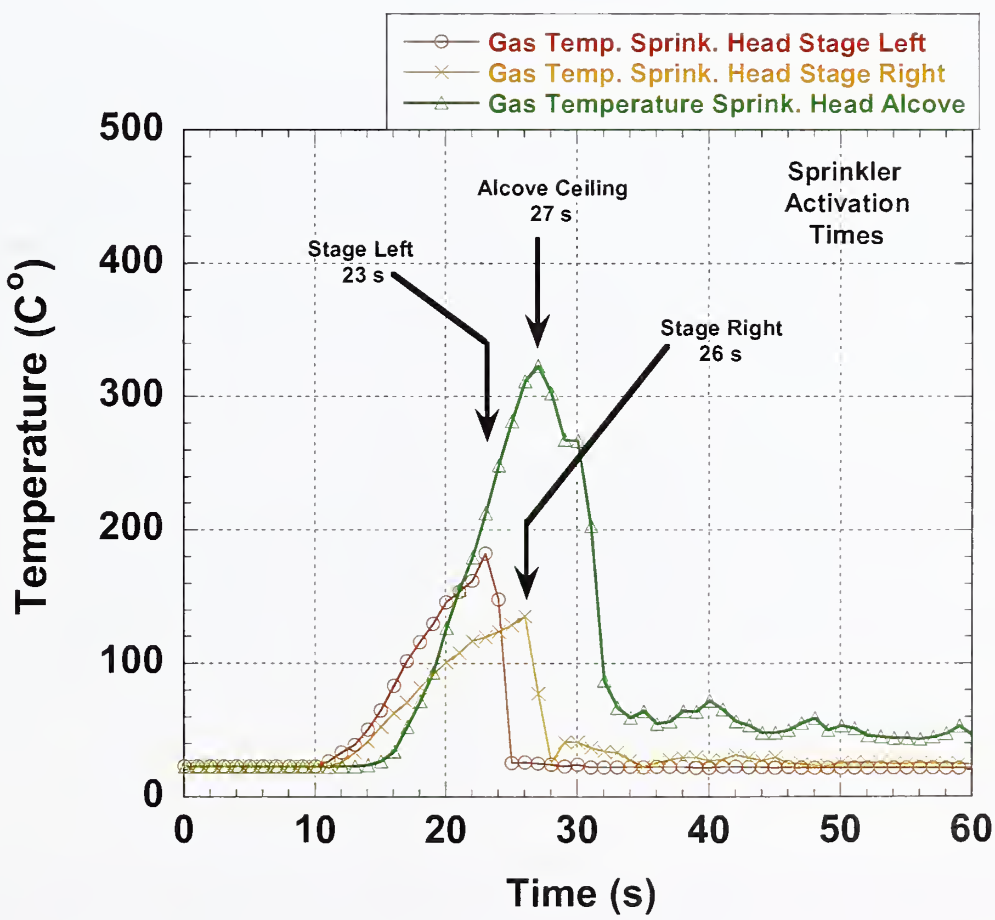


Figure 4- 42. Temperature versus Time for Sprinkler Thermocouples.

Table 4.5 Time to Reach Untenability Criteria, or maximum deviation obtained

	Temperature > 120 °C	Heat Flux > 2.5 kW/m²	Oxygen < 12 %	Hydrogen Cyanide > 0.02 %	Carbon Monoxide > 0.5 %
Sprinklered					
Location B	< 28 °C	not measured	not measured	not measured	not measured
Location C	< 24 °C	< 0.32 kW/m²	not measured	< 0.004 %	< 0.002 %
Location D	< 24 °C	< 0.21 kW/m²	> 20.6 %	< 0.0006 %	< 0.04 %
Unsprinklered					
Location B	71 seconds	not measured	not measured	not measured	not measured
Location C	76 seconds	61 seconds	87 seconds	71 seconds	82 seconds
Location D	71 seconds	61 seconds	85 seconds	75 seconds	92 seconds

sprinkler installation and water supply were based on a light hazard classification in accordance with NFPA 13 [21].

For the sprinklered experiments, each of the five installed sprinklers was supplied via a common water source capable of providing approximately 4.1 mm/min water spray density if all heads were activated. The sprinklers used were commercially available pendent-type with a nominal 15 mm standard orifice. The listed activation temperature for all of the sprinklers used was 74 °C and were of the quick response type. The temperatures monitored by a thermocouple that was positioned next to the sprinkler head are plotted versus time in Fig. 4-42. The first sprinkler, above the platform at stage-left, activated in 23 seconds. The sprinkler above the platform on stage-right was the next to activate at 26 seconds. One second later the sprinkler in the alcove activated. No other sprinkler was triggered.

In the unsprinklered experiment, standard response pendent sprinklers were installed without a water supply. The sprinklers were attached to a 150 mm (6 in) length of 19 mm (0.75 in) pipe that was filled with water and pressurized with air. The sprinkler was monitored for time to activation with a pressure sensor that was attached to the short length of pipe. The only difference between the sprinklers installed in the unsprinklered experiment and the sprinklered experiment was the thermal element. In the unsprinklered experiment, at 33 s after ignition, the sprinkler above the platform at stage left was the first standard response sprinkler to activate.

4.6.8 Tenability

According to Purser [22] a room becomes untenable for people when any of the following occur: the temperature exceeds 120 °C (250 °F), a heat flux exceeds 2.5 kW/m², or the oxygen volume fraction drops below 12 %. These levels provide guidelines generally accepted by the fire protection engineering profession as leading to quick incapacitation, but may be tolerated for a short (unspecified) time. Hydrogen cyanide and carbon monoxide also represent significant hazards to humans. The lowest concentration of a material in air that has been reported to have caused death in humans is termed Lethal

Concentration Low (LCLo). The LCLo (inhalation) for hydrogen cyanide is reported as 0.02 % for 5 minutes [23]. For carbon monoxide the LCLo (inhalation) is listed at 0.5 % for 5 minutes [23].

The upper portion of Table 4-5 summarizes the temperatures, heat fluxes, oxygen volume fractions, CO volume fractions, and HCN volume fractions measured at locations B, C, and D at an elevation 1.4 m above the floor(approximately head-height) for the sprinklered test. Also listed are the tenability criteria and LCLo levels. In the sprinklered test, conditions did not exceed any of the tenability criteria (temperature, heat flux, or oxygen volume fraction), or the LCLo volume fractions for either hydrogen cyanide or carbon monoxide during the entire duration of the test (> 200 seconds). The maximum values for temperature, heat flux, hydrogen cyanide and carbon monoxide as well as the minimum value for oxygen that were recorded during the sprinklered test are shown in the table.

In the test with the unsprinklered mock-up, the temperature criterion can be seen in Table 4-5 to have been exceeded in less than 76 seconds at all three locations. The thermal flux exceeded 2.5 kW/m^2 in about 60 seconds. At sampling location C and D, the oxygen concentration dropped below 12 % in less than 87 seconds. The hydrogen cyanide concentrations exceeded the LCLo in less than 75 seconds and the carbon monoxide concentrations reached its LCLo in less than 92 seconds.

Exceeding the tenability limit does not imply that any or all occupants who are present in that environment will succumb due to a particular limit exceeded. The length of time exposed, the rate of change of the environmental conditions, possible antagonistic effects, and the susceptibility of the individual all play a role. With this limited set of data from a single mockup experiment, it is not possible to determine whether an occupant of The Station nightclub would have first fallen victim to the high heat flux, to the high temperature, to the lack of oxygen, or to the hydrogen cyanide, carbon monoxide or smoke levels, or even to the crush of the crowd. (Note that NIST was unable to get access to the Rhode Island Medical Examiner's report due the ongoing criminal investigation, and was therefore unable to relate findings regarding the conditions in the nightclub to possible causes of death.) Given the rapid spread of the fire and combustion products, it is likely that the victims succumbed to multiple conditions. If conditions developed in The Station in the same manner as during this mock-up, most occupants likely would have had less than 90 seconds to escape under tenable conditions.

4.7 REFERENCES FOR CHAPTER 4

[1] Duval, R., "Fires in Places of Assembly", presented at NFPA Fall Education Conference, Miami, FL, November 14 – 17, 2004, National Fire Protection Association, Quincy, MA.

[2] UL 94- Test for Flammability of Plastic Materials for Parts in Devices and Appliances, Fifth Edition, October 29, 1996, Underwriters Laboratories, Inc., Northbrook, IL, p. 34.

[3] ASTM E84-04 – Standard Test Method for Surface Burning Characteristics of Building Materials, ASTM Fire Standards, Sixth Edition, American Society for Testing and Materials, West Conshohocken, PA, pp 1000- 1018.

[4] ASTM E 1354-04a, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, ASTM International, West Conshohocken, PA, 2004.

[5] ASTM D 1929 - *Standard Test Method for Determining Ignition Temperatures of Plastics*, ASTM International, West Conshohocken, PA, 2004.

[6] *Society of Fire Protection Engineers' Handbook of Fire Protection Engineering*, Third Edition, P.J. DiNenno, Editor-in-Chief, Society of Fire Protection Engineers, Bethesda, MD, pp. A-32 - A-42, 2002.

[7] *Fire Protection Handbook, Nineteenth Edition*, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, MA, pp. 8-38 – 8-39, 2003.

[8] Troitzsch, J., "The Burning of Plastics", Chapter 4 in International Plastics Flammability Handbook, Second Edition, Hanser Publishers, New York, NY, 1983, pp 16 – 30.

[9] Ma, S., Venart, J.E.S., and Sousa, A.C.M., "Cone Calorimeter Measurements of Ignition and Fire Properties of Several Building Materials," *International Conference on Fire Science and Engineering*, Hong Kong, March 15 – 16, 1995, pp. 629 –634.

[10] ISO 1716, "Reaction to fire tests for building products-Determination of the heat of combustion," *ISO*, Annex B, 2002.

[11] Marchal, A., Yoshida, M., and Hasemi, Y., "Asia-Oceania ISO 5660 Cone Calorimeter Inter-Laboratory Trials," in *Thirteenth Meeting of the UJNR Panel on Fire Research and Safety, March 13 – 20, 1996*, NISTIR 6030, National Institute of Standards and Technology, Gaithersburg, MD, 1997, pp. 173 – 214.

[12] "Polyurethanes," in *Fire Retardant Materials*, Edited by A.R. Horrocks and D. Price, Woodhead Publishing Limited, Cambridge England, 2001, pp.243-245.

[13] *Fire Protection Handbook, Seventeenth Edition*, A.E. Cote, Editor-in-Chief, National Fire Protection Association, Quincy, MA, p. 3-111, 2001.

[14] ASTM E 1354-04a, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter*, ASTM International, West Conshohocken, PA, 2004.

[15] *ASTM E84: Standard Test Method for Surface Burning Characteristics of Building Materials*, ASTM International, West Conshohocken, PA, 2002.

[16] Omega Engineering Inc., (2000) *The Temperature Handbook*, Vol. MM, pages Z-39-40, Stamford, CT.

[17] Blevins, L.G., "Behavior of Bare and Aspirated Thermocouples in Compartment Fires", *National Heat Transfer Conference, 33rd Proceedings*. HTD99-280. August 15-17, 1999, Albuquerque, NM, 1999.

[18] Pitts, W.M., E. Braun, R.D. Peacock, H.E. Mitler, E. L. Johnsson, P.A. Reneke, and L.G.Blevins, "Temperature Uncertainties for Bare-Bead and Aspirated Thermocouple Measurements in Fire Environments," *Thermal Measurements: The Foundation of Fire Standards. American Society for Testing and Materials (ASTM). Proceedings*. ASTM STP 1427. December 3, 2001, Dallas, TX.

[19] Bryant, R.A., Ohlemiller, T.J., Johnsson, E.L., Hamins, A.H., Grove, B.S., Guthrie, W.F., Maranghides, A., and Mulholland, G.W., *The NIST 3 MW Quantitative Heat Release Rate Facility*, NIST Special Publication 1007, National Institute of Standards and Technology, Gaithersburg, MD, 2003.

[20] "Cyanides, Aersol and Gas, Method 7904," *NIOSH Manual of Analytical Methods*, Fourth Edition, 8/15/94.

[21] NFPA 13 (2002), *Standard for the Installation of Sprinkler Systems*, National Fire Protection Association, Quincy MA.

[22] Purser, D.A., "Toxicity Assessment of Combustion Products," in Society of Fire Protection Engineers' Handbook of Fire Protection Engineering, Third Edition, DiNenno,P.J., Editor-in-Chief, Society of Fire Protection Engineers, Bethesda, MD, 2002.

[23] Lewis, R.J., Sax's *Dangerous Properties of Industrial Materials*, Ninth Edition, Van Nostrand Reinhold, New York, NY, 1995.

[24] Zicherman, J.B., The Fire Incident at "The Station", Report FCA NO 04-5667, Fire Cause Analysis, 213 W. Cutting Blvd., Richmond, CA 94804, November 10, 2003.

Chapter 5
COMPUTER SIMULATION OF FIRE AND SMOKE SPREAD

The WPRI-TV video tape provided information to the investigation of the start and spread of the fire that was almost unprecedented in fire forensics. Supplemented with first person interviews and examination of the scene after the fact, a clear overall picture of the event emerged rather quickly. However, a number of important details could not be gleaned from the evidence, nor was it possible to examine the impact of the fire on the occupants. Both would have helped to understand the fire's effect on the evacuation process and to determine the relative importance of different contributors to the building failure.

Computer simulation has been demonstrated to be credible, when properly applied, as a tool to help fill in critical details of a fire incident and to demonstrate the value of alternative building designs and fire safety measures[1-14]. This chapter presents the results of numerical simulations and analyses of fire spread, smoke movement, tenability, and operation of fire protection systems that relate to the conditions in The Station on the night of Feb. 20, 2003.

The numerical models used in this investigation were the NIST Fire Dynamics Simulator (FDS) [15] and Smokeview [16]. The essential fire properties of the materials needed as input to FDS were generated from the small scale and real scale measurements described in Chapter 4. The following sections provide an overview of the models, describe how the testing was used to add credence to the simulations, and present the results of the full nightclub simulations.

5.1 NIST FIRE DYNAMICS SIMULATOR

The NIST Fire Dynamics Simulator is a computational fluid dynamics (CFD) 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 [17]. Version 1 was publicly released in February 2000. The predictions performed here were made with the public pre-release version 4 of the model. Version 4 includes several new features, including multi-blocking, which were critical in performing the full nightclub simulations.

A CFD model requires that the room or building of interest be divided into small three-dimensional rectangular control volumes or computational cells. The CFD model computes the density, velocity, temperature, pressure and species concentration of the gas in each cell as it steps through time. Based on the laws of conservation of mass, momentum, species, and energy, the model tracks the generation and movement of fire gases. Radiative heat transfer is included in the model via the solution of the radiation transport equation for a non-scattering gray gas. All solid surfaces are assigned thermal boundary conditions, plus information about their burning behavior. Heat and mass transfer to and from solid surfaces is usually handled with empirical correlations. FDS utilizes material properties of the furnishings, walls, floors, and ceilings to compute fire growth and spread. A complete description of the FDS model as well as the technical references which support the model are given in references [15,17].

Inputs required by FDS include the geometry of the structure, the computational cell size, the location of the ignition source, the energy release rate of the ignition source, thermal properties of walls, ceilings, floors, furnishings, and the size, location, and timing of door and window openings to the outside which critically influence fire growth and spread.

5.1.1 Geometry

FDS approximates the governing equations on a rectilinear grid. This three-dimensional grid represents the volume modeled by FDS. The grid is isolated from the surroundings, that is, all the smoke and heat generated by the fire stays within the grid and the air does not enter the grid. The user may, however, prescribe vents that allow smoke and heat to leave and air to enter the grid area. The user prescribes rectangular obstructions that are forced to conform to the underlying grid. Multi-blocking is a term used to describe the use of more than one rectangular grid or mesh in a calculation.

FDS predictions are sensitive to grid size; using a larger number of smaller cells will generally capture more features of the flow; however, the computation time increases more than linearly with the increase in number of grid cells. Computation times of one day on a fast computer are not uncommon but may increase to several months with a large number of grid cells. Therefore, it is important to use the smallest number of grid cells that still capture the important features of the fire. One way to reduce the number of grid cells is the use of multi-blocking. With multi-blocking, smaller grid cells that capture more detail are used near the fire and larger grid cells with less detail are used remote from the fire.

Building items such as walls, floors, windows, doors and furniture are described in FDS as rectilinear blocks. These blocks must have sides that are either horizontal or vertical and no sloped or curved surfaces are allowed. The blocks may be colored for identification and may be assigned material properties. The blocks may be entered into the simulation with exact measurements from the building. However FDS can only work with items that fall exactly on grid cell boundaries. FDS takes the input blocks and adjusts them to match the grid cell boundaries. As a result, items may either grow or shrink to match the grid. In most cases this does not have a major impact on the calculations, although it can result in walls with no thickness or walls with gaps at intersections. Usually these issues are resolved by adjusting the size of the blocks slightly to produce the desired geometry that matches the grid size.

5.1.2 Materials

When a wall, ceiling, floor, piece of furniture, or any other material is defined for use in the FDS model, it is given a set of physical and thermal properties that are used by the model. Some of these properties such as thermal diffusivity, thermal conductivity, density and thickness impact the heat transfer in the material. For materials that burn, additional parameters such as ignition temperature, heat of combustion, heat of vaporization and maximum burning rate are specified. The properties for the materials, to the extent they were available, were taken from standard references or fire experiments.

The combustion process is handled in two ways within FDS. In one version, the fuel gasification rate is related to the radiant heat flux imposed from the fire onto the material. The mass burning rates of these same materials are measured in a cone calorimeter (or similar) apparatus; hence, the importance of collecting these data as described in Chapter 4. An alternative way to handle the gasification of fuel in FDS is to base the fuel generation rate on a measured heat of vaporization and ignition temperature. Both versions utilize a mixture fraction combustion model, in which burning occurs in regions where the fuel and air are in stoichiometric proportion. The second approach was used in FDS to model both the mock-up experiments and the full nightclub fire.

The accuracy of either of these combustion models is related to the complexity of the fuel and the resolution of the numerical grid used during the simulation. A maximum burning rate is imposed to limit the amount of pyrolysis that can occur regardless of the amount of heat flux impinging on the surface of the fuel. To the extent that the heat release rates measured for the polyurethane foams by NIST and ATF differed, this had no effect on the calculations presented in this chapter since the same ignition temperature, heat of vaporization, and maximum burning rate were used for simulations of the experimental mock-up and the full nightclub fires.

5.1.3 Vents

Vents in FDS are openings from the model to ambient conditions outside the computational domain. Vents allow smoke and heat to leave the grid area and air to enter. Vents may be either simple openings that allow natural flow to occur based on the buoyancy of the hot gases, or vents may use a specified or forced flow rate such as the flow from a fan. Vents can also be used to introduce heat into the modeling domain. In both the mock-up and the incident simulations, vents are used to represent the areas of the foam which were initially ignited.

5.1.4 Openings Within the Grid

The placement of blocks within the grid forms the structure of the building and its contents. The hydrodynamic calculations performed by FDS allow air, hot gases, smoke and flames to flow through the simulated building. Thermal radiation travels by line-of-sight and may be intercepted by obstacles within the grid.

Normal buildings may appear tightly constructed, but there are many small openings or leaks within a building that allow for the flow of air or combustion products. Since objects can only exist at grid boundaries, small leaks may be created by either using a very small grid size, or by representing many small leaks by fewer large leaks.

During the course of a fire, some items within the building may be consumed by the fire or otherwise change position. FDS does not have the capability to calculate burn-through or collapse but the user can remove items during the course of the calculations. Items that are removed can represent objects that fall or are destroyed by fire, or objects that are changed by people such as doors or windows that are opened.

5.1.5 Smokeview

Smokeview is a scientific visualization program that was developed to display the results of an FDS model computation [16]. Smokeview allows the viewing of FDS results in three-dimensional snapshots or animations. Smokeview can display contours of temperature, velocity and gas concentration in planar slices. It can also display properties with iso-surfaces that are three-dimensional versions of a constant value of the property. Iso-surfaces are most commonly used to provide a three-dimensional approximation of the flame surface where fuel and oxygen are present such that flames may exist.

5.2 FDS SIMULATIONS OF THE FULL-SCALE MOCK-UP

The major objective of the mock-up experiments was to observe the primary mode of flame spread and smoke movement under fire conditions that were similar to what likely existed early in The Station fire on Feb. 20, 2003. Results from the experiment, which included video records, measurements of heat release rate, temperature, heat flux, oxygen volume fraction, and gas velocity, were used to compare with FDS results for this complex fire environment. The secondary objective was to examine the impact of automatic fire sprinklers under experimental conditions, again to provide a basis of comparison with FDS.

In addition to using data from bench-scale experiments, input values to FDS were developed, as described in this section, based on comparisons with the full-scale mock-up experiments. The complete FDS input files are provided in Appendix L.

5.2.1 Computational Domain, Grid Size, Initial Conditions, and Boundary Conditions

Selecting the appropriate grid size required balancing the need to resolve critical dimensions and physical phenomena, and the need to budget enough time to perform the hundreds of computer runs necessary to assess the importance of different variables on the outcome. FDS was run on a Linux cluster with eight 3.2 MHz processors. To complete the estimated 100 simulations needed of 300 seconds actual time for the full nightclub fire in a six month window necessitated runs with a turn-around time of less than two days. Based upon the software needs and the hardware capabilities, this translated to a limit of about 2 million grid cells. The computational domain used to simulate the full nightclub measured about 22 m by 33 m by 4 m high, which led to a minimum computational grid size of about 145 mm.

Grid size sensitivity has been examined in several studies as noted by McGrattan [17]. For full-scale experiments involving a small compartment, 2.4 m (8 ft) by 3.6 m (12 ft) by 2.4 m (8 ft) high, with fires ranging from 55 kW to 110 kW, 100 mm computational grids were found to provide temperatures within 15 percent of the measured values. Based upon that work and the imposed time constraints, 100 mm was selected as the baseline computational grid size, with computational time savings sought through multi-blocking and the physical evidence provided by the WPRI video and the full-scale mock-up experiments described in Chapter 4.

The choice of computational grid size influenced the selection of the appropriate values for the initial conditions, boundary conditions and material properties, including the size and energy of the ignition source, heat transfer at the boundaries, and burning properties of the fuel. With all other inputs kept constant, doubling the grid size did not lead to the fast growing fires seen in the video or mock-up experiments; halving the grid size led to a fire growth rate that was faster than the evidence (and a single run-time of 10 days). Hence the simulations could not be shown to be grid size independent. This confirmed that if the mock-up experiments and mock-up simulations were to be used to develop input parameters for the full nightclub computer simulation, then the computational grid size needed to be consistent between the two simulation cases. With the grid size selected at 100 mm, the mock-up simulation computational domain required 319,000 grid cells. Approximately 17 hours were required to generate a 200 second simulation of a mock-up experiment. The FDS input parameters could be adjusted to the 100 mm grid by comparing the simulation results with the measured results from the full-scale mock-up experiments. The FDS inputs, described later in this section, were then applied to the full nightclub simulation, with the WPRI video serving as a source of comparison.

For the full-scale mock-up, the platform area and the dance floor area to the west of the platform were located in a compartment that was 10.8 m east to west and 7.0 m north to south. The ceiling height over the dance floor was 3.8 m. The drummer's alcove, located to the west of the platform, was 3.1 m wide, 2.4 m deep, and 1.96 m high. The height of the drummer's alcove floor and ceiling relative to the dance floor were 0.74 m and 2.7 m respectively. The platform was 7.0 m wide and 2.4 m deep and 0.4 m high. Figures 5-1 shows the resulting FDS model in Smokeview based upon a 100 mm grid size. Refer to Fig. 4-16 through Fig. 4-18 for additional details on the mock-up design.

The exposed interior finish materials used in the experiment consisted of convoluted polyurethane foam, plywood paneling, gypsum board, and carpeting. In Fig. 5-1a, the foam is shown as a dark gray surface, the paneling is depicted as the brown surface and the carpet is shown as a light blue surface. The remaining light gray surfaces are gypsum board. Foam, spruce, gypsum board and carpet material properties were used in conjunction with tabulated [15] and experimentally derived properties of polyurethane. The bottom of the domain was considered to be an inert, adiabatic solid.

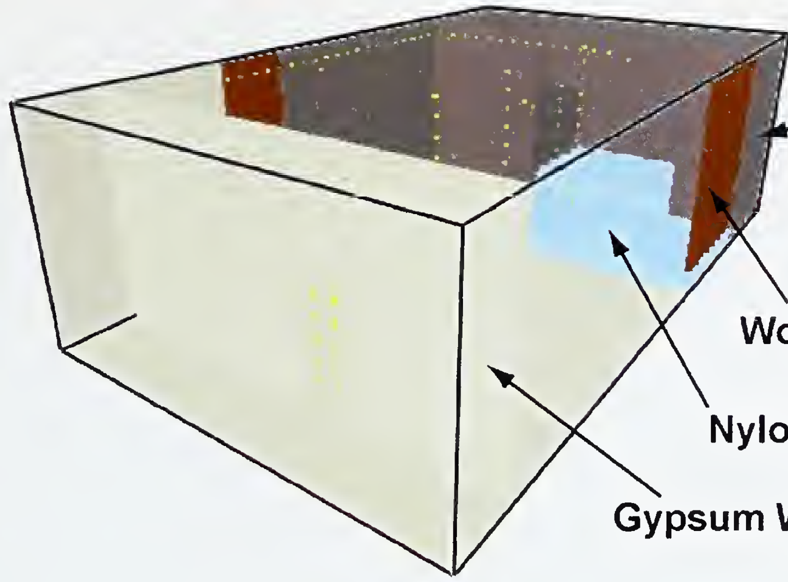


Figure 5-1a. FDS model of mock-up in Smokeview

The principal fuels in the mock-up were the convoluted polyurethane foam and plywood paneling. In the area of the platform and the drummer's alcove, the foam was installed over the plywood paneling. The complexity of this arrangement limited the extent to which the burning composite fuel could be modeled *a priori*. Therefore, several simplifications and assumptions were made in order to generate model results that were representative of the experimental data. The thickness of the convoluted polyurethane foam varied significantly as shown in Figure 5-1b. Typical thickness variations ranged from 6 mm (0.24 in) valleys up to 30 mm (1.2 in) peaks in the "egg crate" configuration. Given that the thickness of two nested sheets was consistent at 36 mm (1.4 in), the foam was approximated as a uniform flat solid with an average thickness of 18 mm (0.7 in).

The other material properties used to describe the foam are given in Table 5-1. All of the foam material properties were derived directly from the experiments that were documented in Chapter 4, with the exception of the maximum burning rate. Given the complex nature of the foam over plywood composite, it was difficult to determine when only the foam was pyrolyzing, when only the plywood was pyrolyzing and when they were pyrolyzing at the same time. Therefore a series of simulations was conducted to determine a representative maximum burning rate. The value of the maximum burning rate was varied from 0.004 kg/m^2-s to 0.028 kg/m^2-s. The maximum burning rate which yielded the heat release rate closest to the experimental results for the unsprinklered mock-up experiment was 0.008 kg/m^2-s.

The plywood paneling is based on the thermal properties of spruce [18] and is modeled as a charring material as described in [15]. The only modeled difference between the spruce material in the FDS

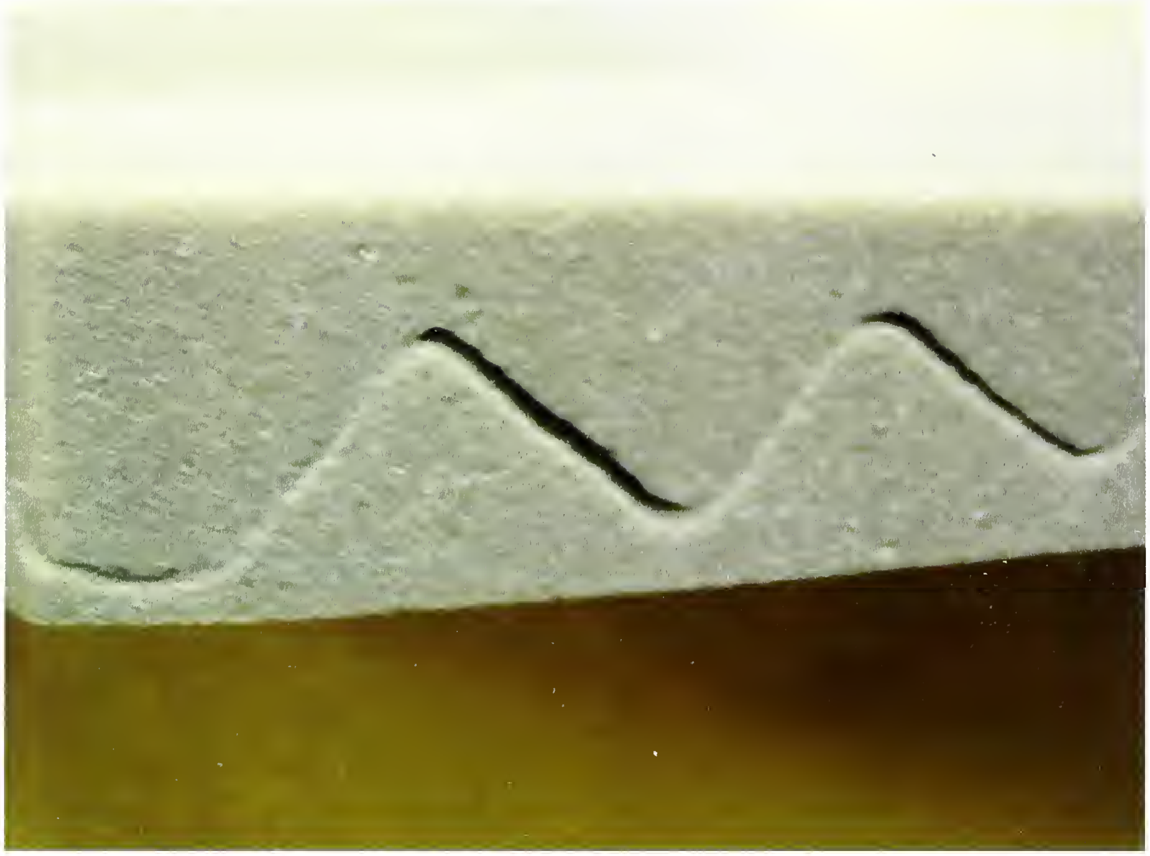


Figure 5-1b. Photograph of the edge of two sheets of convoluted polyurethane foam.

Table 5-1. Polyurethane foam material properties used as FDS input.

Property	Value
Thermal Conductivity	0.034 W/m °C
Specific Heat	1.4 kJ/kg °C
Thickness	18 mm
Density	22 kg/m^3
Ignition Temperature	370 °C
Heat of Vaporization	1350 kJ/kg
Maximum Burning Rate	0.008 kg/m^2-s

database and the paneling is in the thickness of the material; 5 mm (0.2 in) was used to represent the paneling. The material properties of gypsum board and carpet were taken directly from the FDS 4 database with no changes [15].

Four heat producing vents were used to simulate the initial fire areas on both sides of the alcove. Two 100 mm (4 in) wide by 200 mm (8 in) tall vents, were located on the west side of the platform wall, at the north and south edge of the drummer's alcove. Two more heat vents, 100 mm (4 in) square were located on the north and south walls of the drummer's alcove adjacent to the vents of the platform wall. The lower edge of the vents was located 1.50 m (5 ft) above the platform floor. The vents had a defined heat release rate per unit area of 1500 kW/m^2. These vents produced heat for the duration of the simulations. The size and location of the vents were based on the locations where the foam was ignited in the full-scale mock-up experiments and the approximate of area involved in fire within a few seconds after ignition. The heat release rate was determined after conducting a series of simulations to match the heat release rate per unit area needed to provide enough energy per unit volume (grid cell volume) to provide reasonable agreement with the results of the full-scale experiment

The only opening within the grid of the model itself was the doorway in the east wall of the compartment, as shown in Figure 5-1a. The doorway was 0.9 m (3.0 ft) wide and 2 m (6.6 ft) high. The computational grid extended outside the door 1.2 m to allow unrestricted flow into and out of the doorway.

Two simulations of the mock-up experiment are presented in the next section. The first simulation was unsprinklered. The second simulation examined the conditions resulting from the use of automatic fire sprinklers. The capability to model the sprinkler activation and the effects of suppression can not be done *a priori*. Several simulations were conducted by varying both the parameters that impacted the activation of the sprinklers and the parameters that impacted the suppression physics. The values that are presented in Table 5-2 provided the best fit to the data.

Three parameters of the sprinkler are used in a lumped-mass model for the thermal element in the sprinkler: response time index (RTI), activation temperature, and conduction factor [19]. This lumped mass sub-model is used to calculate the time of sprinkler activation. However, the lumped mass model

Table 5-2. Sprinkler Properties Used as FDS Input

Property	Value
Sprinkler Type	Pendant
Operating Pressure	174 kPa (25 psi)
K-factor	8.0 L/min/kPa$^{1/2}$ (5.6 gpm/psi$^{1/2}$)
Response Time Index	16 m$^{1/2}$ s$^{1/2}$ (32.6 ft$^{1/2}$ s$^{1/2}$)
C-Factor	0
Activation Temperature	74 °C (165 °F)
Offset Distance	100 mm (3.9 in)
Size Distribution	Global Average
Median Volumetric Diameter	675 µm (0.03 in)
Minimum Spray Angle	75°
Maximum Spray Angle	105°
Speed	15 m/s (49 ft/s)

does not account for radiative heat transfer, only conductive and convective heat transfer. In this incident given the location of the fire and the rapid flame spread, radiative heat transfer played a role. The activation temperature used was the listed temperature of the sprinkler from the experiment. No conductive losses were considered in order to eliminate another variable and simplify the determination of the "effective" RTI. The RTI was chosen based on matching the response time of the first sprinkler activated in the experiment. The other sprinklers were given the same RTI.

The remaining sprinkler parameters describe how much water would be discharged, what the water droplet size distribution would be and the direction of the droplets discharge. The water flow rate is determined by the operating pressure and the discharge factor (or K-factor). As modeled, the water flow from each sprinkler was 94.6 L/min (28.0 gpm). This flow rate was determined from a series of simulations to develop suppression results that were representative of the full-scale mock-up experiment with sprinklers. The resulting flow rate and spray angle inputs are what was required to simulate the suppression in FDS. They are not a measure of the actual flow rate or spray angles from the experiment. In addition, the computational droplet tracking parameters; age, droplets per second, maximum number of droplets and drop vertical velocity were determined empirically from numerous computations.

The water droplet size distribution is based on a median droplet diameter to which a size distribution is applied. A median droplet diameter of 675 μm (0.03 in) was used with the FDS default parameters of the Rosin-Rammler/log-normal distribution (γ= 2.4). [20, 15]

The droplets were distributed uniformly in the conical spray pattern emanating from the sprinkler deflector. The spray pattern is defined by the minimum and maximum spray angles. Relative to a sphere that is centered on the sprinkler, with a radius equal to the offset distance, the spray pattern ranged from 75° north of the south pole to 15° above the equator. Further discussion of the sprinkler properties is provided in section 5.2.3.

5.2.2 FDS Full-scale Mock-up Simulation, Non-Sprinklered Results

The results of the non-sprinklered simulation are compared with the video record of the experiment, and the measurements of temperature, oxygen volume fraction, heat flux, heat release rate and gas velocity. Visual comparisons of the experiment and simulation are shown in Figures 5-2 through 5-11. Quantitative comparisons between the experimental data and the model predictions are given in Figures 5-12 through 5-18.

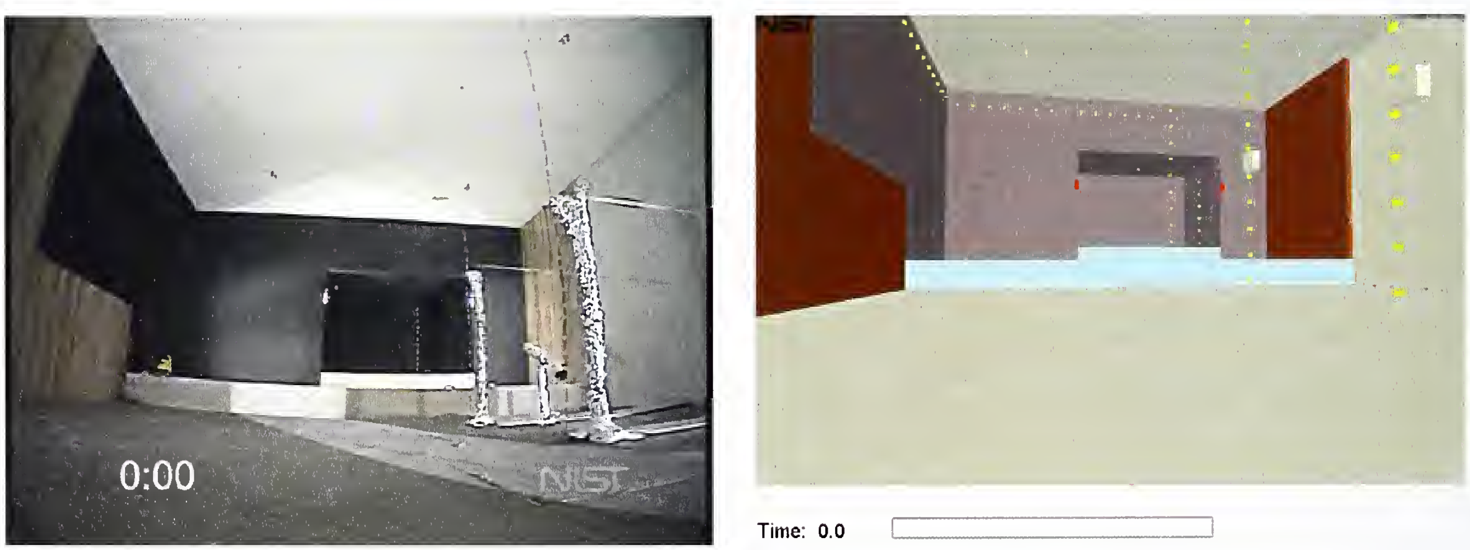


Figure 5-2. Ignition at the corners of the drummer's alcove, t = 0 second.

Figure 5-3. Flames spreading toward ceiling, t = 10 seconds after ignition.

(i) Visual Comparisons

Figures 5-2 through 5-11 are composed of pairs of images. The still frames, captured from video tape, appear on the left. The images on the right are rendered from Smokeview. Both images represent the same time after ignition. The pairs of images begin at ignition, or t = 0 seconds, and continue at 10 seconds intervals until 90 seconds after ignition, when most of the visibility from the video is lost.

Figure 5-2 shows the experiment and the simulation at the time of ignition. The video frame on the left shows the foam covered walls, the wood paneling, and the carpeted platform. Gypsum board covered the ceiling, floor and the remaining wall areas that were not covered with wood paneling or foam. Some of the instrumentation can be seen in the foreground of the video frame. In the image from the simulation, on the right, the comparable interior finishes can be seen. The instrumentation in the right figures is represented by colored dots. The thermocouples appear as yellow dots in evenly spaced arrays. The light gray blocks represent the locations of the heat flux sensors and the gas sampling locations, which were installed at approximately 1.5 m (5 ft) above the floor.

Figure 5-3 compares the fire development at 10 seconds after ignition. A flame is shown on both corners where the platform wall intersects with the drummer's alcove. In the case of FDS, the area that appears to be involved with flames is based on the stoichiometric mixture fraction, where there is the ideal mixture of fuel and oxygen for a robust flame to exist. The heat release rate per unit volume represented by the simulated flames is 285.5 kW/m^3. The flames in the simulation appear wider due to the grid resolution, which is 100 mm (4 in) throughout the room.

The video frame to the left in Figure 5-4 shows flames 20 seconds after ignition growing vertically and impinging on the ceiling. The simulated flames on the right, however, have not yet reached the ceiling. As noted above, the simulated flame is constrained to grow in 100 mm (4 in) increments, both vertically and laterally. This may account for the wider flame and the accompanying redistribution of energy that would reduce the propensity for rapid vertical flame spread. Light smoke can be seen in both images along the ceiling of the alcove, with light wisps of smoke along the ceiling above the platform.

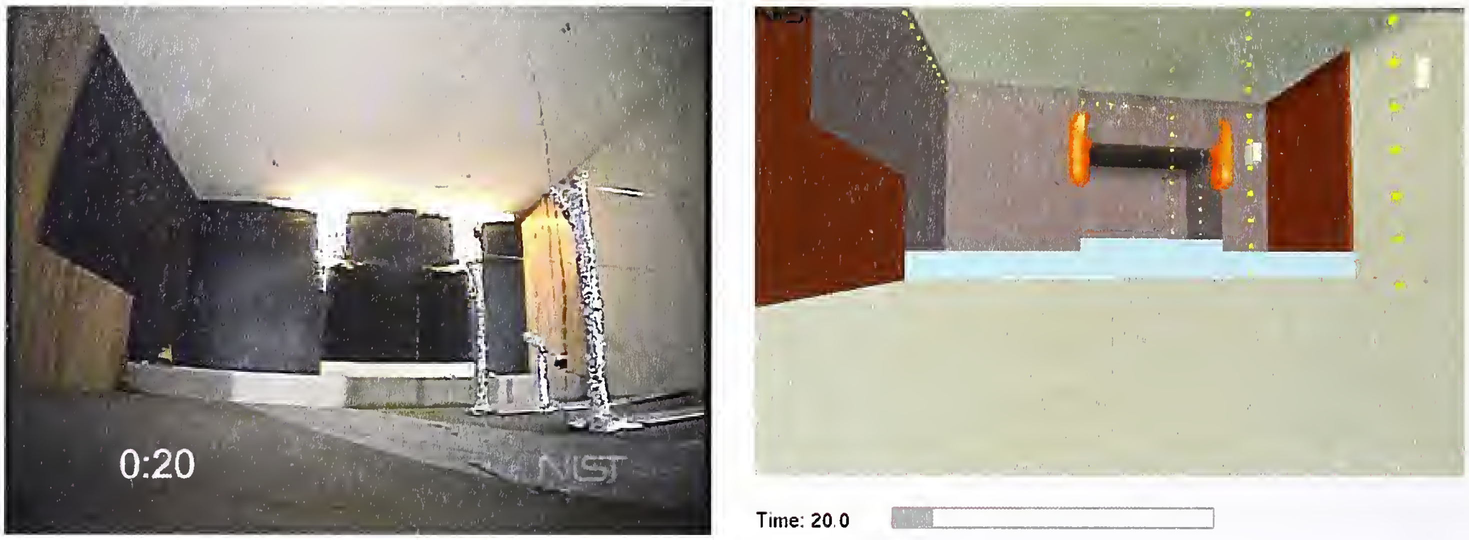


Figure 5-4. Flames impinging on ceiling, t = 20 seconds after ignition.

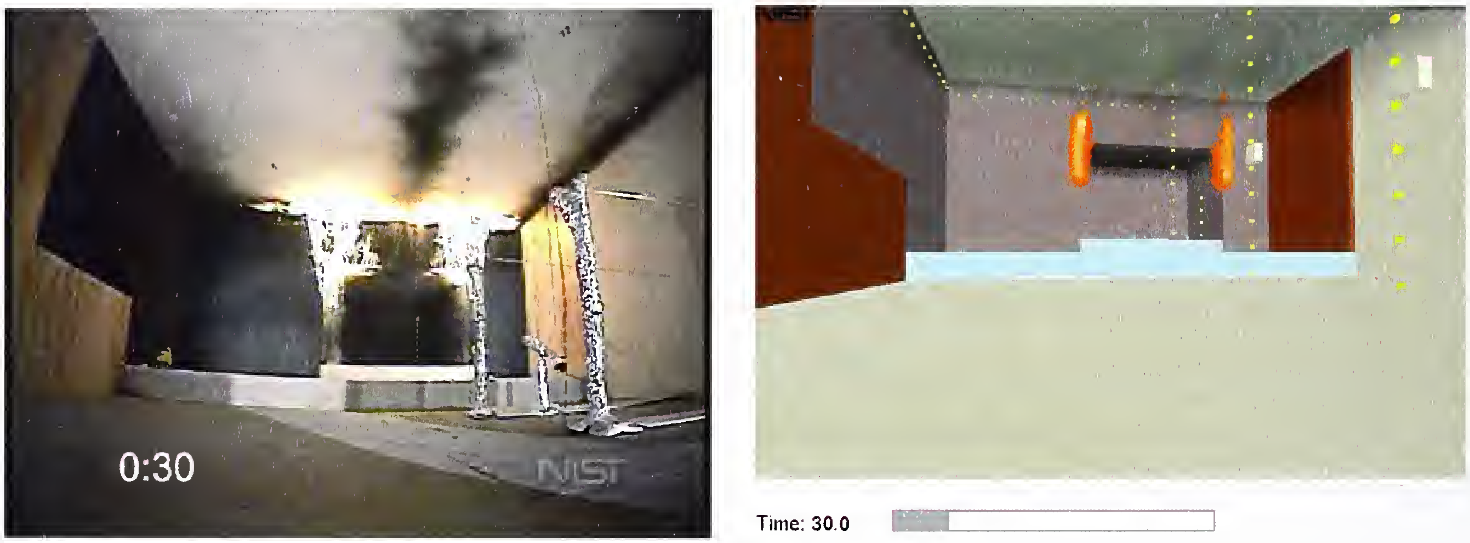


Figure 5-5. Visible smoke spreading across ceiling, t = 30 seconds after ignition.

Figure 5-5 shows an increased amount of smoke flow across the ceiling at 30 seconds after ignition. The actual fire continues to grow at a faster rate than the simulated flames. In the video frame on the left the flames have formed twin V-patterns on each side of the alcove and the flames are spreading across the alcove ceiling. Notice the light smoke that is coming up from the carpeting below the two fire plumes. This is the result of foam melting and the burning foam droplets falling to the floor. This mode of flame spread is not accounted for within the FDS model. At 40 seconds after ignition, the video frame in Figure 5-6 shows areas of the foam on the platform wall have burned out (note the dark area directly above the point of ignition on the left side of the alcove). The actual flame fronts have continued to spread and into the alcove, where fire is visible on portions of the side walls and the ceiling of the alcove. The flames simulated with FDS have also grown, although at a slower rate. Both of the simulated flames have impinged on the ceiling.

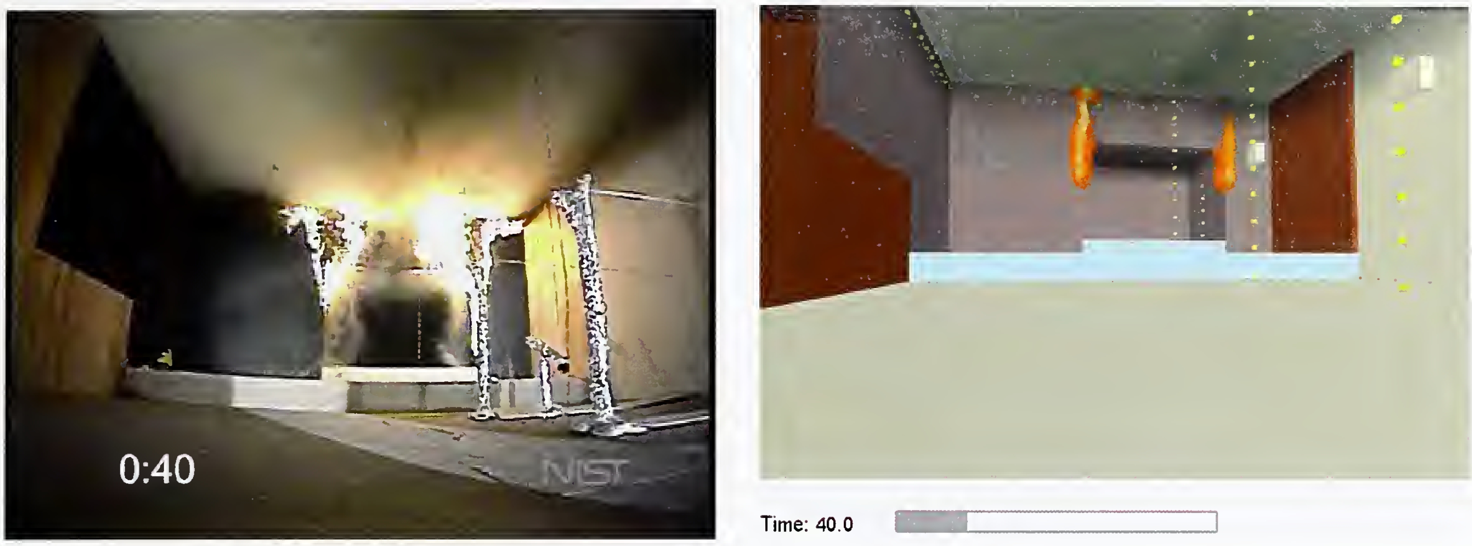


Figure 5-6. Flames continue to spread into alcove, t = 40 seconds after ignition.

Figure 5-7. Ceiling of alcove fully involved in fire, t = 50 seconds after ignition.

Figure 5-7, has images captured at 50 seconds after ignition. In the experiment, it appears that the entire ceiling of the alcove is burning, as well as the area of the platform wall above the opening to the alcove. There is also more smoke from drop-down of the burning foam onto the carpet, both in the alcove and on the platform. In the simulation, the flames have moved into the alcove and are spreading across the ceiling. In both images, the smoke or hot gas layer has developed across the ceiling of the enclosure.

In Figure 5-8, the ceiling and the walls of the alcove have become fully involved with fire in both of the images. At 60 seconds after ignition, flashover has already occurred in the experiment and flashover is about to occur in the simulation. In both cases, flames are extending out of the alcove across the ceiling and the smoke layer has become thicker and darker.

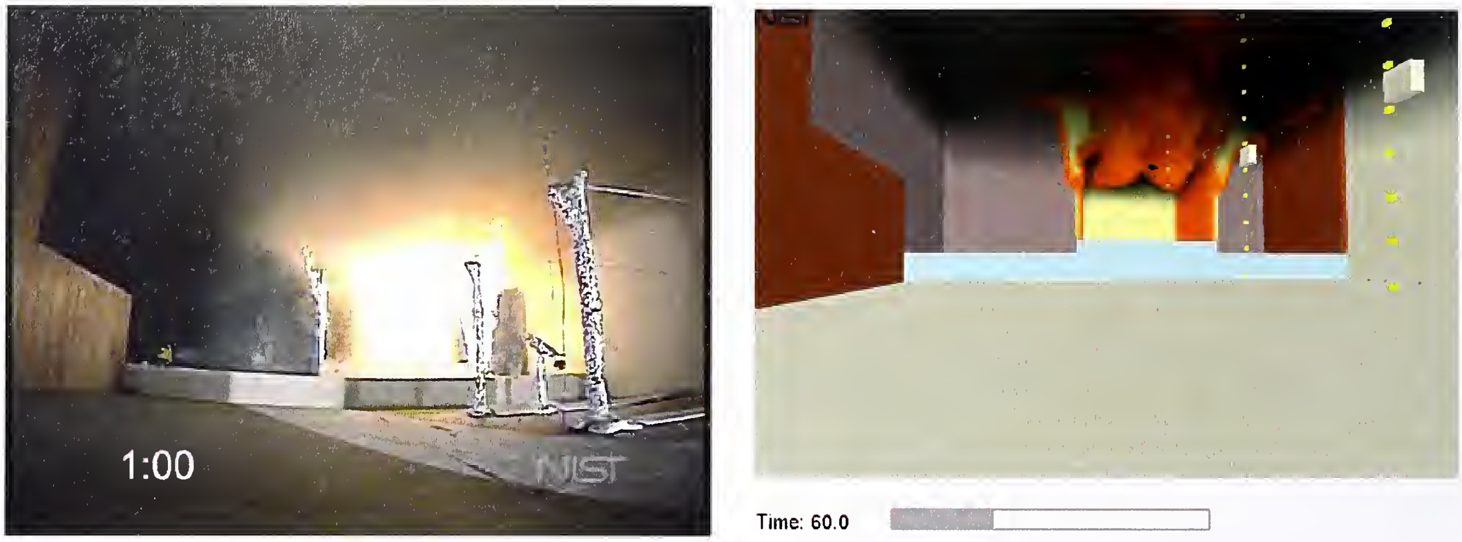


Figure 5-8. Flashover has occurred in alcove area, t = 60 seconds after ignition.

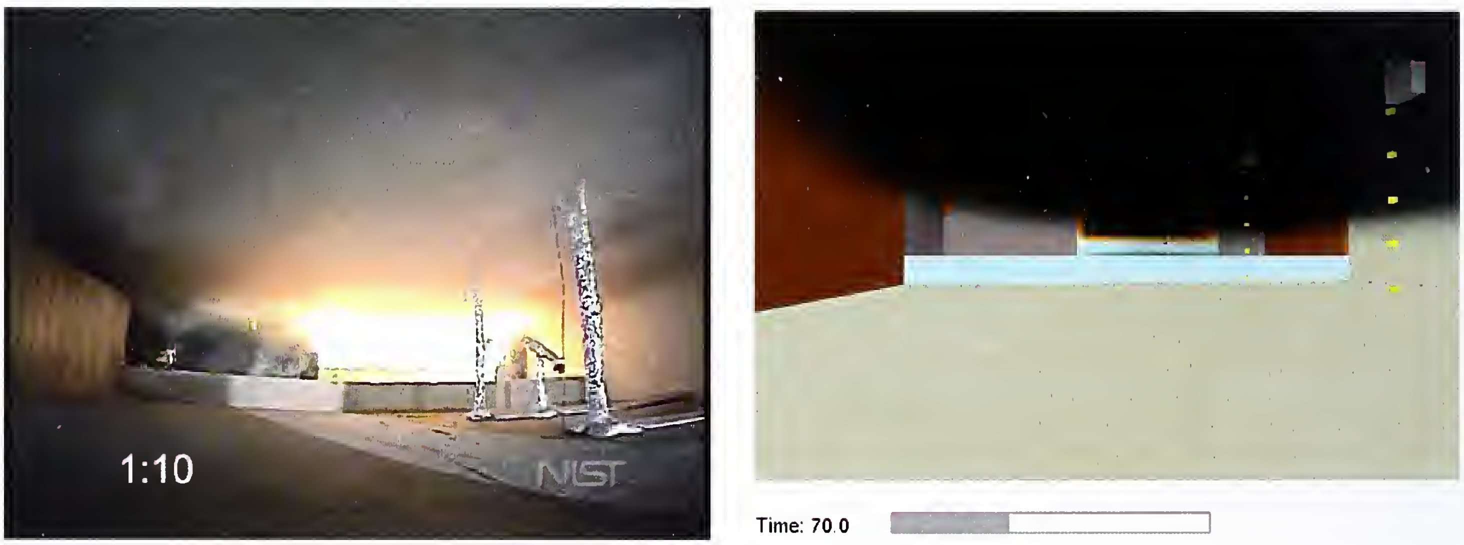


Figure 5-9. Smoke layer has dropped to 1.5 m above floor, t = 70 seconds after ignition.

The images in Figure 5-9 show a significant increase in the amount of the smoke in the enclosure. The smoke layer has descended to within 1.5 m (5 ft) of the floor. The flames have spread along the wall behind the platform and can be seen at the lower edge of the smoke layer in both the video frame and the image from the simulation. The smoke in the experiment appears lighter in color than it actually is due to light that is being reflected from floor level halogen lights that were used to improve the visibility for the video cameras.

The fire continues to grow in both the experiment and the simulation as shown in Figure 5-10. The smoke layer has continued to descend. The interface height of the smoke layer is approximately 0.75 m (2.5 ft) above the floor at 80 seconds after ignition for both the experiment and the simulation. Both images also show the flame extension on the left wall of the enclosure. The upper portion of the left wall near the platform had foam installed over the paneling.

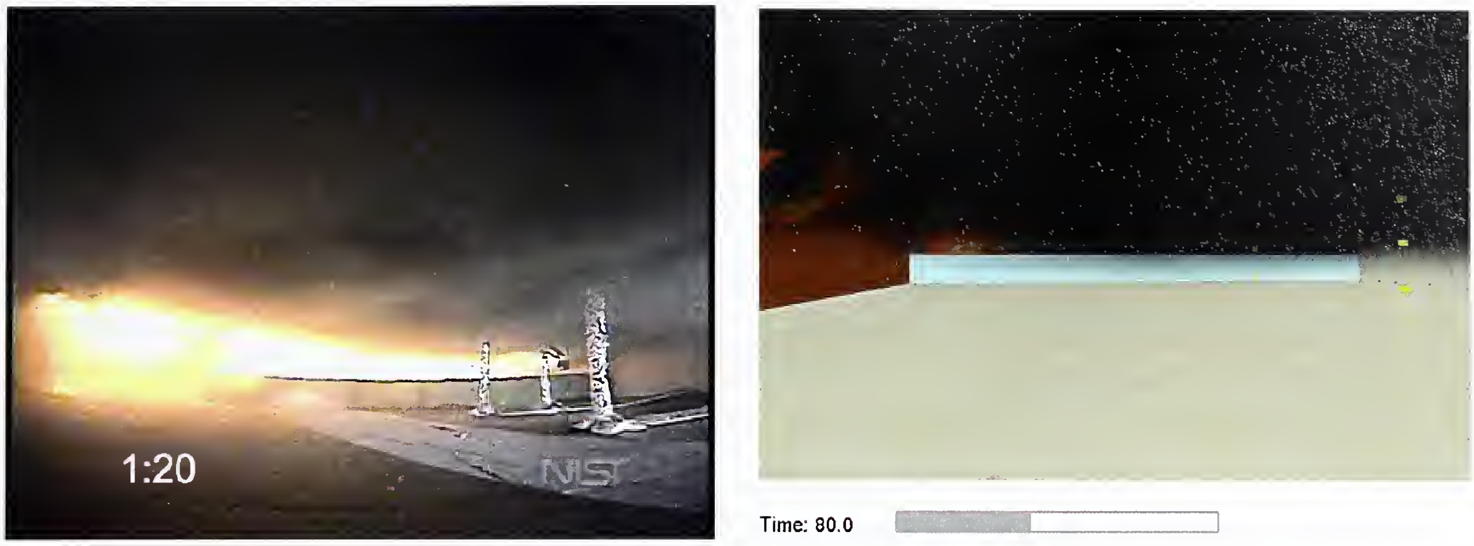


Figure 5-10. Fire continues to spread, t = 80 seconds after ignition.

Figure 5-11. Visibility lost, t = 90 seconds after ignition.

The last set of images, Figure 5-11 demonstrate that most of the visibility in the enclosure has been lost due to smoke filling. A small layer of clear area can be seen near the floor in both the experiment and the simulation. This is due to fresh air being drawn into the fire enclosure through the open doorway.

The image pairs show that the simulation is not exact with respect to time, in reproducing the development and growth of the fire, especially during the initial growth stages of the fire. Based on the images during the first 40 seconds of the fire FDS appears to lag behind in fire growth by approximately 10 to 20 seconds. As the fire reaches the transition point of flashover, the simulation has reduced the time lag significantly. Post-flashover, the appearance of the fire progression and the smoke development for both the experiment and the simulation are more closely synchronized with each other.

(ii) Numerical Comparison

In this section, measurements of power generated, temperature, heat flux, oxygen volume fraction, and gas velocity from the full-scale mock-up experiments described in Chapter 4 are compared with the values generated by the FDS simulation.

The heat release rate of the fire is the source for the energy transfer that occurs throughout the fire environment. Heat release rate is critical in fire protection engineering for assessing the development of a hazard due to a fire within a building. In addition, the heat release rate is a function of oxygen depletion. Therefore, differences in the heat release rate comparison also impact the comparison of the temperature, heat flux, oxygen, and gas velocity measurements.

Figure 5-12 compares the measured heat release rate leaving the door of the experiment (based upon oxygen consumption) to the heat release rate from the fire within the compartment as predicted by FDS. For fires burning in the open under the laboratory hood, the thermal power measured by the oxygen depletion calorimeter is equal to the heat release rate from the fire. However, for a fire within an enclosure, the effluent from the room is a mixed average of the upper layer gases, and does not represent the instantaneous heat release rate of the fire. Smoke did not exit the compartment doorway until approximately 60 seconds after ignition. This means that a direct comparison between the experimental measurements and the numerical predictions cannot be made because the oxygen depletion calorimeter does not respond to a fire within an enclosure until the combustion products have had time to exit the door and become entrained into the hood. The heat release rate predicted by FDS in Fig. 5-12 represents the instantaneous heat release throughout the room. The heat release rate reaches a peak of

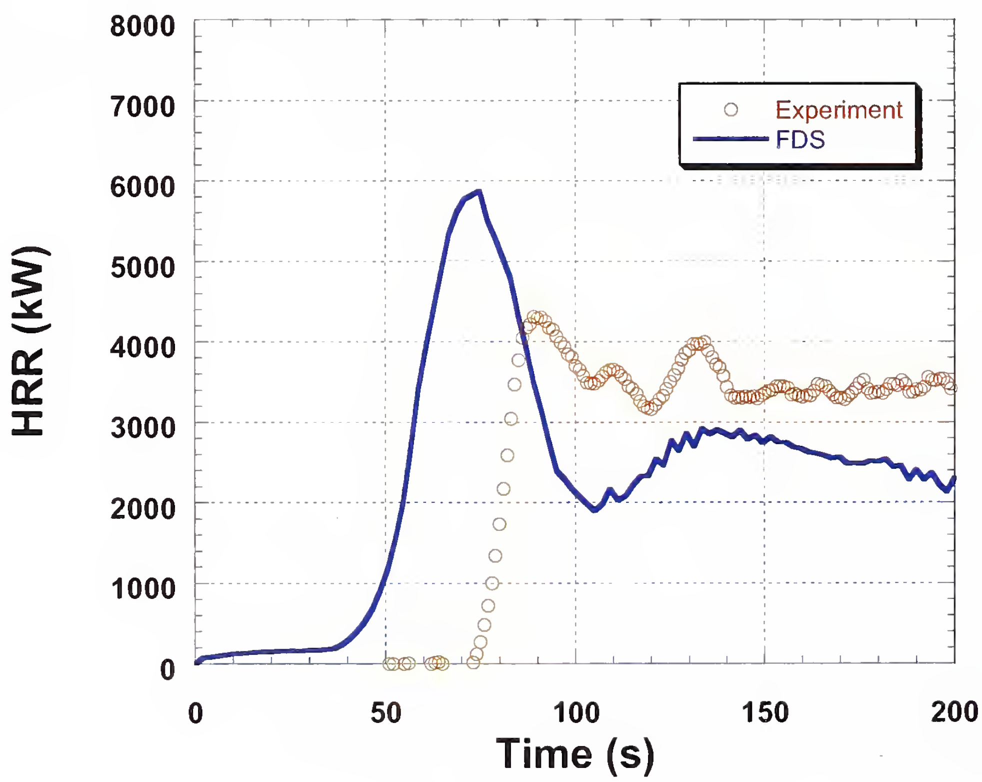


Figure 5-12. Power generated in experiment as measured outside of doorway, compared to FDS simulation of heat release rate from fire within compartment.

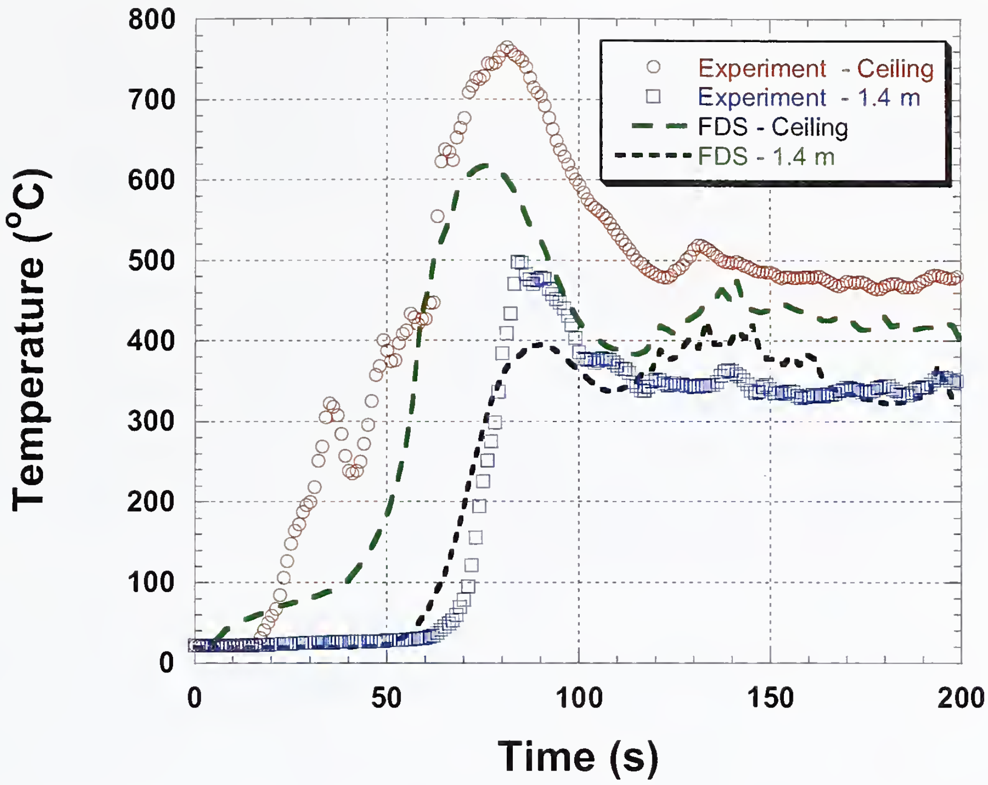


Figure 5-13. Temperature comparison between the un-sprinklered fire experiment and the FDS simulation at Station C.

approximately 6 MW about 70 seconds into the simulation, 20 seconds prior to the peak in thermal power measured in the oxygen depletion calorimeter. Both curves approach 3000 kW ± 300 kW approximately 150 seconds into the fire, again consistent with a ventilation-limited condition. The heat release rates diverge at longer times as the model consumes the remaining interior finish fuels while the physical fire continues to burn at a reduced rate into the wood supporting the platform and walls. When the areas under the heat release rate curves were integrated, the resulting energies were found to agree within 10 %.

Figure 5-13 is a comparison of the temperatures predicted and measured 25 mm below the ceiling and 1.4 m above the floor at the thermocouple array located at Station C (4.25 m west of the door opening or 1.7 m from the platform). The FDS output has been smoothed by applying a Stineman function (a geometric weight applied to the current point ±10 % of the data range). The temperature data show reasonable agreement with the predictions, including an overshoot followed by a leveling off as the fire reaches a ventilation limit. The temperatures near the ceiling increase faster in the test; conversely, the lower level temperatures increase at a slower rate in the test.

Note that, unlike the heat release rate, the temperature measurements respond to the local environment within a second; hence, the experimental temperatures and FDS predictions can be compared directly. Initially, the experimental measurements near the ceiling increase more rapidly than predicted. This is probably due to the strong transverse temperature gradients associated with the ceiling jets created early in the fire (see Fig. 5-5), where small differences in position between the experiment and simulation can have a large change in temperature. The simulated thermocouple temperatures are temperatures averaged over the grid cell volume(s) that they are associated with, which results in differences in positions between the experimental point measurement and the FDS output. The peak temperatures for the experiment and the simulation occur within 5 seconds of each other.

Figure 5-14 is a comparison of the temperatures predicted and measured 25 mm below the ceiling and 1.4 m above the floor at the thermocouple array located at Station D (2.35 m west of the door opening). Similar to the previous figure, the temperature data show reasonable agreement with the predictions. The trends are also similar and both of the measured temperatures and the predictions exhibit a reduction in peak temperatures relative to the values from Station C that is located approximately 2 m closer to the platform.

Figures 5-15 and 5-16 present the heat flux measurements taken at Stations C and D respectively. There were three total heat flux sensors at each position: one installed at ceiling level with the sensor aimed at the floor; and two sensors installed at approximately 1.5 m (5 ft) above the floor with one aimed at the ceiling and the other aimed toward the platform end of the enclosure. In both cases, the predictions follow the trends of the measured heat flux. Better agreement in terms of magnitude occurs at the ceiling level. The predicted heat fluxes 1.5 m above the floor are low by almost 50 % when compared with three out of four measurements.

Figures 5-17 and 5-18 represent the oxygen volume fraction comparisons between the measurements at Stations C and D and the predicted values from FDS. The measurements and the predictions were positioned at 1.5 m (5 ft) above the floor. The oxygen levels predicted by FDS dropped sooner but slightly less rapidly than the experimental measurements; both reached the same low value of about two percent, confirming that the fire was close to ventilation-limited at this point.

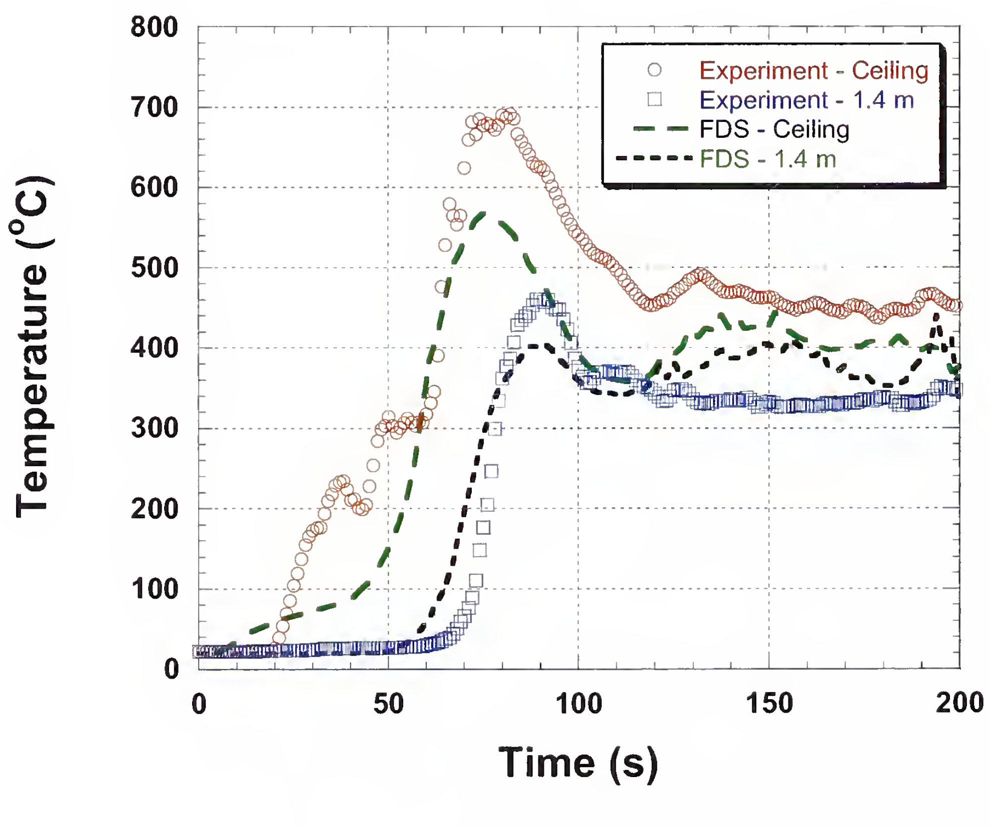


Figure 5-14. Temperature comparison between the un-sprinklered fire experiment and the FDS simulation at Station D.

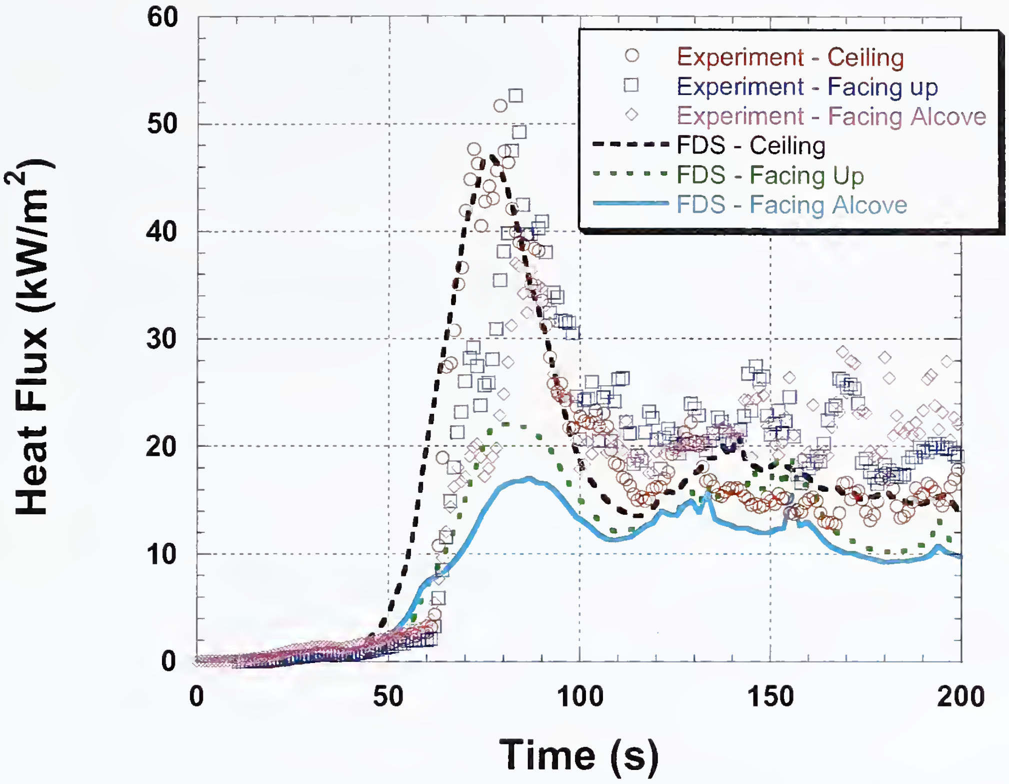


Figure 5-15. Heat flux comparison between the un-sprinklered fire experiment and the FDS simulation at Station C

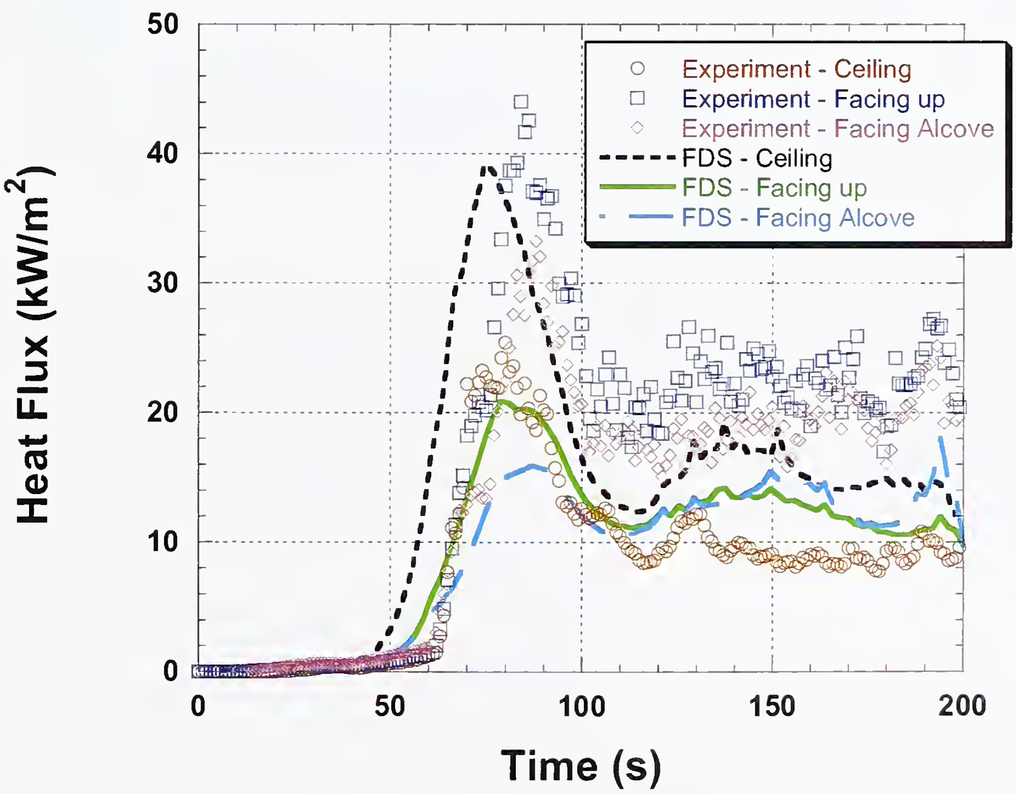


Figure 5-16. Heat flux comparison between the un-sprinklered fire experiment and the FDS simulation at Station D.

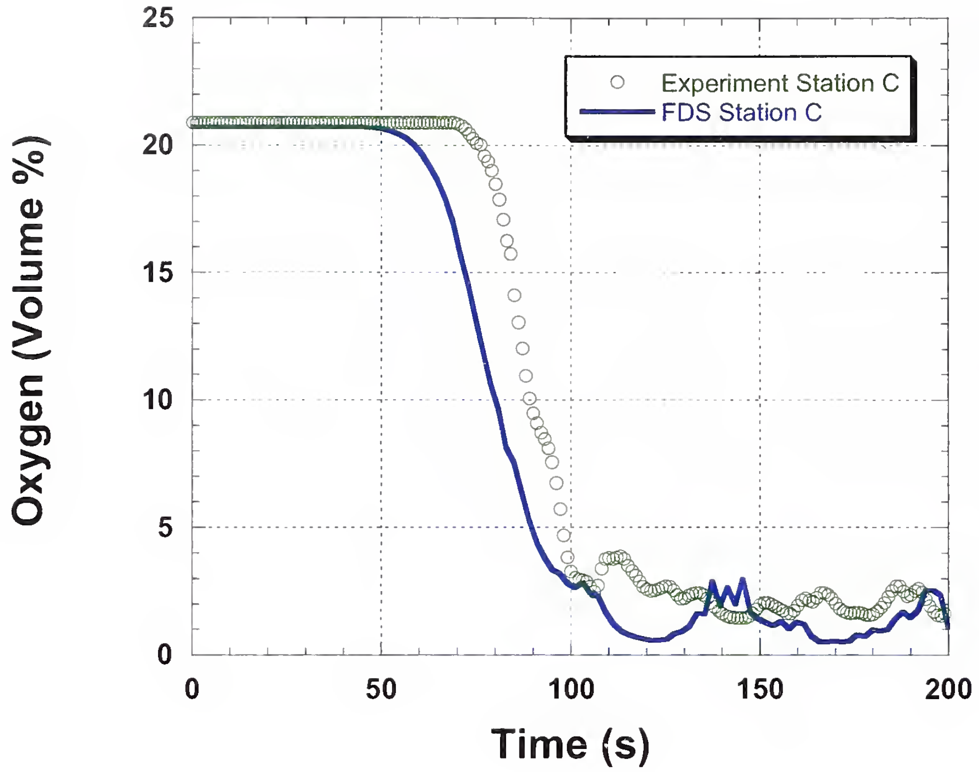


Figure 5-17. Oxygen volume fraction comparison between the un-sprinklered fire experiment and the FDS model at approximately 1.5 m above the floor at Station C.

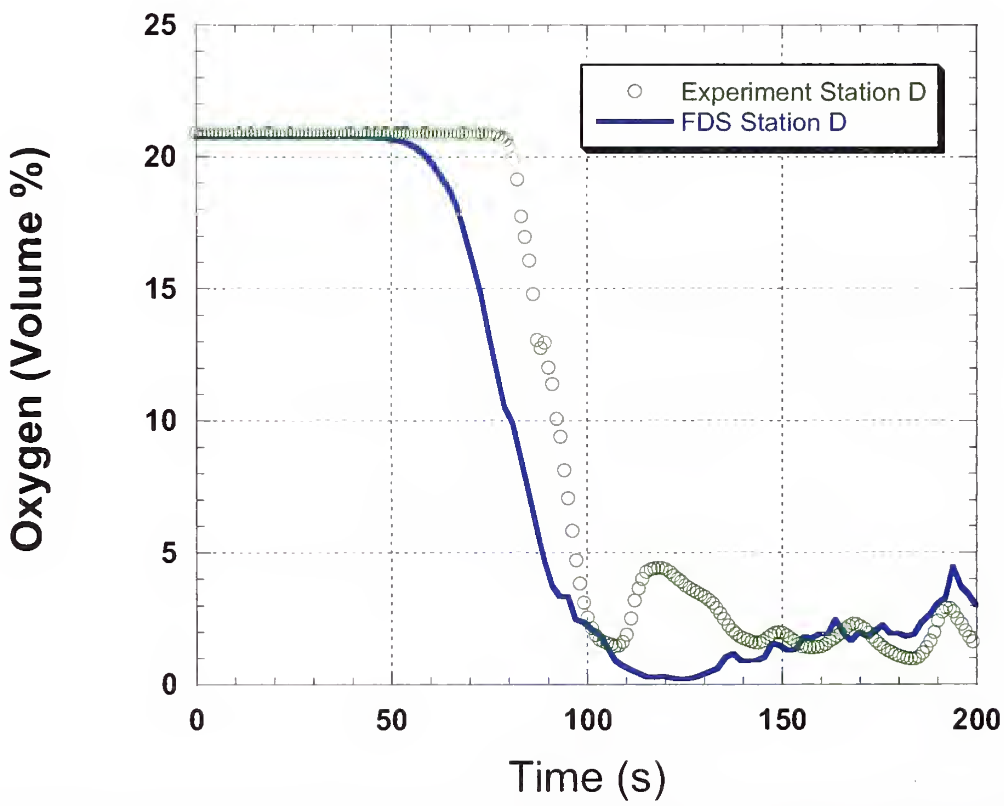


Figure 5-18. Oxygen volume fraction comparison between the un-sprinklered fire experiment and the FDS model at approximately 1.5 m above the floor at Station D.

(iii) Tenability

Tenability limits based upon the work of Purser [21] were discussed in section 4.6.8. The time predicted by FDS to reach the limits of temperature, heat flux, and oxygen are summarized in the top portion of Table 5.3. The agreement between the simulation and experimental measurements at Location C is within eight percent, with both methods indicating the heat flux criteria is exceeded first, around one minute into the fire.

Table 5.3 Time to reach untenability criteria at Location C, or maximum deviation obtained, in sprinklered and unsprinklered simulations, compared to experimental measurements

	Temperature $> 120\,^{\circ}C$	Heat Flux $> 2.5\ kW/m^2$	Oxygen $< 12\ \%$
Unsprinklered			
Experiment	76 seconds	61 seconds	87 seconds
FDS	72 seconds	57 seconds	80 seconds
Sprinklered			
Experiment	$< 24\,^{\circ}C$	$< 0.32\ kW/m^2$	$> 20.6\ \%$
FDS	$< 22\,^{\circ}C$	$<0.15\ kW/m^2$	$> 18.8\ \%$

5.2.3 FDS Full-scale mock-up Simulation, Sprinklered Results

The results of the sprinklered simulation are compared with the video record of the experiment, and the measurements of temperature and oxygen volume fraction. Visual comparisons of the experiment and simulation are shown in Figures 5-19 through 5-27. Quantitative comparisons between the experimental data and the model predictions are given in Figures 5-28 through 5-32. Given the limited growth of the fire during the experiment, the oxygen depletion calorimeter did not register a significant rate of heat release.

The comparison of the sprinkler activation times from the sprinklered mock-up experiment and the FDS simulation of that experiment are given in Table 5-4. In FDS, the activation time of the first sprinkler was the result of adjusting the RTI in the simulation until the times were similar. The RTI that provided the best match, $16\ m^{1/2}\ s^{1/2}$ ($32.6\ ft^{1/2}\ s^{1/2}$), was used as the RTI for the remaining sprinklers in both the mock-up and the full nightclub simulation. The order of sprinkler activation, and the number of sprinklers activated, were the same in the simulation and the experiment. The times to activation differed by no more than 6 seconds.

(i) Visual Comparisons

Figures 5-19 and 5-27 are composed of pairs of images. The still frames, captured from the video tape of the experiment, appear on the left. The images on the right are rendered from Smokeview. Both images represent the same time after ignition. The pairs of images begin at ignition or t = 0 seconds and continue at 10 second intervals until 60 seconds after ignition, when most of the fire in the experiment had been suppressed. Additional sets of images are included at 25 seconds after ignition to show the initial sprinkler just after activation and at 90 seconds to demonstrate the lack of significant fire spread after

Table 5-4. Comparison of sprinkler activation times.

Sprinkler Location	Sprinkler Activation Times (seconds)	
	Experimental	Fire Dynamic Simulator
Northwest	24	23
Southwest	29	35
Alcove	30	36
Northeast	Did Not Activate	Did Not Activate
Southeast	Did Not Activate	Did Not Activate

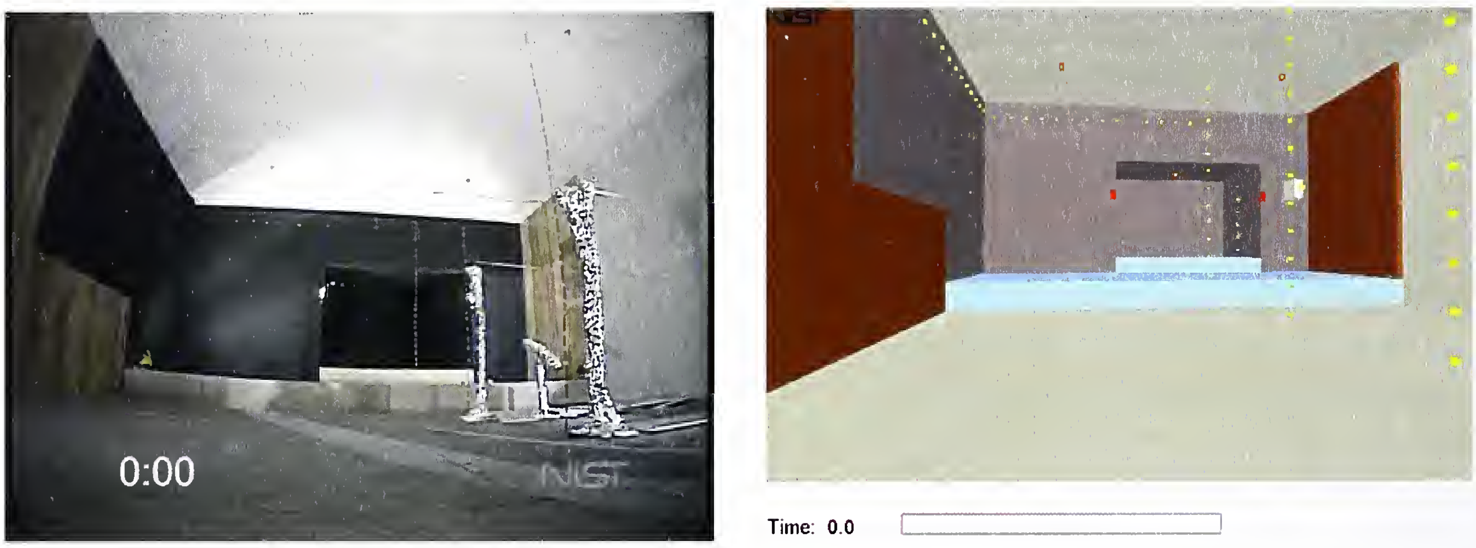


Figure 5-19. Ignition at the corners of the alcove, t = 0 seconds.

Figure 5-20. Flames spreading toward ceiling, t = 10 seconds after ignition.

Figure 5-21. Flames impinging on ceiling, t = 20 seconds after ignition.

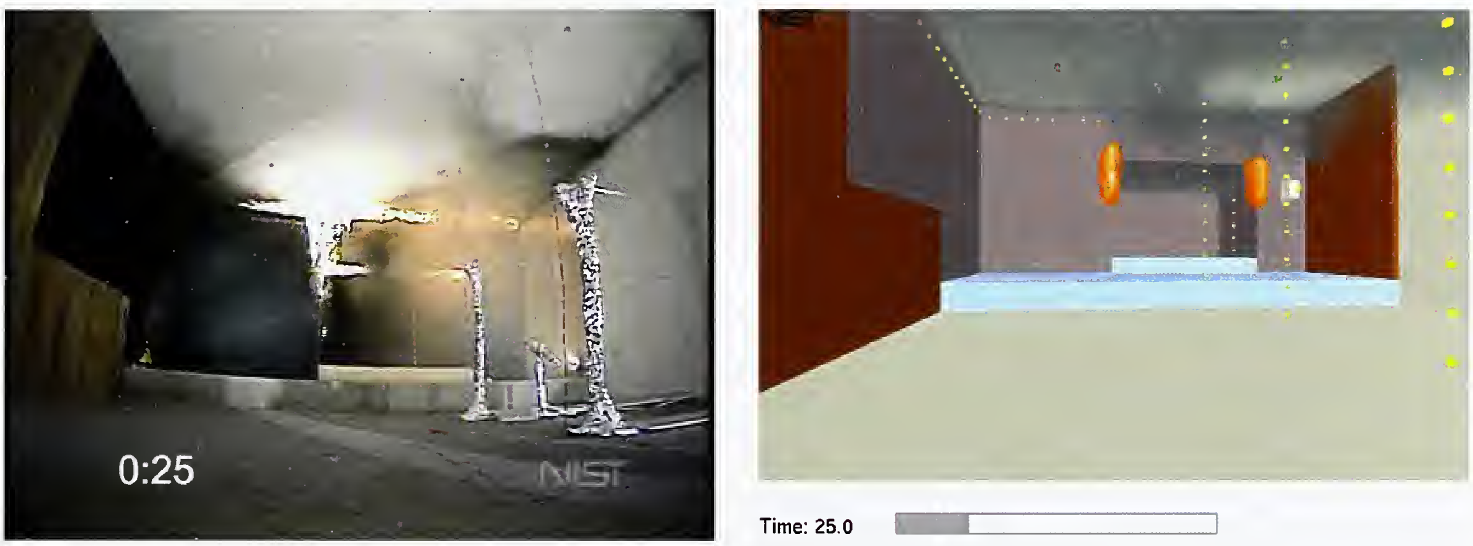


Figure 5-22. Initial sprinkler operating, t = 25 seconds after ignition.

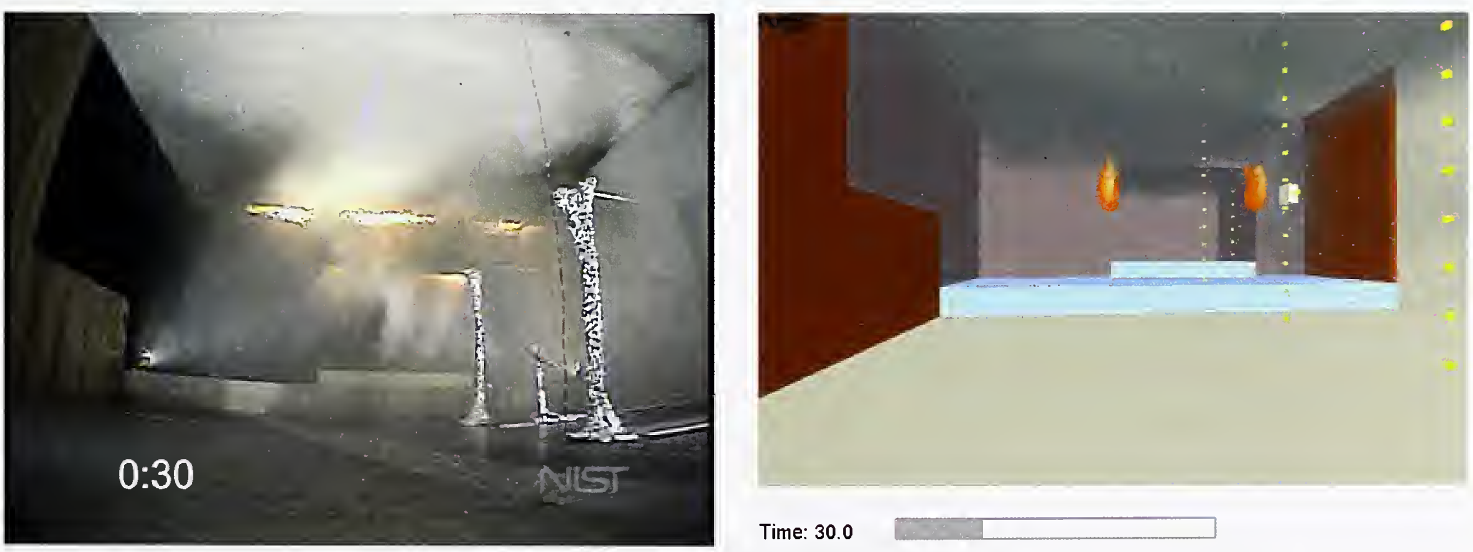


Figure 5-23. Third sprinkler operating in experiment, t = 30 seconds after ignition.

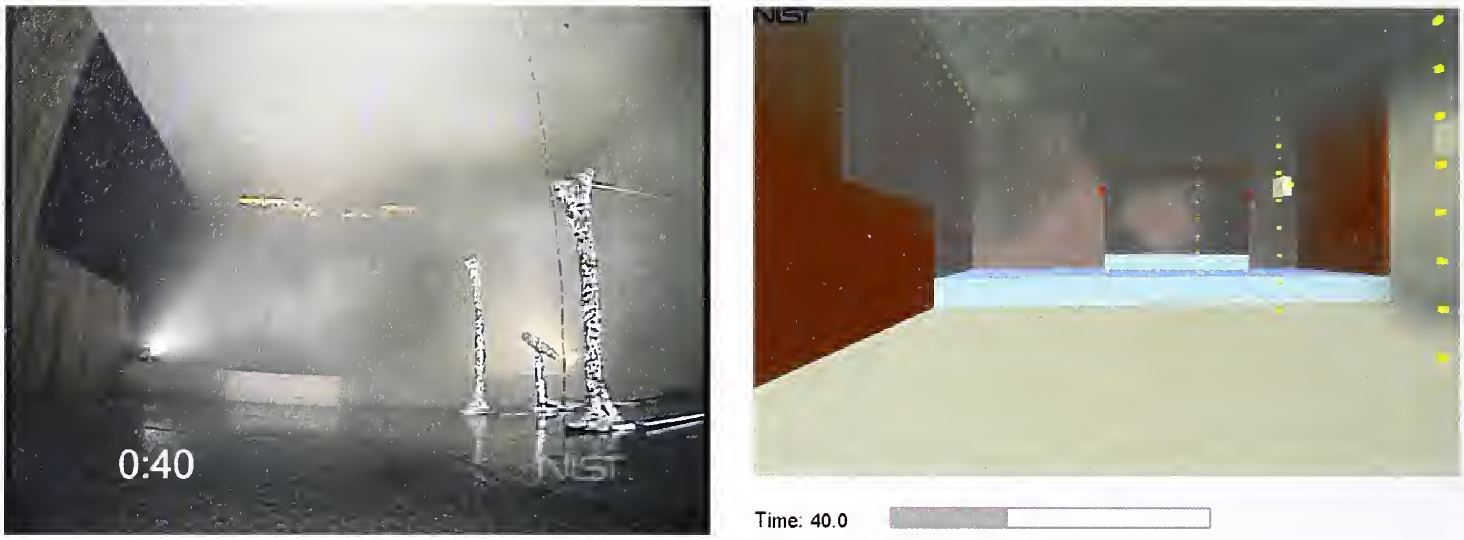


Figure 5-24. Suppression with three sprinklers operating in each case, t = 40 seconds after ignition.

Figure 5-25. Fire suppression continues in both the experiment and the simulation, t = 50 seconds after ignition.

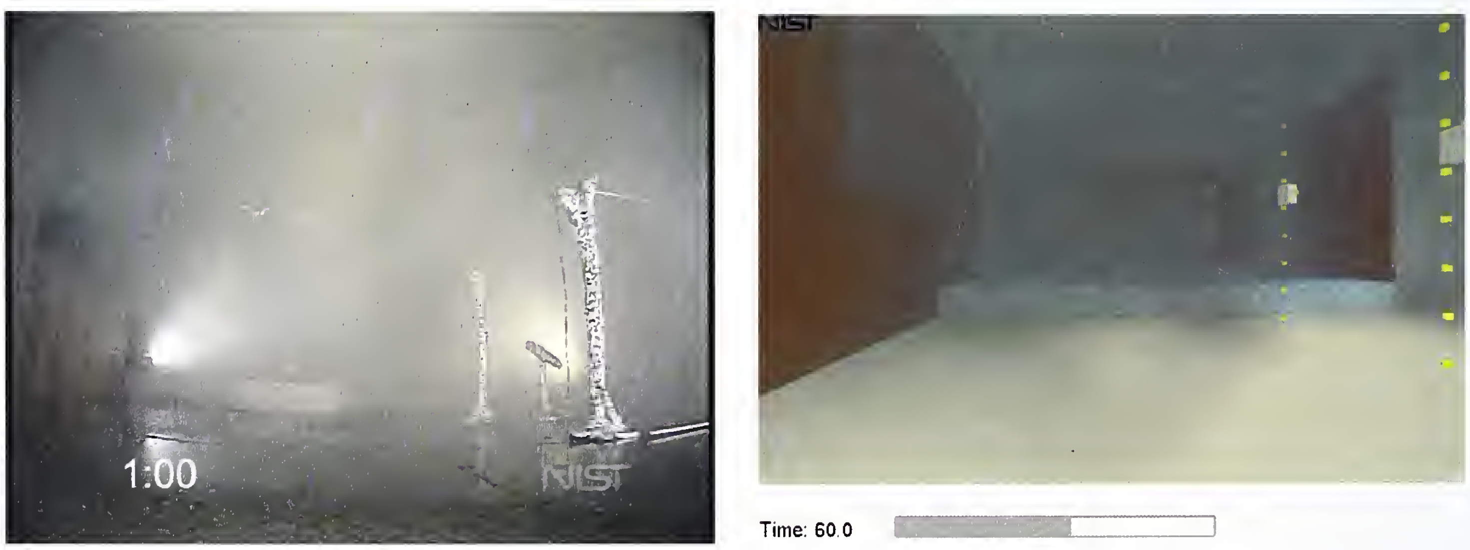


Figure 5-26. Fire controlled in both cases, t = 60 seconds after ignition.

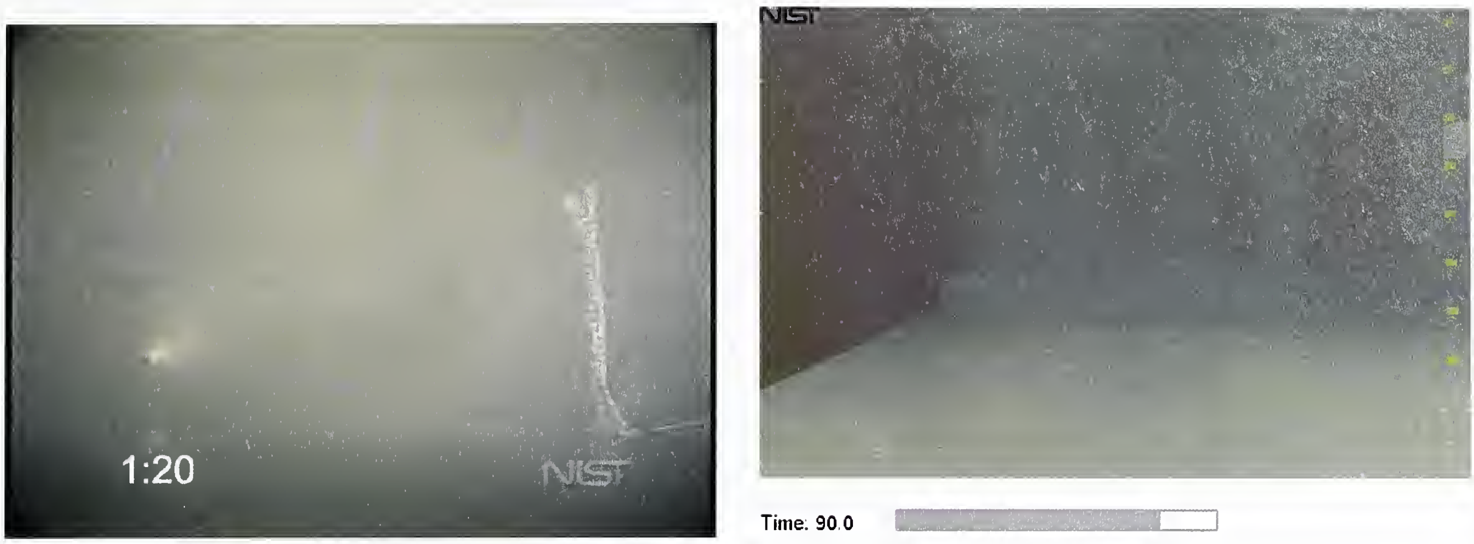


Figure 5-27. Fire controlled in both cases, t = 90 seconds after ignition.

sprinkler activation. Figures 5-19 through 5-21 show a very similar progression in fire growth as the unsprinklered case for both the experiment and the FDS simulation between ignition and 20 seconds after ignition. Figure 5-22 was captured at 25 seconds after ignition, approximately 1 second after the first sprinkler activated in both the experiment and the simulation. With the experiment, the impact of the sprinkler can be seen as the fire on the right side of the platform wall is suppressed. In FDS the flame height on the right side of the alcove can be seen to be reduced.

By 30 seconds (see Fig. 5-23) the effect of both of the sprinklers above the platform operating as well as the sprinkler in the alcove is apparent. Burning continues at the intersection of the platform wall and the ceiling. This area is above where the water spray is hitting the wall. Also notice the flames on the ceiling of the alcove. This area is shielded from the water spray of the two sprinklers. The smoke being pushed out of the alcove is due to the activation of the sprinkler on the ceiling of the alcove. In the simulation, only one sprinkler is operating at this time. The fire growth on the right side of the alcove has been limited by the single sprinkler.

By 40 seconds after ignition, three sprinklers in the experiment and in the simulation have activated. The video frame in Figure 5-24 shows that the fire in the alcove has been suppressed and that the burning above the water line on the platform wall continues. With three sprinklers operating in FDS, the water spray is significantly reducing the visible flames. The flames on the platform wall have been suppressed. However, there are still flames visible at the intersections of the alcove ceiling and the alcove walls on both sides of the alcove. These areas are shielded from the water spray of the sprinklers over the platform and they are above the water impact line from the sprinkler in the alcove.

Figures 5-25 through 5-27 show continued fire suppression for both the experiment and the simulation. In both cases some flames exist in the ceiling area of the alcove. But clearly the rate of fire growth and the resulting hazard development has been reduced significantly when compared with the unsprinklered case.

Both the experiment and the computer model demonstrate that the sprinklers would prevent flashover and considerably mitigate the hazard from the fire. However, the degree to which the fire is controlled is different between the experiment and the model, since the simulation has more flame spread along the edges of the alcove ceiling after activation of the sprinklers.

(ii) Numerical Comparison

In this section, measurements of heat release rate, temperature, heat flux, and oxygen volume fraction from the full-scale mock-up sprinklered experiments conducted in Chapter 4 are compared with values generated by the FDS simulation.

Figure 5-28 shows the FDS predicted heat release rate for the sprinklered enclosure. The experiment failed to produce enough combustion gases for the oxygen depletion calorimeter to measure a heat release rate. This was due to the rapid sprinkler activation, the effective fire suppression and the large volume of the enclosure. This graph demonstrates that in the simulation the fire grew after the activation of the third sprinkler (all were operating by 36 seconds). The decrease in HRR at approximately 140 seconds is when the shielded (dry) foam on the alcove ceiling burns itself out. In the experiment, foam above the line of water impact on the walls and the ceiling continued to burn after sprinkler activation as was shown in Figures 5-24 through 5-26.

The comparison of the temperatures at Stations C and D are shown in Figures 5-29 and 5-30. In both cases FDS under predicts the temperatures near the ceiling. The FDS predictions in these two graphs have not been smoothed in order to show that the peak values near the ceiling are very close to the sprinkler activation temperature of 74 °C. Typically the temperature of the fire gases surrounding a sprinkler at the time of activation is approximately twice the listed temperature.

Due to the continued burning of foam on the ceiling of the alcove prior to complete extinguishment, the temperature in the simulated enclosure increases over the experimental temperatures. However, at the 1.4 m level above the floor the temperature never exceeds 35 °C (95 °F). This is well within the temperature tenability range.

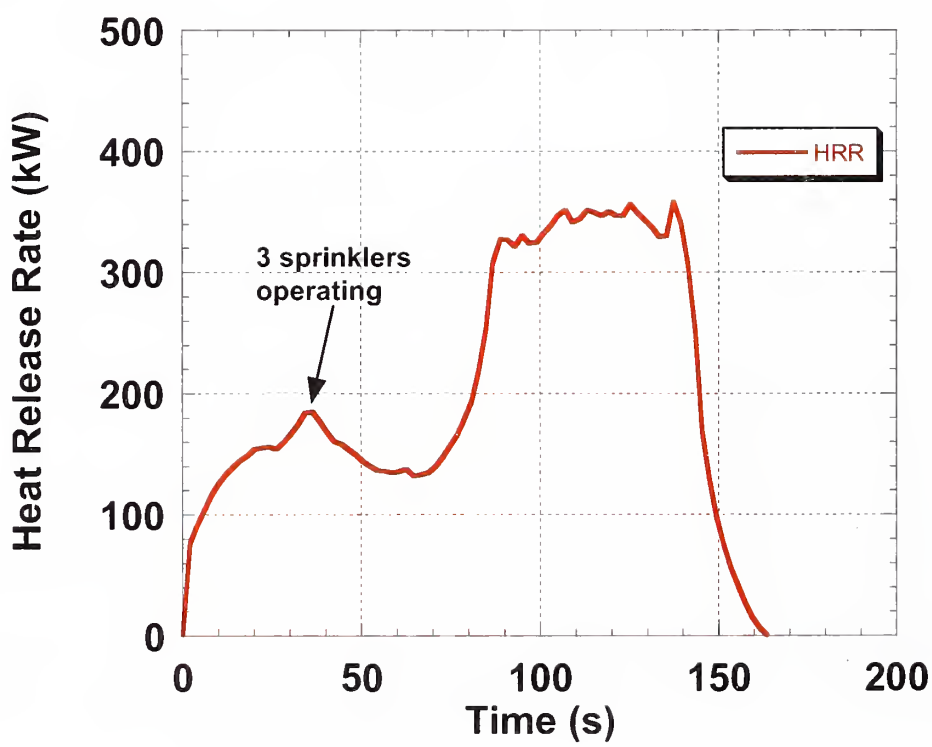


Figure 5-28. FDS predicted heat release rate for the sprinklered case.

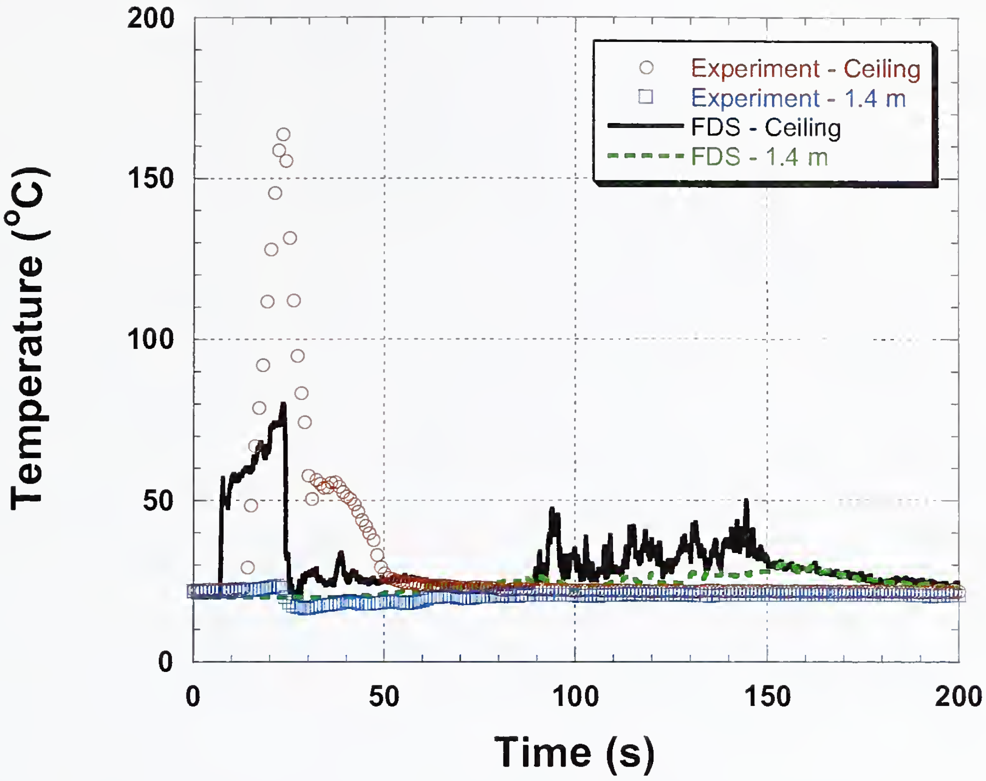


Figure 5-29. Temperature comparison between the sprinklered fire experiment and the FDS simulation at Station C.

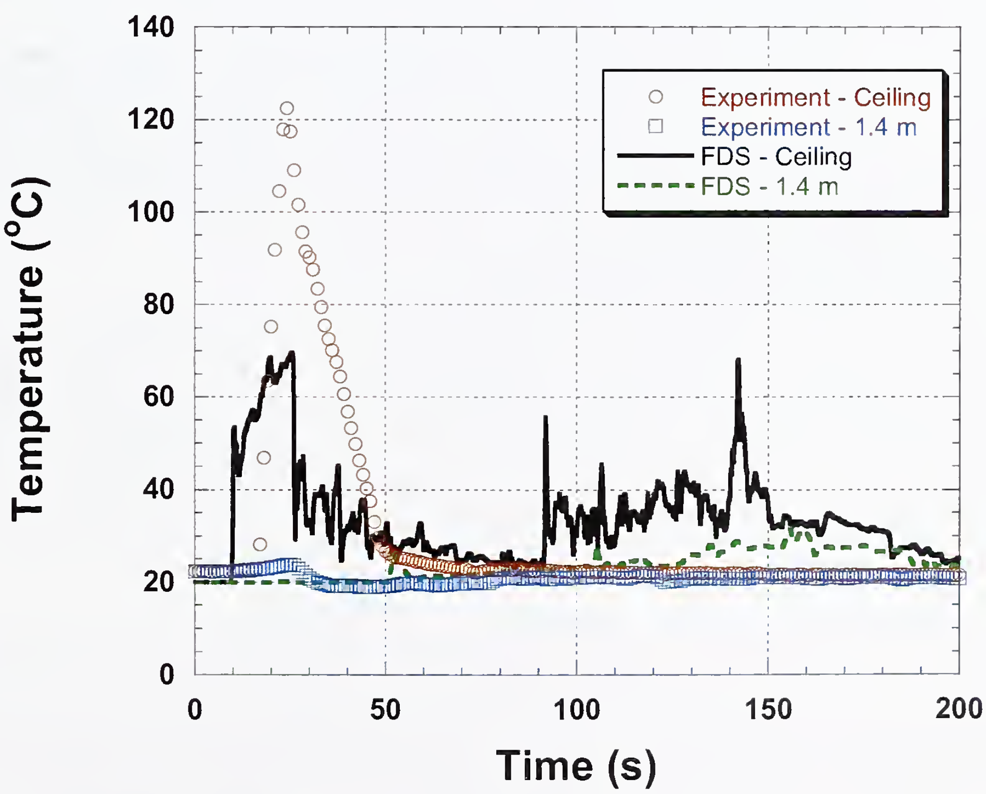


Figure 5-30. Temperature comparison between the sprinklered fire experiment and the FDS simulation at Station D.

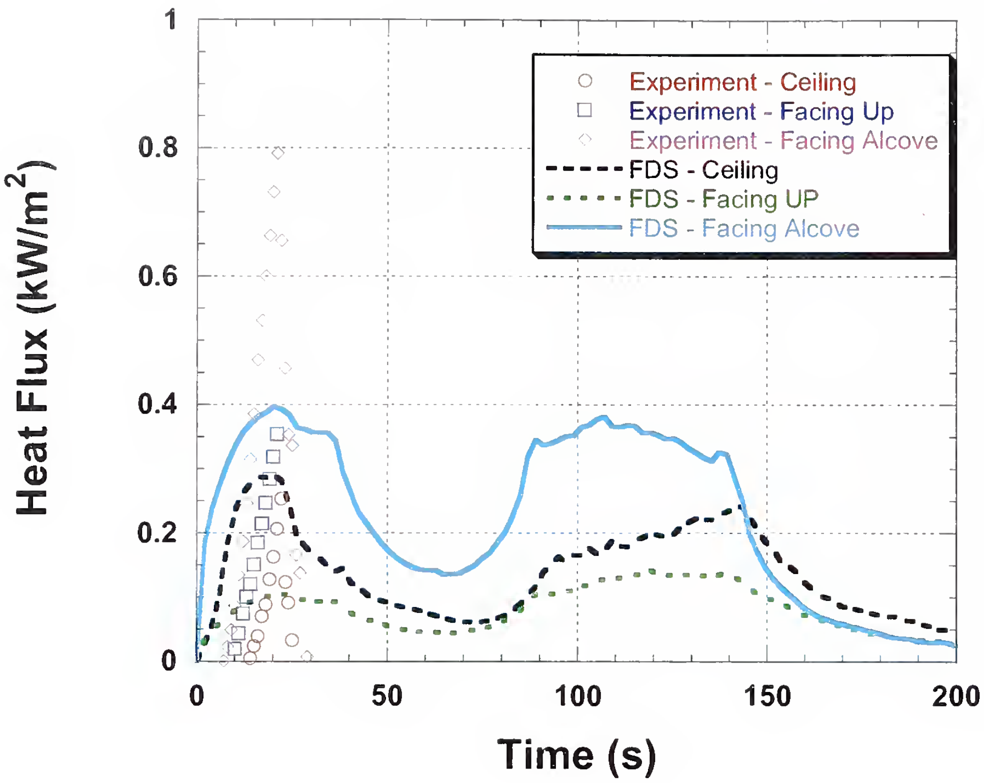


Figure 5-31. Heat flux comparison between the sprinklered fire experiment and the FDS simulation at Station C.

The comparison of the measured heat flux with the calculated heat flux is shown in Figures 5-31 and 5-32. Due to the limited fire growth and significant cooling by the water all of the heat flux values are less than 1 kW/m^2. One notable difference between the experiment and the simulation is after the sprinklers activate in the experiment, the measured heat flux goes to zero, while in the simulation small values heat flux energy continue to be shown.

Figure 5-33 exhibits the comparison of the measured and predicted oxygen concentrations at Station C. The measured oxygen concentration shows only a slight decrease during the 200 seconds, while the simulation shows a decrease of approximately 2 percent. This may be due to the continued burning of the foam along the ceiling of the alcove that is taking place in the simulation of the experiment.

(iii) Full-scale mock-up comparison - Summary

The visual and numerical comparisons demonstrate that the effects of an automatic fire sprinkler system on a fire can be successfully modeled by FDS and visualized with Smokeview. Both the experiment and simulation demonstrate that the sprinklers would prevent flashover and considerably mitigate the hazard from the fire in the test enclosure. However, the degree to which the fire is controlled is different between the experiment and the model, since the simulation has more flame spread along the edges of the alcove ceiling after activation of the sprinklers.

The temperature, heat flux, and the oxygen volume fraction comparisons show reasonable agreement between the experiments and the model in terms of both trends and range. Again some differences were caused by the increased burning after the start of suppression in the shielded areas, but that phenomenon has been documented in other experiments as well [22]. Tenability limits were predicted never to be exceeded using FDS, consistent with what was observed in the full-scale mock-up experiments. The lower portion of Table 5.3 compares the extreme values of heat flux, temperature, and oxygen volume fraction predicted in the simulation to the measured values.

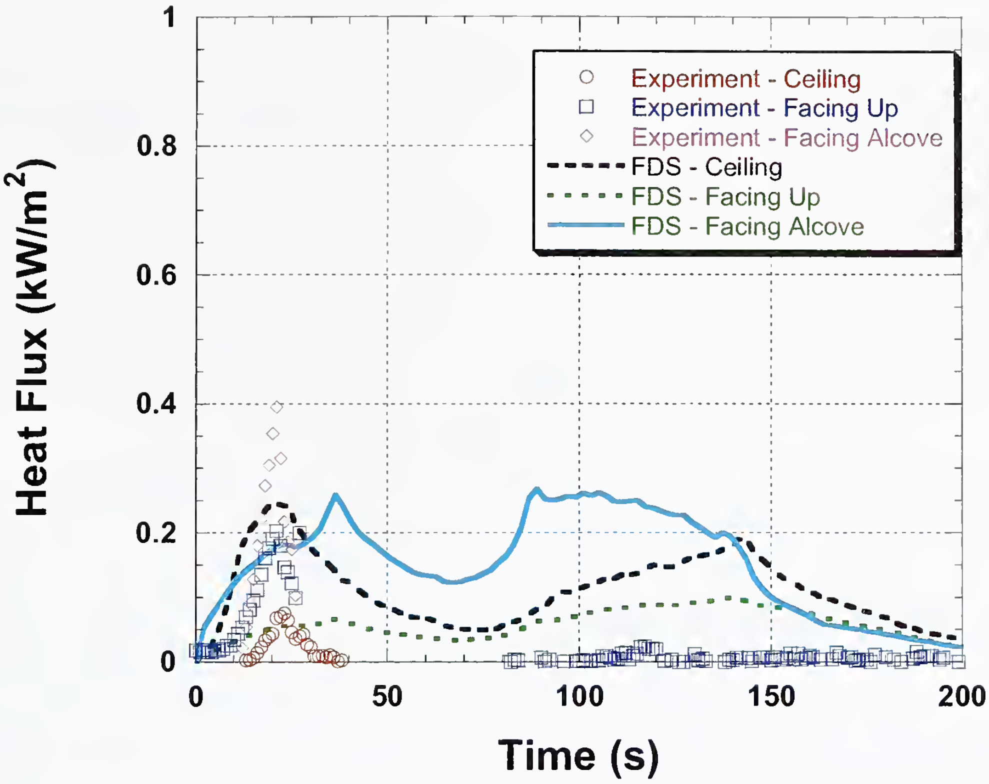


Figure 5-32. Heat flux comparison between the sprinklered fire experiment and the FDS simulation at Station D.

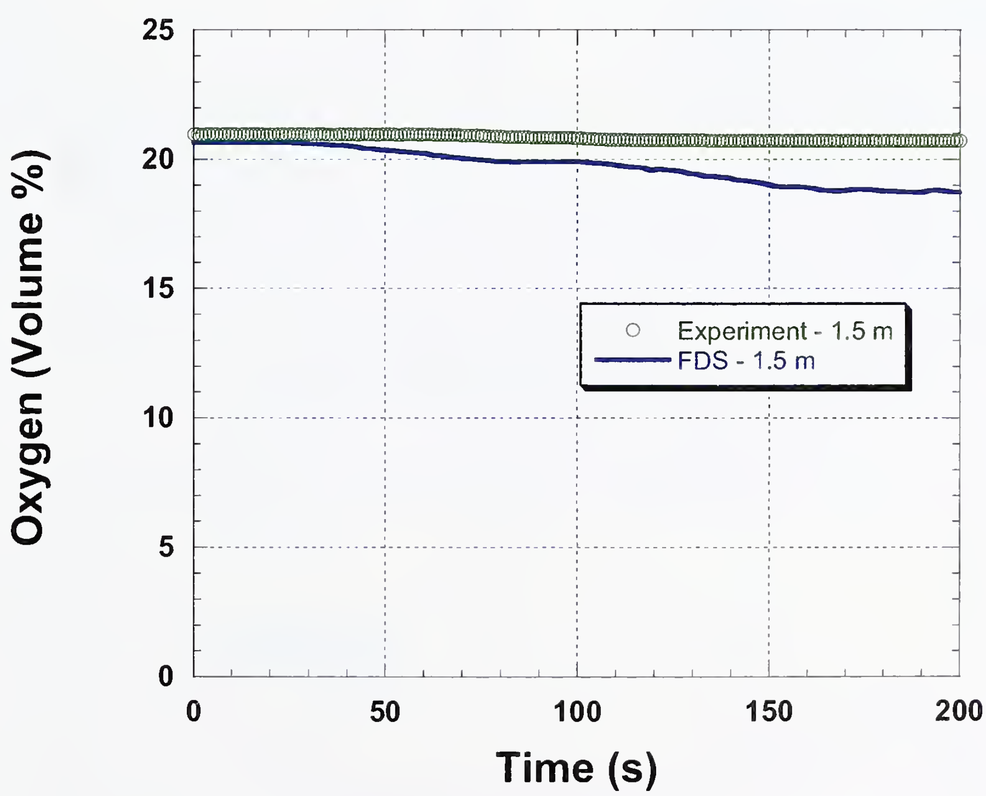


Figure 33. Oxygen volume fraction comparison between the sprinklered fire experiment and the FDS simulation at approximately 1.5 m above the floor at Station C.

5.3 FDS INCIDENT SIMULATION

5.3.1 Computational Domain and Materials

The computational domain used for the incident simulation consisted of eight adjoining rectangular meshes. Figure 5-34 shows an isometric view and Figures 5-35 and 5-36 show two different external views of the building. Each mesh was 4.1 m (13.5 ft) wide and the lengths varied from 10.8 m (35.4 ft) to 21.6 m (70.9 ft) based on the size of the structure and vent location. Each computational (or grid) cell was 100 mm (3.9 in) on a side. The input geometry for the Station nightclub including all wall, door and window sizes and locations was modeled based on the documentation provided in Chapter 2. Figure 5-37 is a plan view, Figures 5-38 shows the grid spacing used for the foam on the platform, and Figure 5-39 is a view looking toward the horseshoe bar and side exit from the center of the nightclub.

The interior finishes of the structure were simplified and modeled as five different materials: foam, wood, ceiling tile, gypsum board and carpet. The foam was prescribed with a wood backing due to the fact that the foam burns away leaving the wood paneling behind. Typically, FDS accounts for the burning of a single material; thus, the model was modified to allow the wood behind the foam to burn once the foam had burned away. The actual structure was lined with multiple types of wood such as paneling, wafer boards and bead board. In the simulation, all of these woods were prescribed with a single set of material properties. The ceiling tile, gypsum board and nylon carpet properties were based upon a combination of the cone calorimeter tests described in Chapter 4 and the FDS materials database. The view of the platform area seen in Figure 5-40 contains foam (grey), wood (brown and black), gypsum board (tan) and ceiling tile (tan).

Table 5-5 lists the material properties used in the simulation of the full-scale nightclub. The only difference in the properties used in the full nightclub versus the mock-up simulation was the thickness of the foam and the paneling. Based on materials observed in the field, the foam recovered from the nightclub was thicker than the foam used in the mock-up; a value of 30 mm (1.2 in) was chosen. The paneling that remained in the nightclub was installed in two layers. Therefore the thickness of the paneling for the incident simulation was doubled relative to the mock-up. The ceiling tile, gypsum board, and carpet used the same values as the FDS database, which were the same values used in the mock-up simulation. The complete FDS input files are provided in Appendix L.

Table 5-5. Simulation Material Properties

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	NA	NA	0.0611	NA
Gypsum Board	0.013	400	NA	0.48	NA
Carpet	NA	280	3000	NA	NA

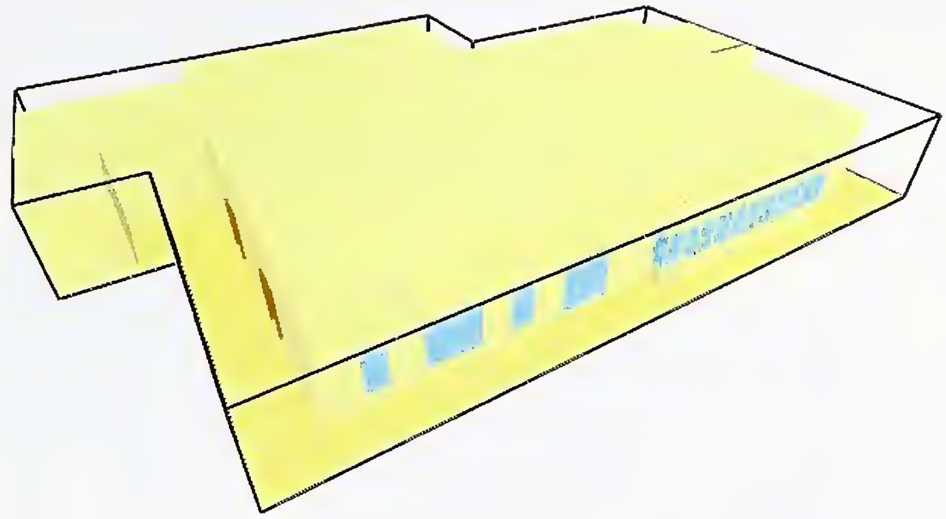


Figure 5-34. FDS computational domain of full nightclub

Figure 5-35. External view of nightclub from northeast corner

Figure 5-36. External view of nightclub from northwest corner

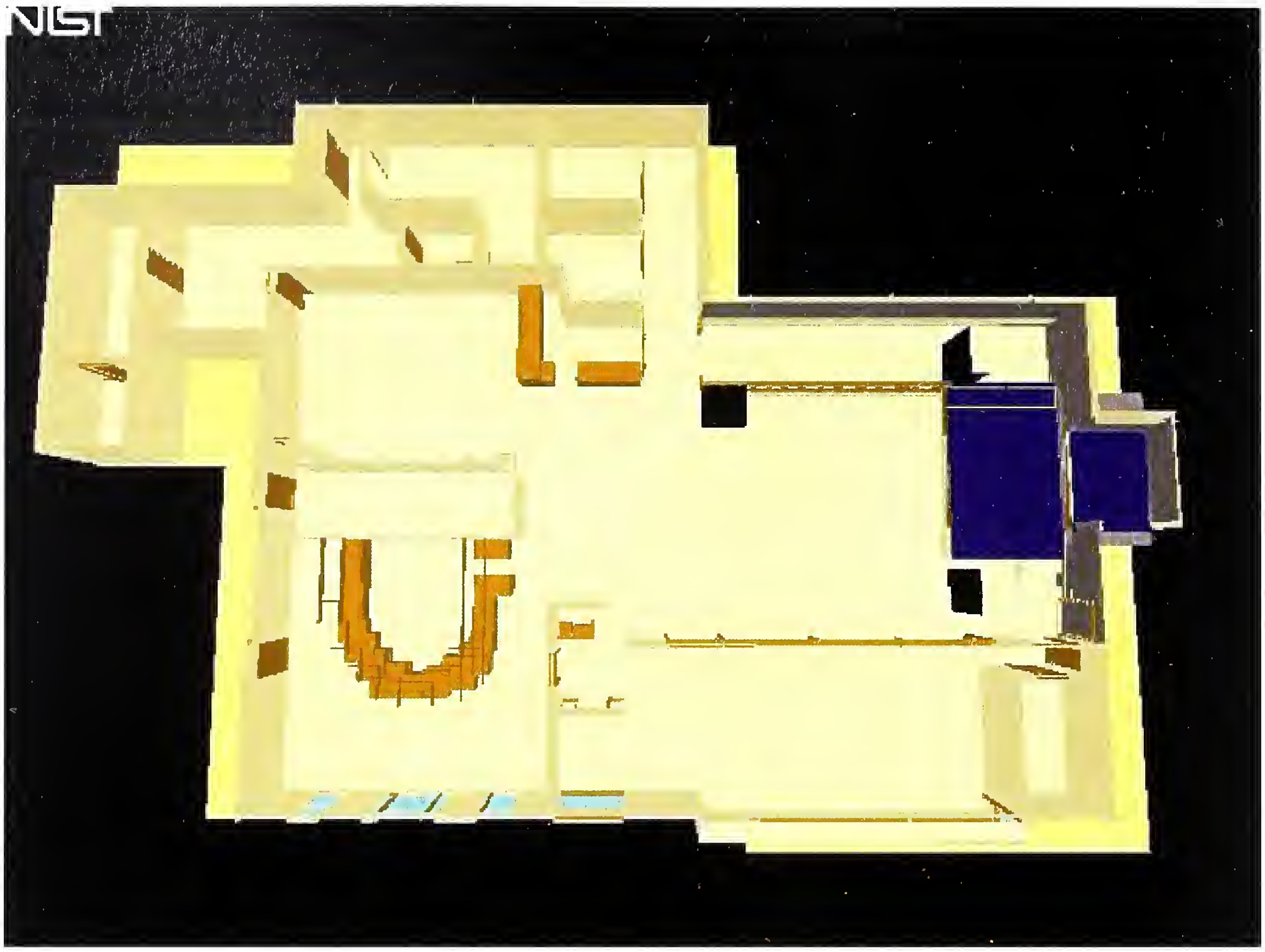


Figure 5-37. View from above with structure sliced 2.5 m above floor

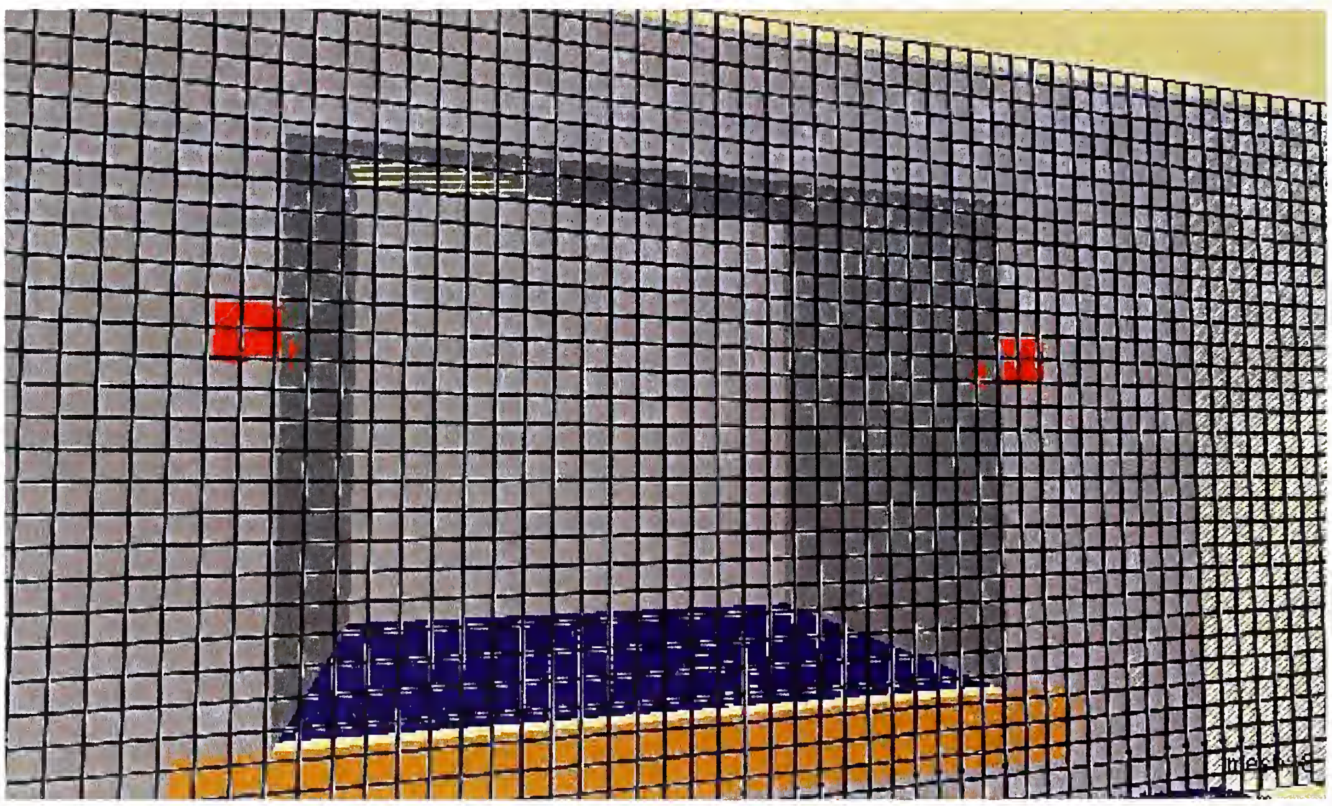


Figure 5-38. Numerical grid used for foam covered walls on platform. Red squares represent the points of ignition

Figure 5-39. View from center of nightclub toward horseshoe bar, with side exit and front windows in background

Figure 5-40. View of platform and dance floor showing different materials

5.3.2 Vents and Openings

All four sides and the top of the computational domain were modeled as open to the environment outside of the domain to allow air to enter and combustion products to exit. The outside temperature was assumed to be the same as the initial temperature inside, and the wind was assumed to be calm[1]. The bottom of the domain was considered to be an inert, adiabatic solid. Four heat producing vents were modeled: two 200 mm (7.8 in) square vents on the front corner of the alcove, and two 100 mm (3.9 in) square vents located 100 mm (3.9 in) back from the corner, into the alcove. All of the heat producing vents were 1.24 m (4 ft) above the floor of the alcove. The vents have an energy flux of 1500 kW/m^2 and emit energy for 35 seconds beginning at t = 0 seconds.

The structure's doors and windows were opened during the simulation based on estimations from the WPRI video. The first door to open was the door adjacent to the platform. This door was observed opening in the video 29 seconds after ignition. The front double door was assumed to open shortly after the stage door at 30 seconds. This time was selected due to the crowd beginning to notice the fire and to move toward the front door. The side door near the main bar was opened at 45 seconds and the side door in the kitchen was opened at 60 seconds. These times were estimated by the crowd movement seen in the video and the remoteness of the doorways from the stage area.

At 78 seconds, the lower portion of one of the bay windows was removed. This appeared to occur as the cameraman passes by on his way to the rear of the structure. Portions of the windows located on the front of the structure, left of the main entrance were removed at 80 seconds. This included the lower half of each of the matching windows next to the large window in the center, the entire large window in the center, all of the thin window to its left and the lower half of the thin window to its right. Finally, more sections of the bay window, surrounding the portion that was removed at 78 seconds, were removed between 100 and 130 seconds. The side bay window facing the main entrance was seen open in the WPRI video and the three other windows between the side window and the lower portion of the window were removed at 78 seconds based on the sounds heard in the video. Vent opening times are summarized in Table 5-6 and visualized in Figure 5-41.

Table 5-6. 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

[1] The temperatures recorded at T.F. Green Airport that night were in the high 20s (°F) and the winds were light.

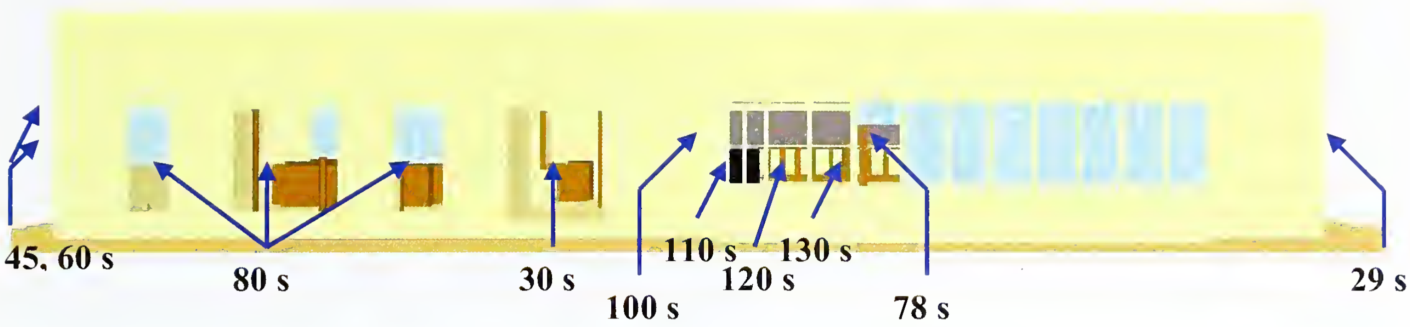


Figure 5-41. Visualization of Opening Times

5.3.3 FDS Simulation Results

The focus of this simulation was the examination of the conditions that may have been present in The Station nightclub during the early stages of the fire. Results from the bench-scale experiments and existing data were used to develop the input properties for the interior finish materials. The full-scale mockup results were used to compare against the FDS simulations to validate the implementation of the data in the model, and to determine the model's capabilities for this fire incident. Further, the sprinklered mock-up results were used to develop a means to model the sprinkler in the full nightclub simulation. Images from the WPRI video were utilized to develop model input to establish the location of the different interior finishes within The Station nightclub as well as being used as a general resource for confirming the physical arrangement of the nightclub. The simulation was run for 300 seconds to examine the time period from ignition to the approximate time of application of water 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. Each of these was compared to published tenability criteria.

In order to gauge the accuracy of the full nightclub simulation results, they were compared with the WPRI video record of the incident. In addition, analysis of the simulation considered published tenability criteria and the location of the victims within the nightclub.

(i) Heat Release Rate

The total heat released in the fire is plotted in Figure 5-42. 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 seconds. 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.

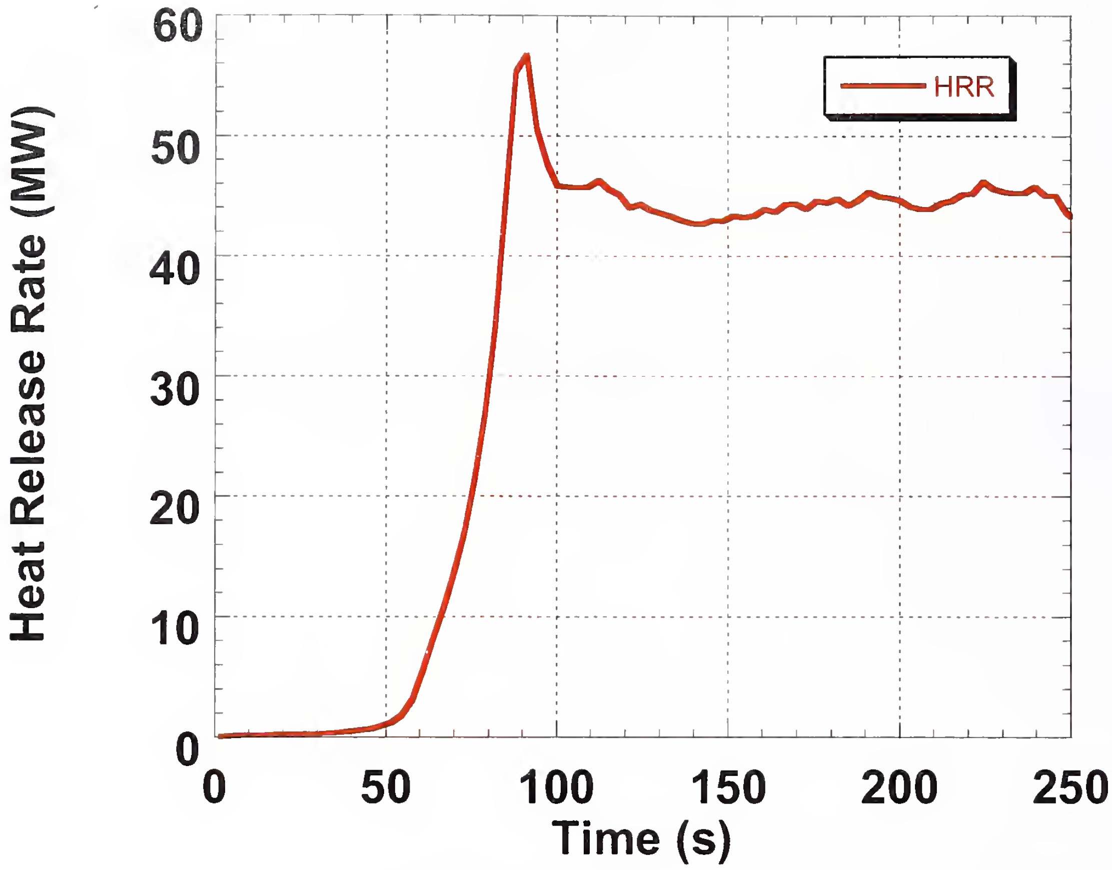


Figure 5-42. Total Heat Released in Building Fire Simulation as a Function of Time

(ii) Fire Growth and Smoke Spread

Images were selected from the WPRI video to compare with the FDS simulation results. Iso-surfaces of the heat release rate per unit volume and three-dimensional smoke density parameters are displayed in the Figures 5-43 through 5-53. It should be noted that the orange color in Smokeview tracked the location of stoichiometric fuel and air mixture. If the temperature were high, then the orange surface could be thought of as a flame; if the temperature were below a threshold value, then no flame was actually present, just a non-burning mixture of fuel and air. Qualitative agreement can be seen between the pairs of images from the video and the simulation for both the initial growth prior to the videographer leaving the structure, and the outside view as the videographer walked around the structure. This similarity helped the investigation draw conclusions as to the conditions inside the structure even though the video was no longer recording inside.

Time "0" refers to the instant of ignition of the foam by the gerbs as documented in the WPRI video. 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. The last image set does not reflect the same time. The simulation stops at 300 seconds 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.

The images from the video in Figures 5-43 and 5-44 capture the initial state of the fires on each side of the platform shortly after the gerb discharge had stopped. At 10 seconds after ignition, the fire can be seen burning on two surfaces at each of the corners; this is also considered in the simulation with the placement of the ignition vents on both sides of the corner. In both the simulation and the actual incident the flames impinge on the ceiling within 20 seconds after ignition.

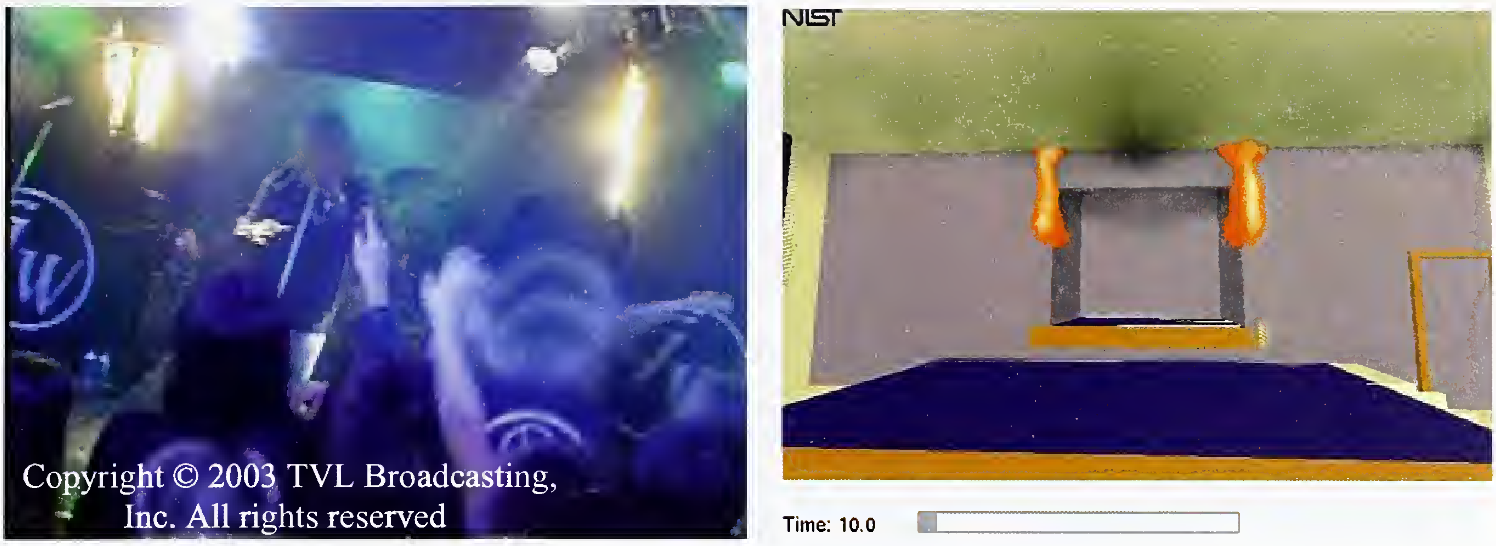


Figure 5-43. Initial growth of fire on foam at corner of the alcove (10 seconds)

Figure 5-44. Flames impinging on ceiling (19 seconds)

At 23 seconds after ignition, Figure 5-45, the videographer has begun to move toward the exit as have many in the crowd. Notice that many people are still facing the platform. The fire continued to grow and smoke has collected in the raised ceiling area over the dance floor. The smoke filling can be seen in the image from the simulation. (Note the black rectangular image on the floor is representative of the speaker cabinet, whereas the boundaries of the smoke layer are irregular.) At 53 seconds after ignition, the flames have grown and spread along the platform wall and into the alcove as shown in video image in Figure 5-46. In addition, the smoke is spreading across the lower level ceiling area toward the main exit. The flames have spread in the simulation as well and smoke is beginning to spill over from the dance floor area towards the exits and the main bar room, although it takes a few more seconds into the simulation for this to occur. Again the black rectangular objects on the floor are representative of speaker cabinets (near the platform) and the sound and lighting board (left side).

The videographer had exited the nightclub at approximately 70 seconds and headed toward the stage door. He then returns toward the main entrance and attempts to pass between the nightclub and the bus when he encounters a plume of black smoke pushing out of one of the window vents in the sunroom. The image from the simulation also shows a similar view. At approximately 110 seconds after ignition, smoke is flowing from the main entrance; the image from the simulation is given in Figure 5-48. The model did not account for people blocking the air flow into the doorway.

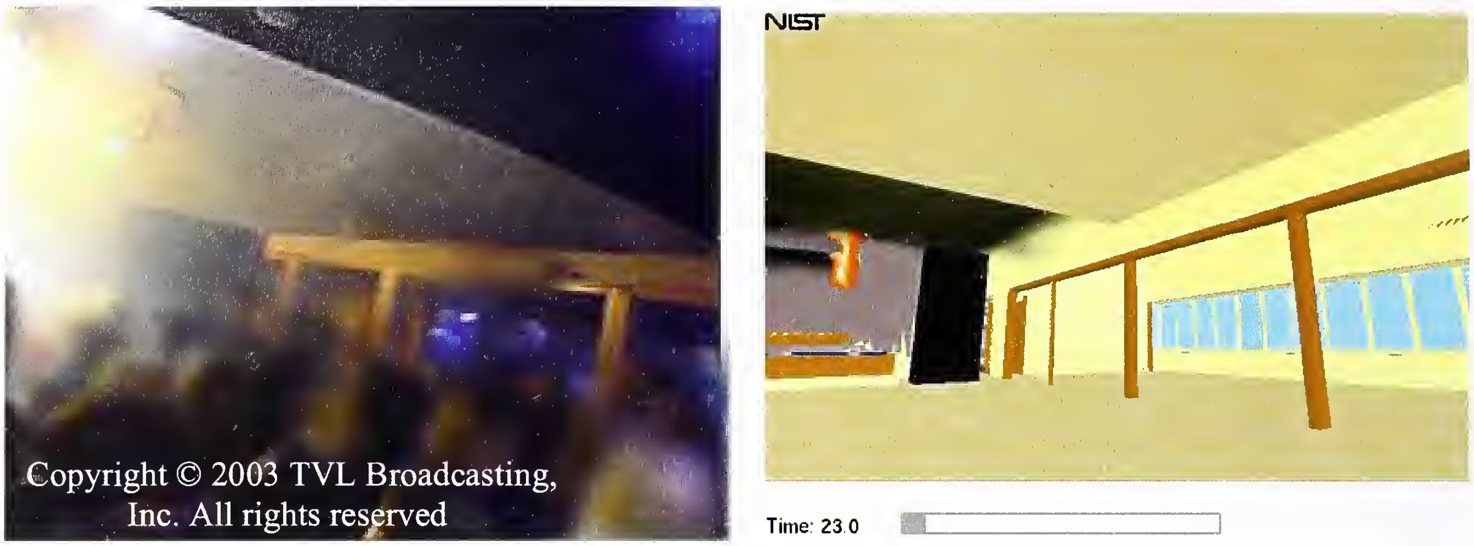


Figure 5-45. Videographer backing away from platform (23 seconds)

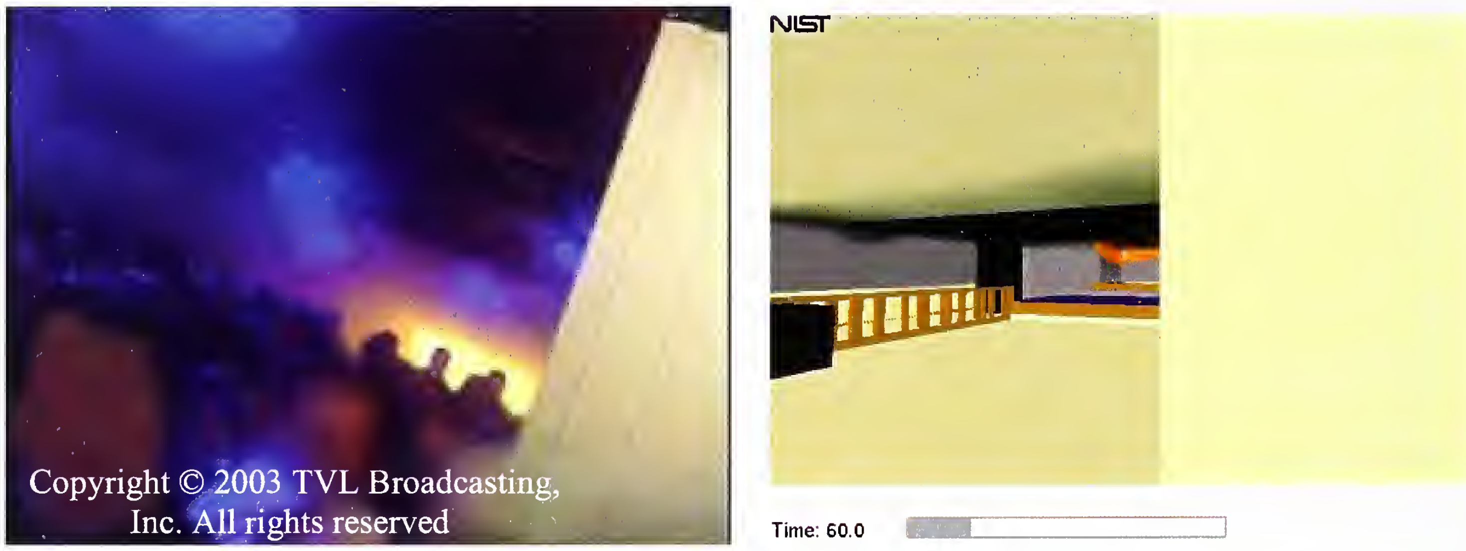


Figure 5-46. Smoke beginning to roll across ceiling (video 53 seconds, simulation 60 seconds)

Figure 5-47. Smoke billowing outside from broken sunroom window (100 seconds)

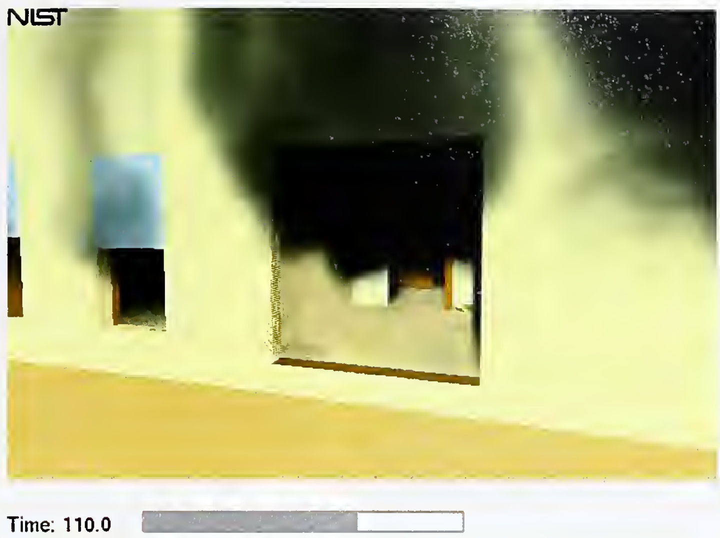


Figure 5-48. Light smoke emanating from front door of nightclub (110 seconds)

The Smokeview image in Figure 5-49 shows the smoke flow from the front door at 160 seconds after ignition in the simulation. In Figure 5-50, the simulated smoke flow from the main bar room windows is shown. More smoke is coming from the center window than the two side windows because the upper and lower portions of the center window have been removed while only the lower portion of the side windows are open in the simulation.

The videographer moves around to the stage door again. The view inside the open door at approximately 289 seconds after ignition is shown in Figure 5-51 The image from the simulation agrees with the video image on the level of combustion products in the doorway. However without a comparison to the temperature in the doorway, the mixture fraction alone would indicate that more flames are in the area of the stage doorway than can be seen in the video image. The videographer continues around to the backside of the nightclub, at 300 seconds after ignition flames are coming through a small portion of the back wall (south wall) of the dance floor area and smoke is leaking from the bathroom hallway wall. The videographer moved toward the front of the nightclub again, at 309 seconds flames can be seen in the area of the front door. It takes another 25 seconds before he is in a position to record the images of the flames coming from the sunroom windows and the main door. The simulation stops at 300 seconds after ignition, short of the time that the entire nightclub reaches flashover conditions.

Figure 5-49. Heavy smoke leaving front door and open main bar window (160 seconds)

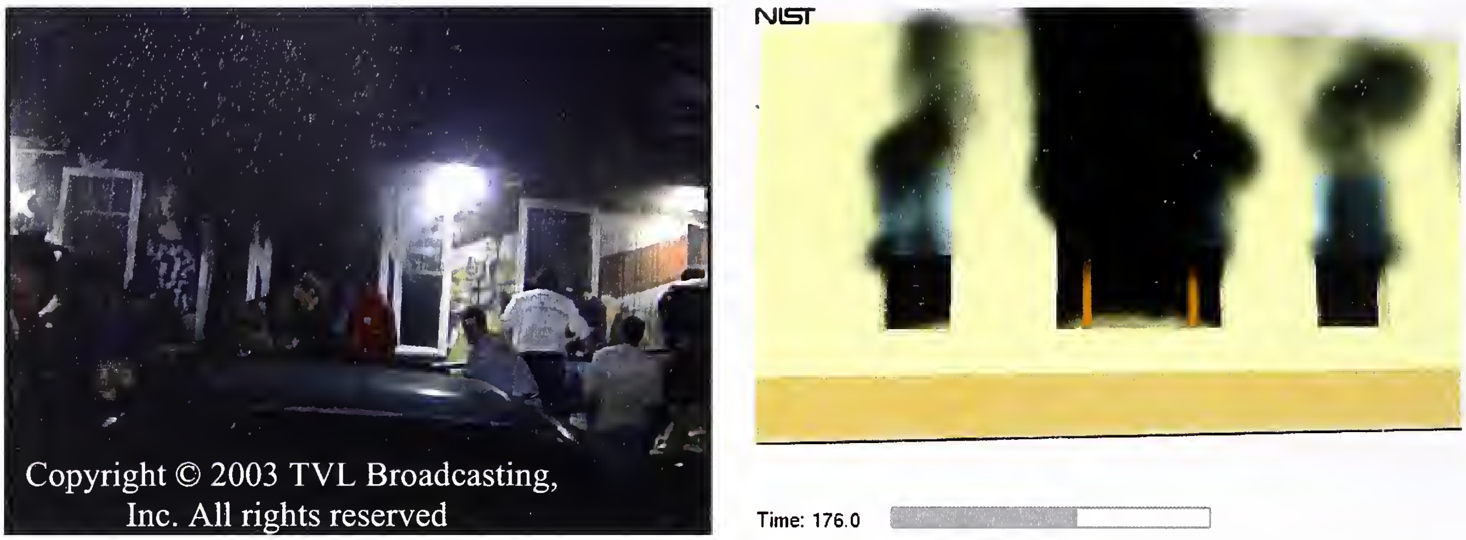


Figure 5-50. View of smoke plumes from front windows of horseshoe bar area (176 seconds)

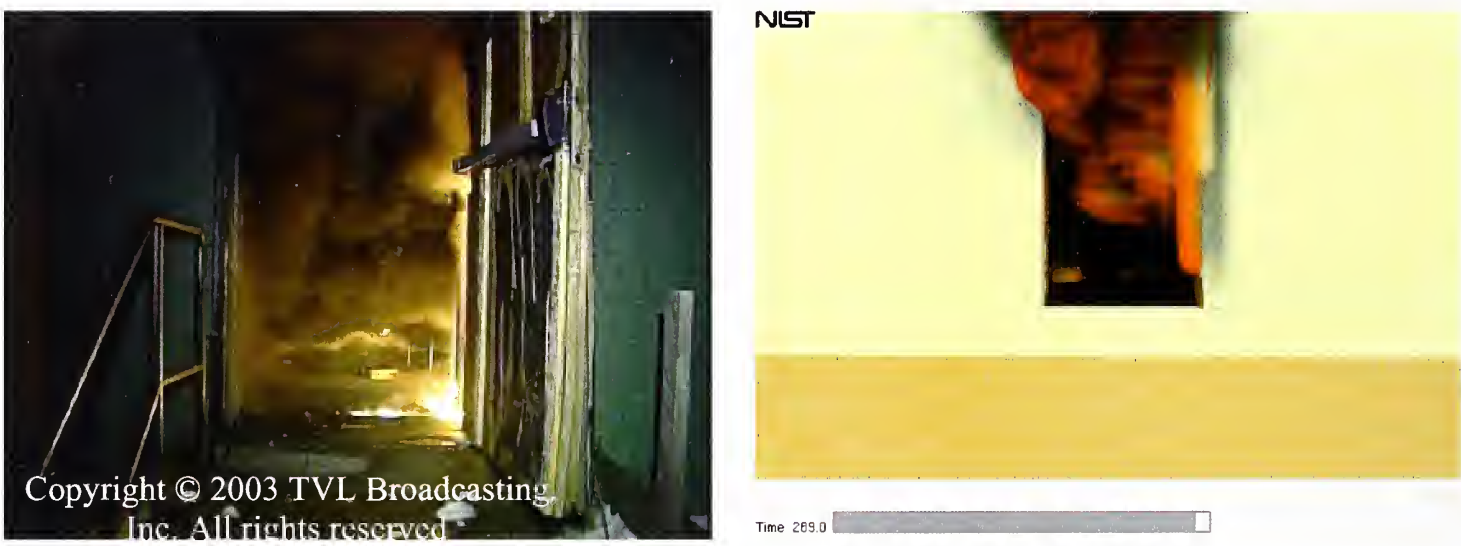


Figure 5-51. Looking into stage door exit (289 seconds)

Figure 5-52. Flames breaking through front door and sunroom windows (337 seconds video, 300 seconds simulation)

Smokeview images were rendered at certain time intervals from the view looking through the far side of the main bar to the platform area. (See Figures 5-53a,b.) This allowed for the conditions to be observed at several key locations: the platform area, the entrance to the main exit way and the main bar area. Many of the occupants traveled this path as either they were able to exit or were overcome by the conditions prior to being able to do so. The fire developed quickly in the platform area as the foam burned and resulted in the alcove becoming fully developed with fire. Once that occurred the flames involved the entire rear wall and spread toward the main entrance, generating large amounts of smoke. At 70 seconds after ignition, the smoke can be seen in the area of the main entrance to the nightclub. This is consistent with the WPRI video. As the videographer leaves the nightclub, at approximately 70 seconds after ignition, smoke is flowing over the heads of people in the main entry foyer. However, even 80 seconds after ignition visibility remained high in the main bar room. This changed suddenly as the smoke and hot gases that were spilling out of the now-filled raised ceiling above the dance floor quickly spread to the main bar room. Based on the FDS simulation, within another 20 seconds, 100 seconds after ignition visibility was impaired, and remained so throughout the rest of the 300 seconds simulation. Flames can be seen in the last three images of Figure 5-53b as the surfaces in the main bar area began to burn.

ignition (0 seconds)

20 seconds

40 seconds

60 seconds

Figure 5-53a. View of fire from beyond horseshoe bar, looking at platform (0 - 60 seconds)

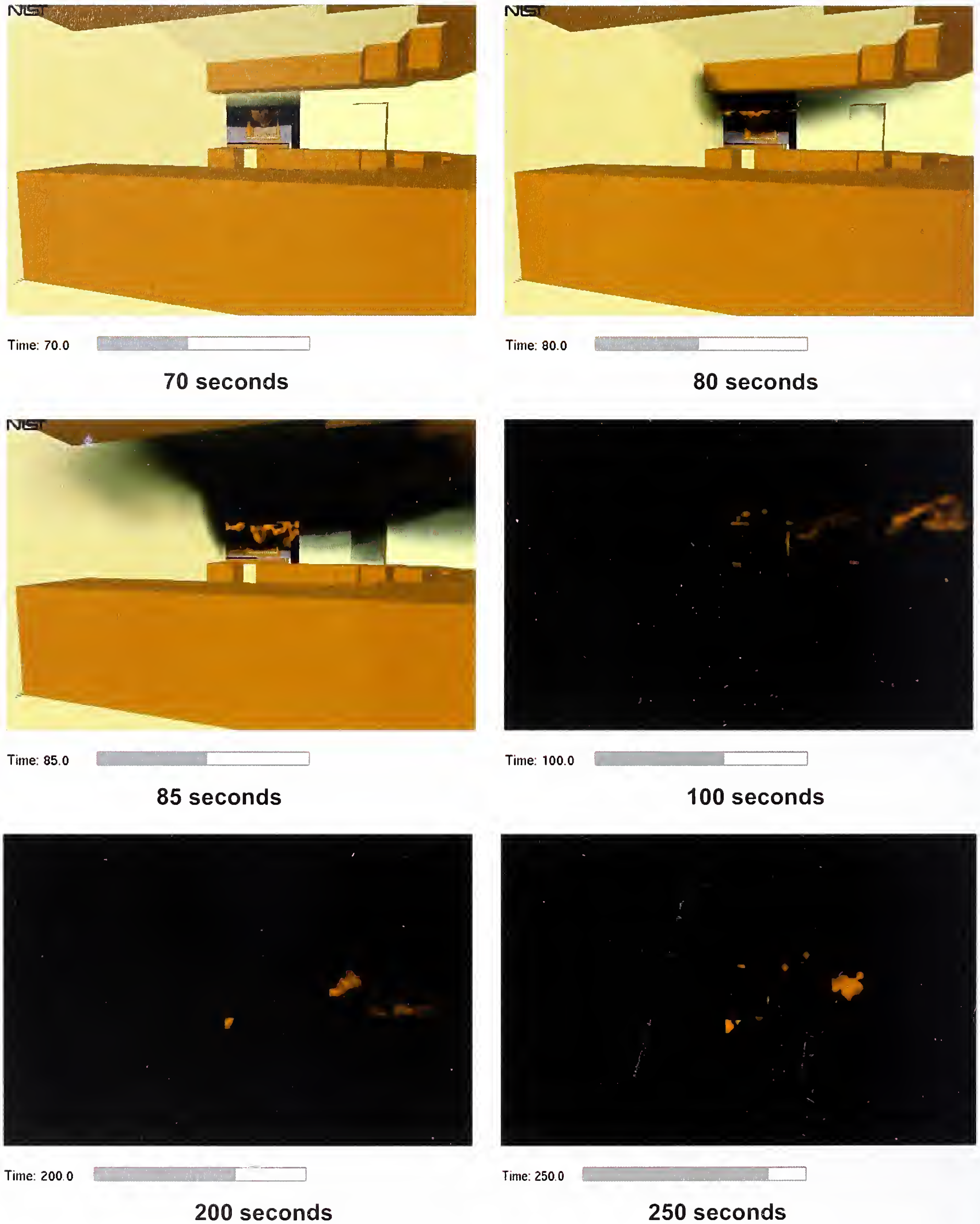


Figure 5-53b. View of fire from beyond horseshoe bar, looking at platform (85 - 250 seconds)

(iii) 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 (5 ft) and 0.6 m (2 ft) levels above the floor with the ceiling rendered transparent to examine the temperature distribution throughout structure as a whole. Vertical slices were used to analyze certain locations where groups of victims were located (See Figure 5-54). These locations included the main entrance as seen through the front door, the area leading into the exit area from the dance floor, and the left side of the sunroom and the open area adjacent to the side bar and kitchen. This analysis utilized 120 °C (248 °F) as the temperature tenability threshold [6]

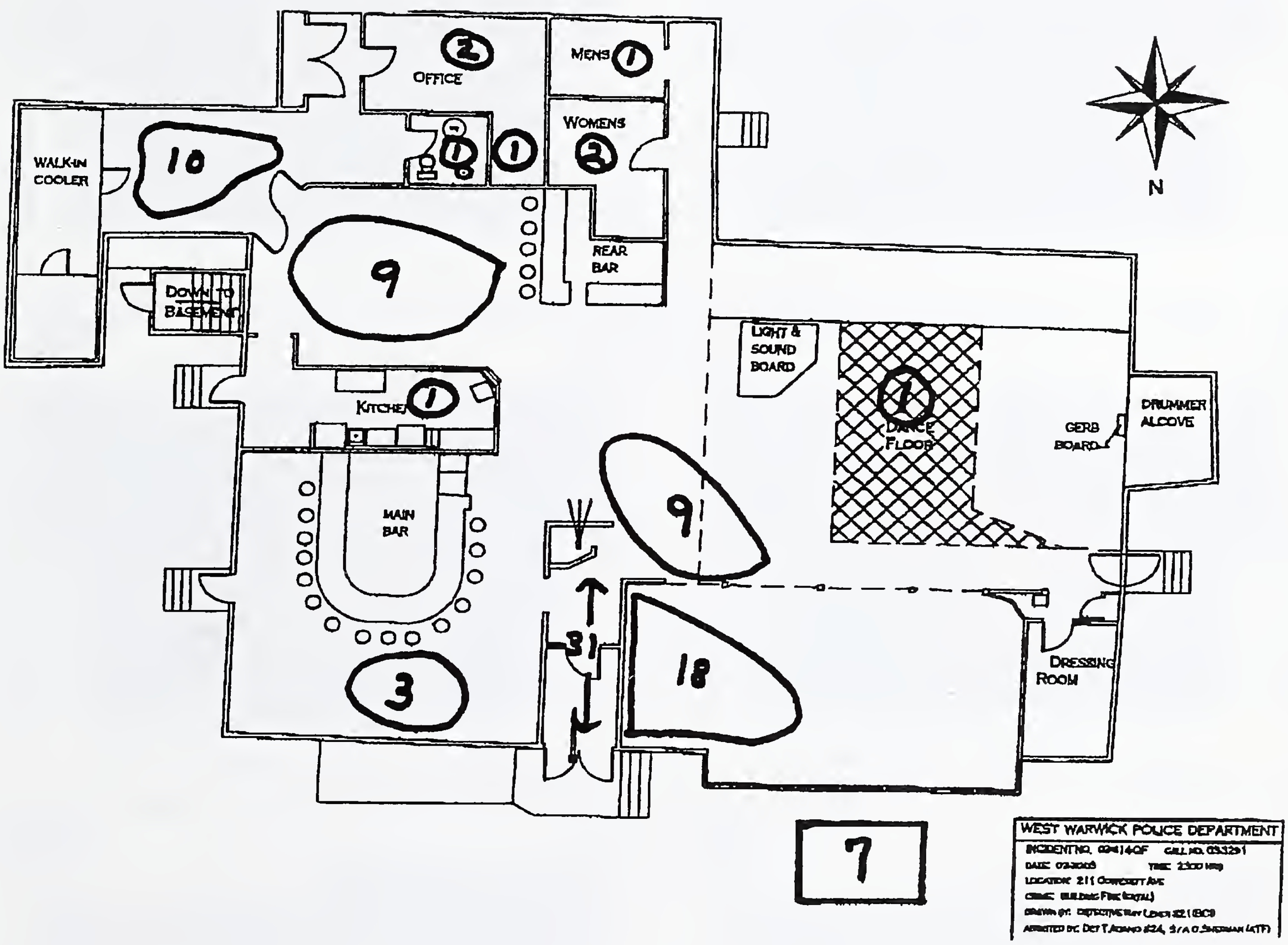


Figure 5-54. West Warwick Police Department Victim location diagram

Temperatures increase dramatically shortly after the alcove area reaches flashover conditions at approximately 65 seconds and then the platform area becomes fully involved in flames. The first two images in Figure 5-55 show the temperatures at 1.5 m (5 ft) above the floor at 80 and 85 seconds. Within that 5 second time interval the simulation predicts that dance floor area of the nightclub would have become untenable due to temperature. By 100 seconds after ignition, the simulation shows a large portion of the structure had become untenable due to temperature at the 1.5 m (5 ft) level. Figure 5-55 continues with the presentation of simulation temperature results from 160 seconds to 250 seconds after ignition. During this time interval temperatures continue to remain in the untenable range throughout the simulated nightclub, with the exception of areas that are considered closed off from the hot gas flow such as the bathrooms, office and storage areas. These areas were assumed to be separated from the rest of the nightclub by closed doors, so they were modeled without a path for the gases to enter the spaces, hence they appear to remain in the tenable range. The kitchen area has an open door from the dart room and a open door that exits to the outside. The hot gas flow goes directly from the dart room to the exit doorway. This leaves the kitchen at a cooler temperature than the surrounding rooms.

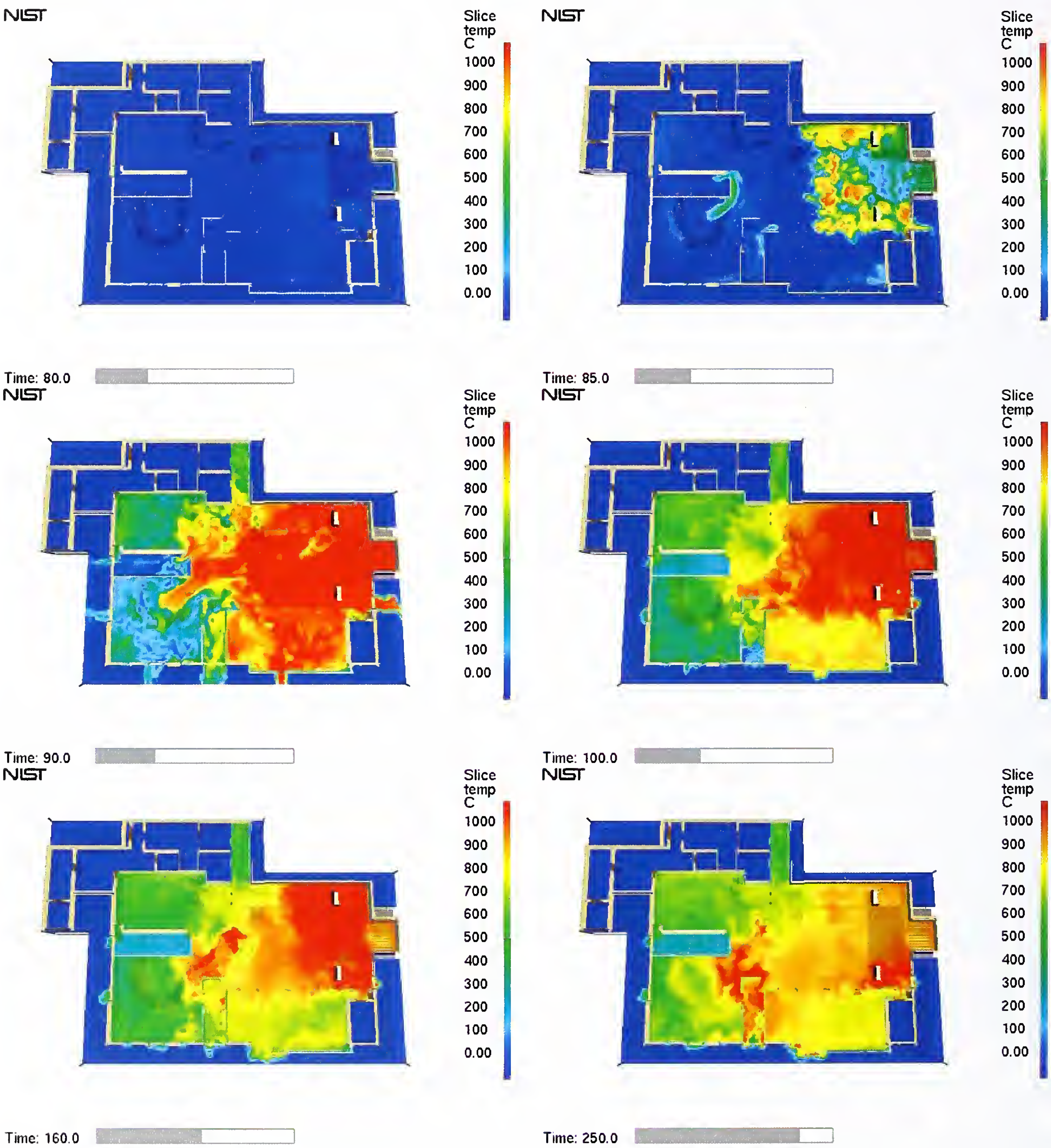


Figure 5-55. Temperatures at 1.5 m (5 ft) above the floor, 80 seconds to 250 seconds

At the 0.6 m (2 ft) height above the floor conditions remain tenable for a longer period of time than at the higher elevation. Figure 5-56 contains images captured at the same time intervals as in the previous figure. One can see that the dance floor and adjacent areas reach untenable temperatures in the simulation within 90 seconds after ignition. The sunroom and dart room areas are predicted to reach untenable temperatures within another 10 seconds.

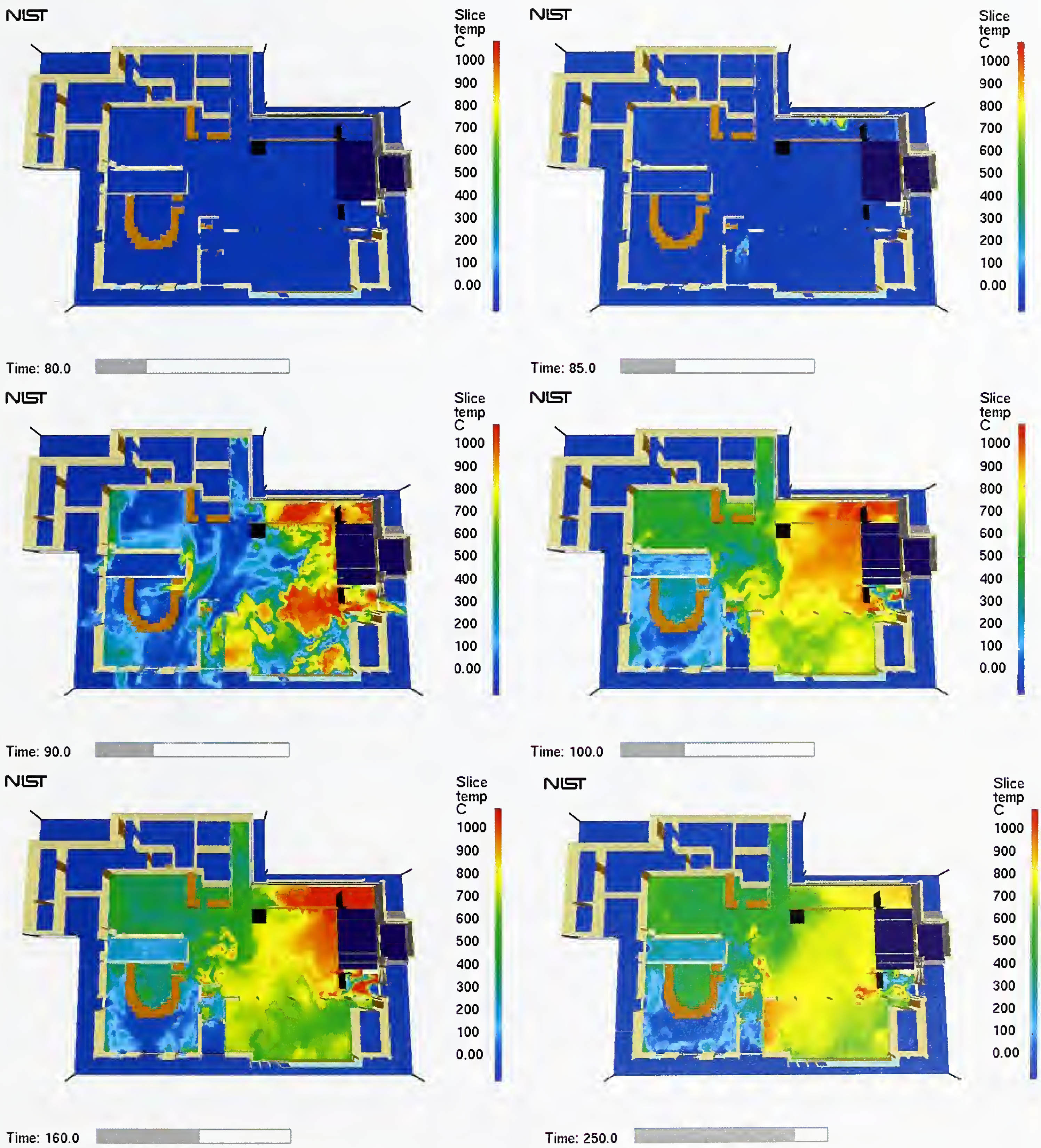


Figure 5-56. Temperatures at 0.6 m (2 ft) above the floor, 80 seconds to 250 seconds

The significant differences in temperature between the 1.5 m (5 ft) elevation and 0.6 m (2 ft) 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 toward the floor at both the front door and main bar area explain why occupants were seen in the WPRI video escaping from the windows and doorway later into incident. The temperatures in later images do not change significantly regarding areas that have untenable conditions versus areas that remain tenable based on temperature only.

Figure 5-57 shows the temperature predictions for the plane of data that is centered along the axis of the entry foyer. Temperatures just inside the front door, near the floor remain below the tenable limit because of the fresh air being drawn in through the doorway. This region of tenability decreases in a triangular orientation as the entranceway goes into the structure and gets smaller as the simulation continues. This simulation does not account for the occupants that accumulated in the doorway. Thirty-one victims were located in this area.

The area in the end of the sunroom adjacent to the entranceway was also a location that many victims were found. A vertical temperature slice through this area, shown Figures 5-58a and 5-58b, suggests that these victims did not have much time before the heat overcame them. Temperatures exceeded the 120 °C (248 °F) tenable threshold within 90 seconds after ignition. The simulation indicates that this change was rapid and extreme with temperatures in the upper portion of the space increasing from ambient conditions to flame temperatures on the order of 1000 °C (1830 °F) within 10 seconds. After the initial energy release due to the burning polyurethane foam (90 seconds), the predicted temperature decreased, but remained in the untenable range throughout the remainder of the simulation. Figure 5-58b shows that the temperatures increased again to 900 °C (1650 °F) at 250 seconds after ignition. The opening of portions of the bay windows between 78 seconds and 120 seconds after ignition had a minimal impact on reducing the temperatures in this part of the building. Eighteen victims were located in this area.

Figure 5-59 depicts the temperatures in the approaches to the main entry foyer. The vertical temperature slices cover the area at the end of the entrance foyer and next to the ticket booth. The view is from the dance floor area looking toward the main entrance (front door). What appears to be a pillar in between the intersection of the two vertical slices is a portion of the wall that separates the sunroom from the main entry foyer. The images demonstrate that temperatures were untenable outside of the entranceway and that if the occupants were not able to make it into the area of cool air coming in from the front doorway, they did not have a chance of survival. Temperatures near the floor exceeded 400 °C (750 °F) within 100 seconds of ignition. Nine victims were located in this area.

The area of the nightclub with the side bar and the dart room is shown in the simulated images with vertical temperature slices bounding the area to the north (toward the main entrance) and to the east (toward the storage/office area entrance). Figure 5-60 shows the rapid change in thermal conditions between 80 seconds and 90 seconds after ignition. As in other parts of the nightclub simulation this significant increase in temperature was due to the burning of the polyurethane foam. Temperatures near the floor ranged from 200 °C (390 °F) to 600 °C (1110 °F) at 100 seconds. The figure indicates that the temperatures remained in the untenable range throughout the rest of the simulation. In the incident, nine victims were found in this area.

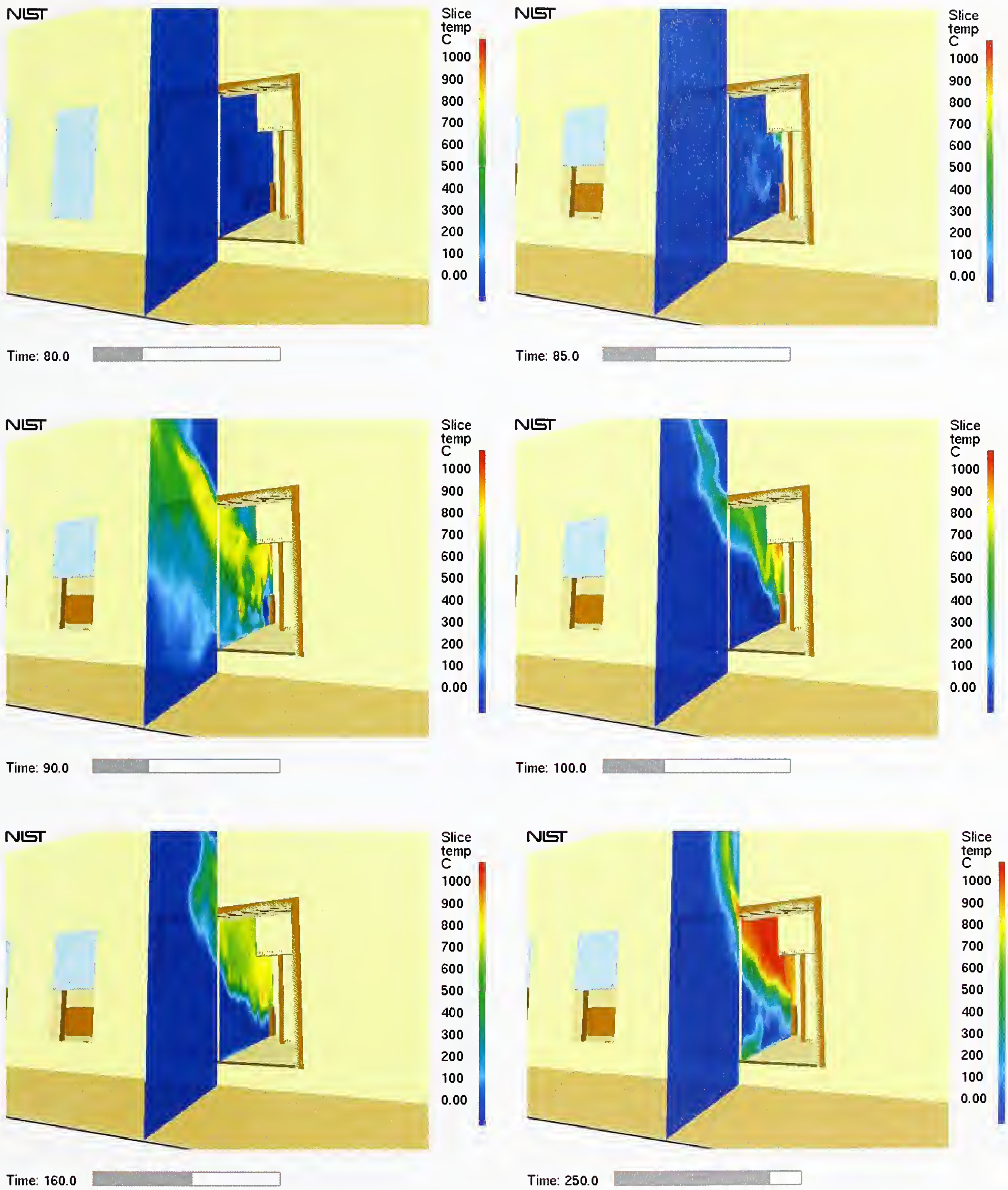


Figure 5-57. Temperature profile through the center of the entry foyer, 80 seconds to 250 seconds

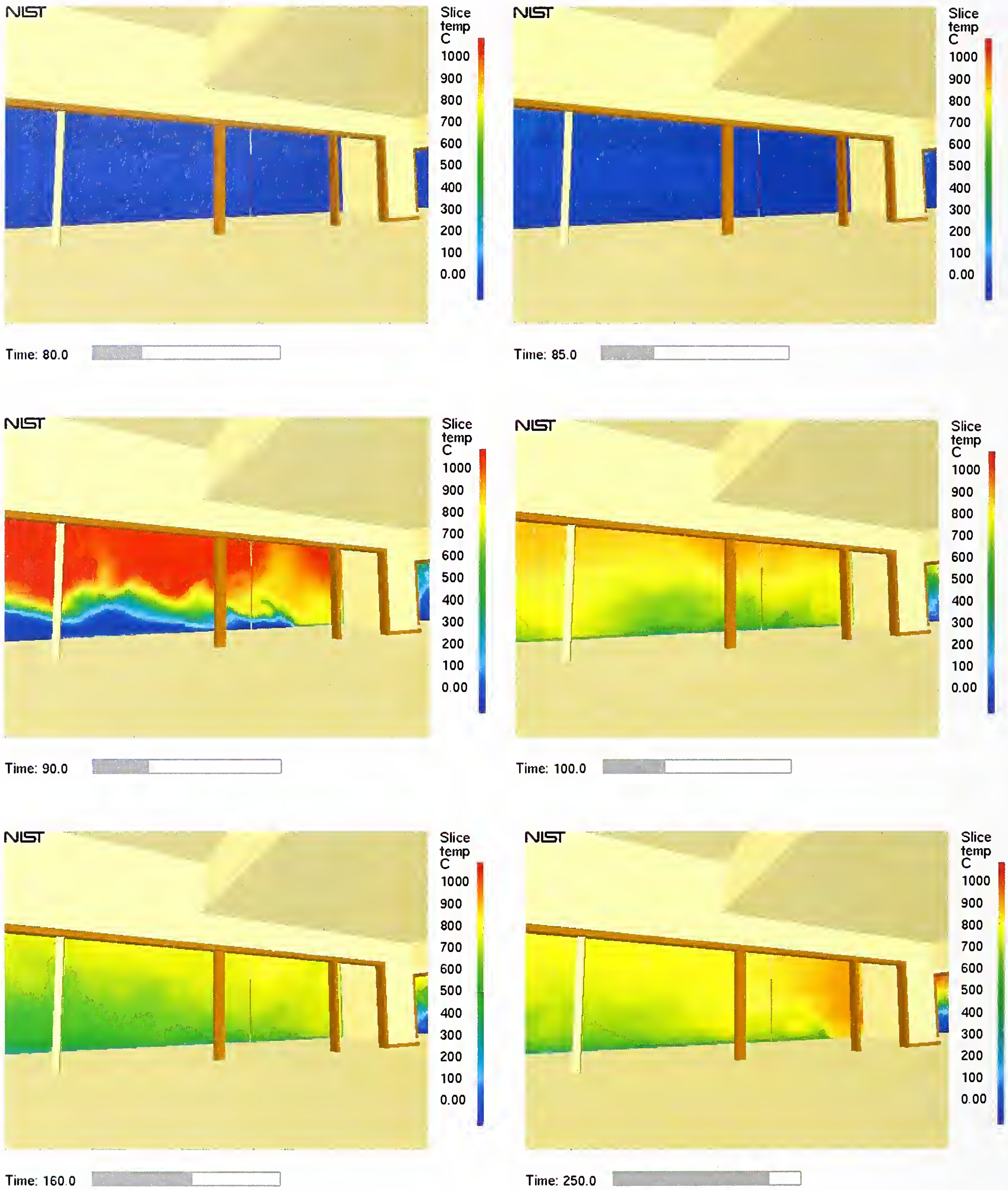


Figure 5-58. Temperature profile through the center of the sunroom, 80 seconds to 250 seconds

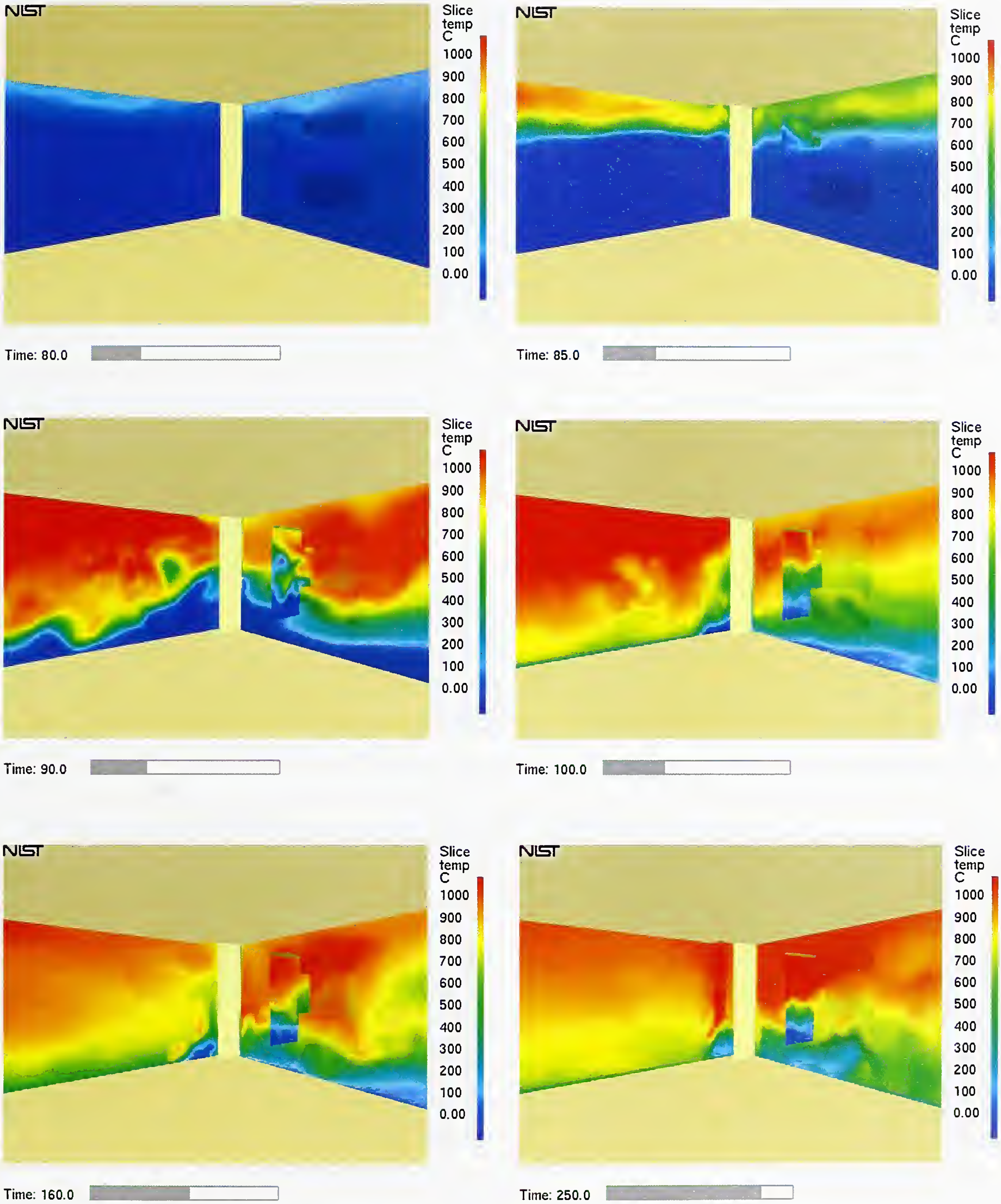


Figure 5-59. Temperature profiles approaching main entry foyer, 80 seconds to 250 seconds

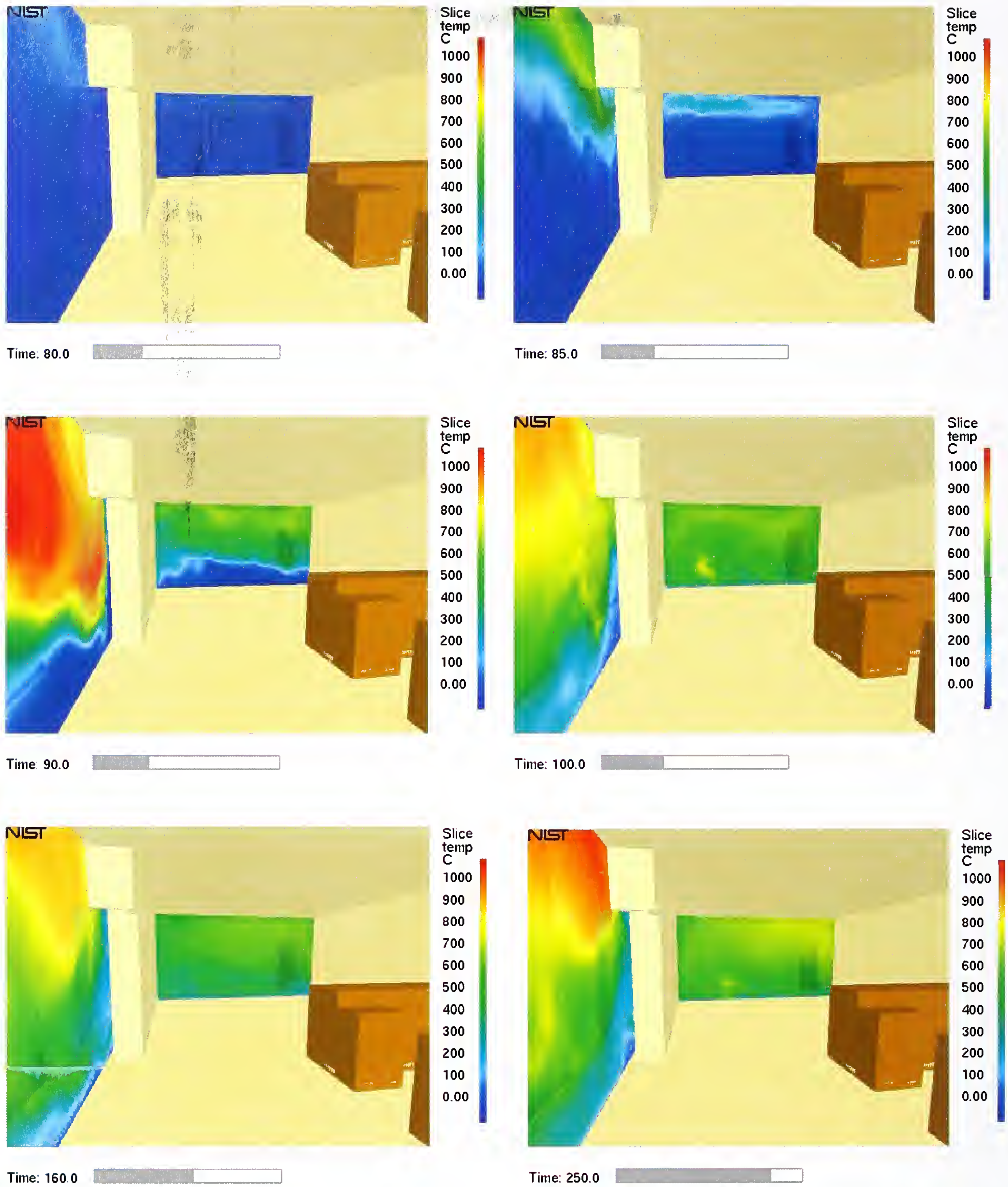


Figure 5-60. Temperature profiles in the dart room, 80 seconds to 250 seconds

(iv) 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 (5 ft) and 0.6 m (2 ft) levels with the roof removed to examine the structure as a whole. This analysis will utilize a volume fraction of 12 % as the oxygen tenability threshold [6]. Based on that oxygen limit the following figures show that occupants would have had less than 100 seconds of tenable conditions.

Just as the temperature levels rose rapidly after the platform area became fully involved in flames, the oxygen levels drop proportionally. As shown by the three dimensional smoke output in the previous section, the smoke spreads quickly through the structure. The first four images in Figure 5-61 range from 80 seconds after ignition to 100 seconds after ignition. This sequence has the most dramatic changes in oxygen concentration. Beyond 100 seconds the entire structure is untenable at the 1.5 m (5 ft) height. Tenability exists for the longest duration in the main bar area. Most of the building, including the platform and dance floor areas, the dart room, the main entry foyer and the main bar room, is shown by the simulation to be significantly depleted of oxygen to less than two percent.

Figure 5-62 shows the predicted oxygen volume fraction 0.6 m (2 ft) above the floor, beginning at 80 seconds after ignition through 250 seconds after ignition. At this lower level it is apparent that tenability is also not likely in any area other that 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, probably saving the lives of occupants as they can be seen being pulled from the windows in the WPRI video. Occupants that stayed low in the main bar area had a better chance of survival.

The images in later in Figure 5-62, once again, show a rapid decrease in tenable conditions due to oxygen depletion throughout most of the simulated nightclub with the exception of the main bar room and the main entry foyer. Due to the open doors and windows in these areas, the simulation indicates that sufficient fresh air was drawn in to maintain a level of tenability with respect to oxygen 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 WPRI video, the last person recorded being assisted through a window from the main bar room occurs at 250 seconds after ignition. This is consistent with the predicted oxygen concentrations near the windows.

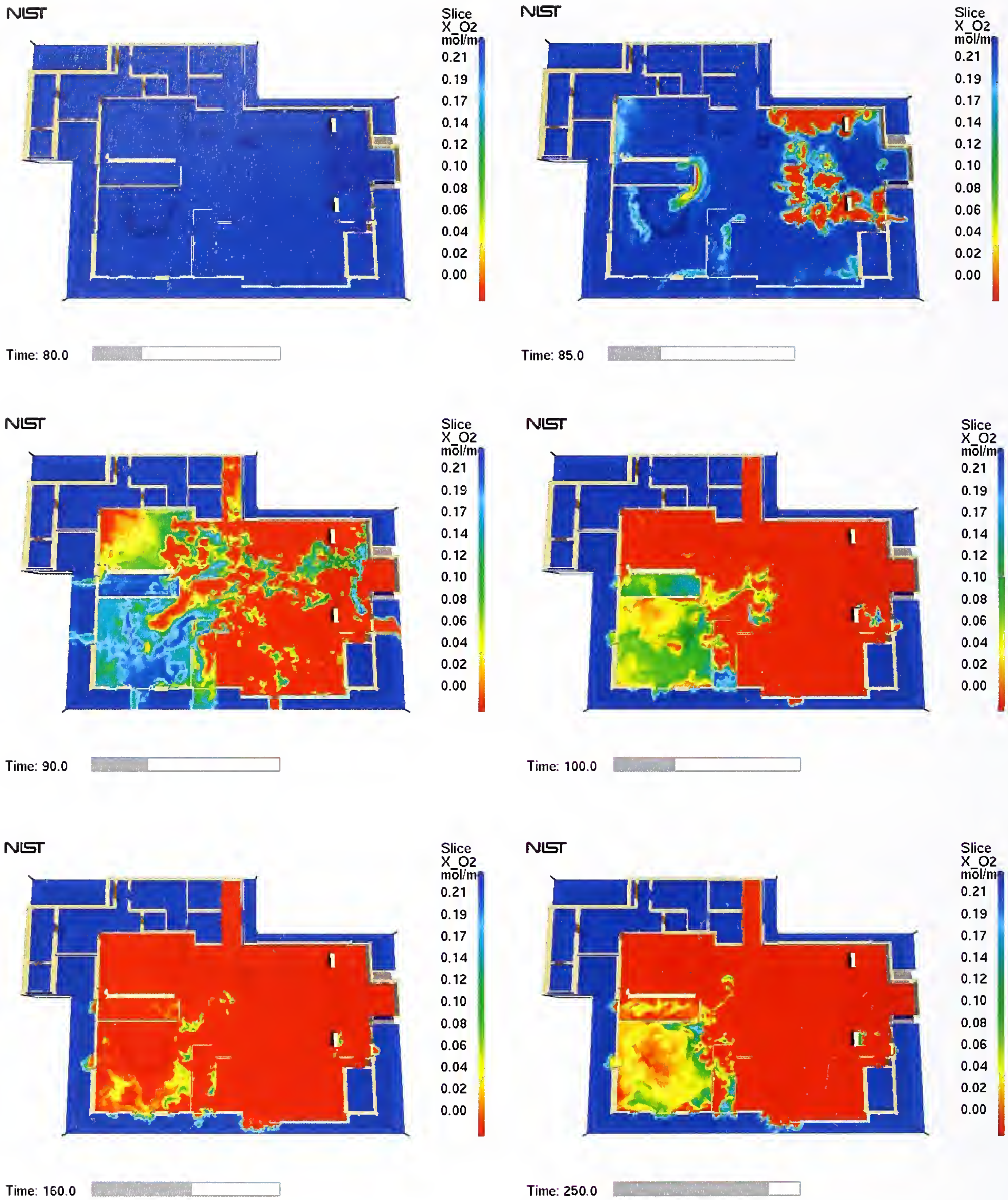


Figure 5-61. Oxygen volume fractions at 1.5 m (5 ft) above the floor, 80 seconds to 250 seconds

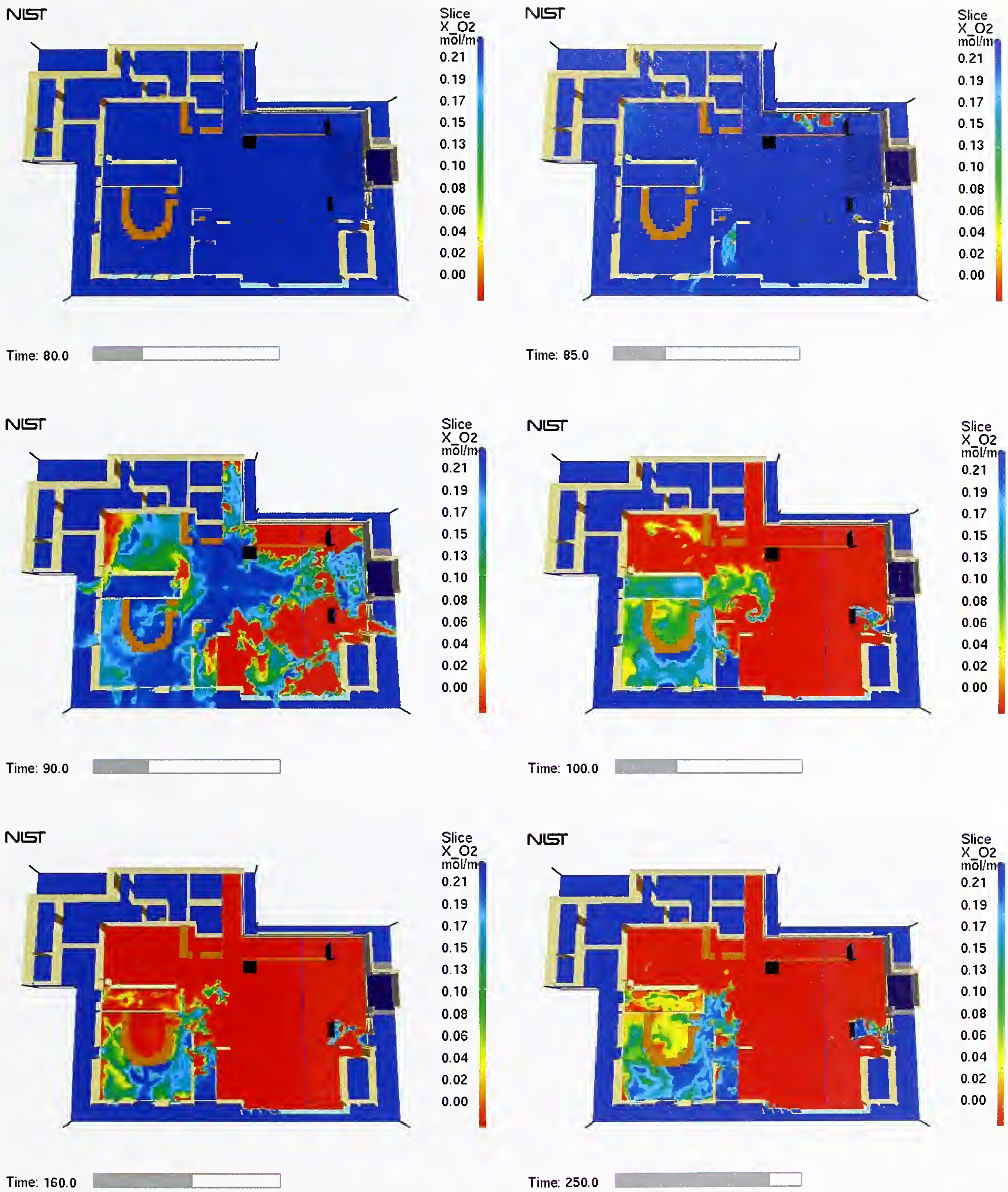


Figure 5-62. Oxygen volume fractions at 0.6 m (2 ft) above the floor, 80 seconds to 250 seconds

5.3.4 Simulation of full nightclub equipped with sprinklers

Another simulation of the full 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 input from the FDS sprinklered full-scale mock-up simulation. 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 (12 ft) spacing. The west sprinklers were 1.8 m (6 ft) north and 1.8 m (6 ft) south of the alcove sprinkler and 1.8 m (6 ft) east of the platform wall. The east sprinklers were also 1.8 m (6 ft) north and 1.8 m (6 ft) south of the alcove sprinkler and 12 ft east of the west sprinklers. While the maximum allowable sprinkler spacing would have been 4..6 m (15 ft) throughout the main portion of the nightclub, the alcove would have required an individual sprinkler regardless of the sprinkler spacing used elsewhere in the nightclub. In the un-sprinklered cases, flashover of the alcove increased the rate of hazard development significantly. The single sprinkler in the alcove (which was full-scale) was shown to prevent flashover in both the sprinklered experiments and the simulations, significantly mitigating the hazard.

The sprinkler activation times from the sprinklered FDS simulation are given in Table 5-7. The sprinklers used in the FDS simulation are identical to those used in the full-scale mock-up FDS simulation. The properties of each sprinkler can be found in Table 5-2.

Table 5-7. FDS Predicted Sprinkler Activation Times

Sprinkler Location	FDS Sprinkler Activation Times (seconds)
Southwest	20
Northwest	16
Alcove	29
Southeast	Did Not Activate
Northeast	Did Not Activate

(i) Visualization

Figures 5-63a and 5-63b are rendered from Smokeview to examine the flame and smoke spread and the effect of the sprinklers. The images begin at ignition or t = 0 seconds and continue until 100 seconds after ignition. The first image in Figure 5-63a shows the two sprinklers over the platform area and the two sprinklers over the dance floor as small red dots along the ceiling. The larger red areas on the platform walls represent the location of the ignition burners. The sprinkler located on the ceiling of the alcove is hidden from view. The second image rendered at 20 seconds shows smoke being pushed away at the first sprinkler, which activated at 16 seconds after ignition. By 30 seconds after ignition, three of the sprinklers had been activated. This caused some of the smoke to be pushed down to the floor. The two sprinklers over the dance floor area did not activate during the simulation. Figure 5-63b has images from 70 seconds to 150 seconds after ignition. During this period the fire was significantly suppressed. The series of images show the smoke dispersing. The fire was extinguished fully at approximately 114 seconds. The smoke continued to spread and is diluted by fresh air entering the area.

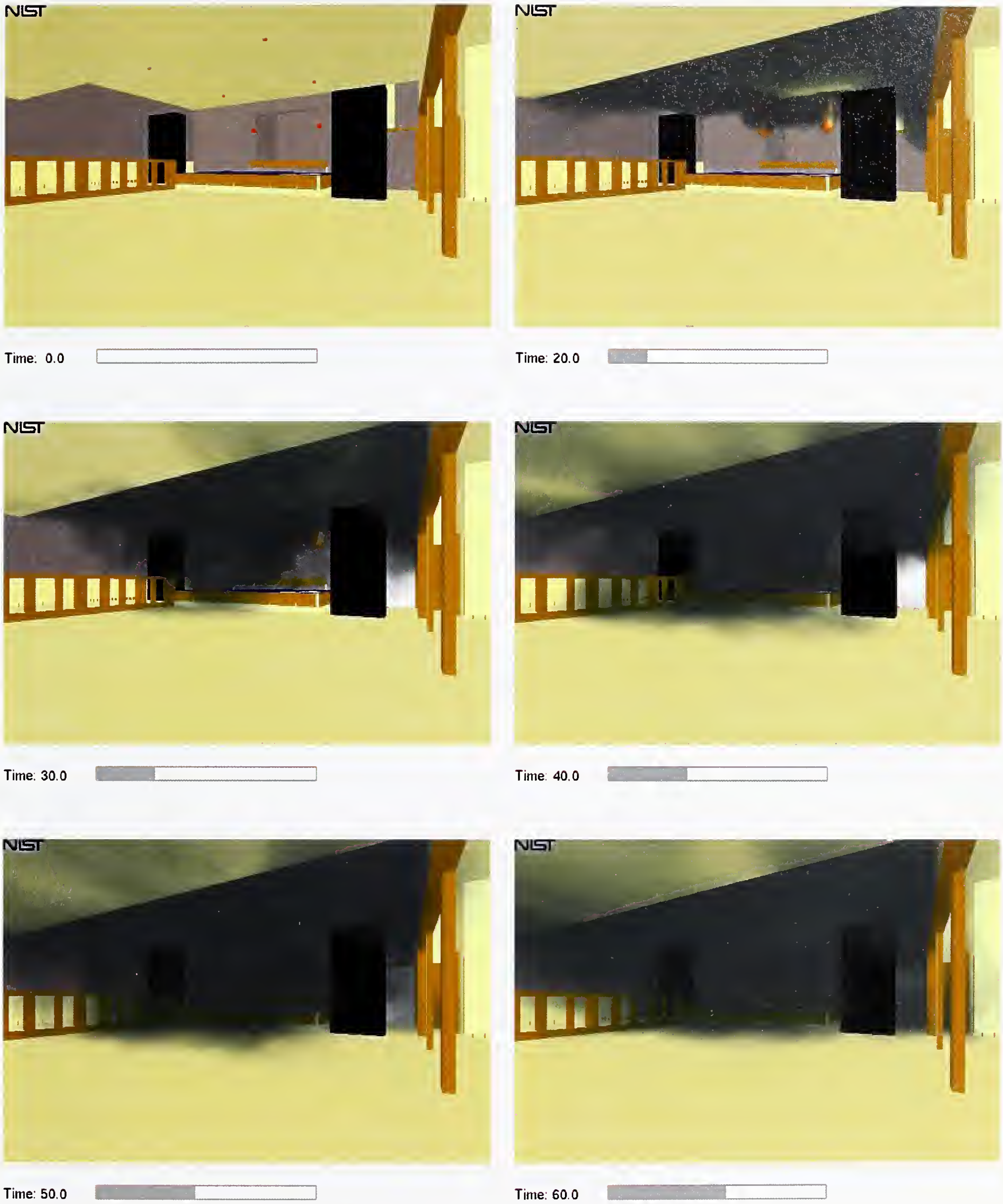


Figure 5-63a. Simulation of nightclub with sprinklers, 0 seconds to 60 seconds

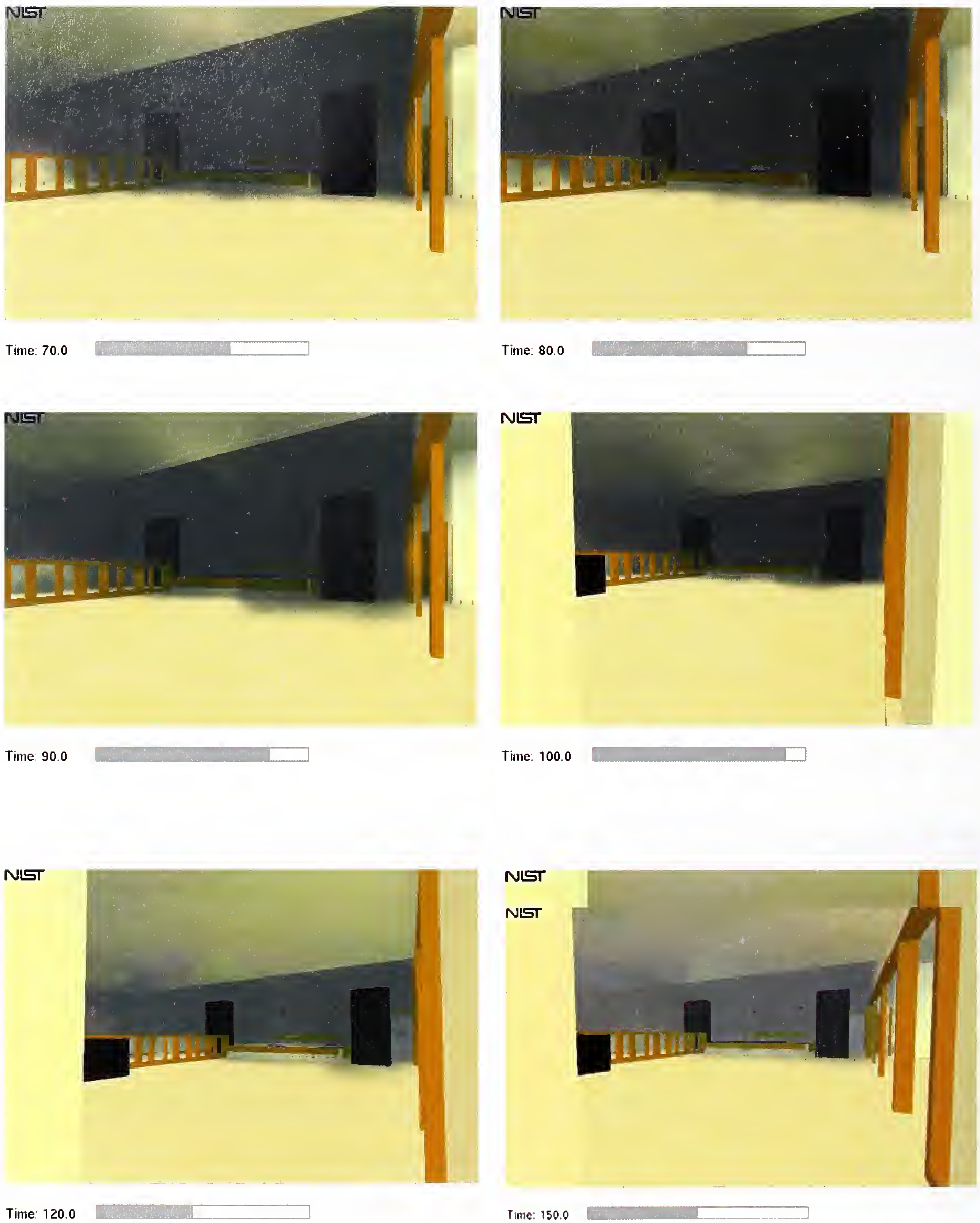
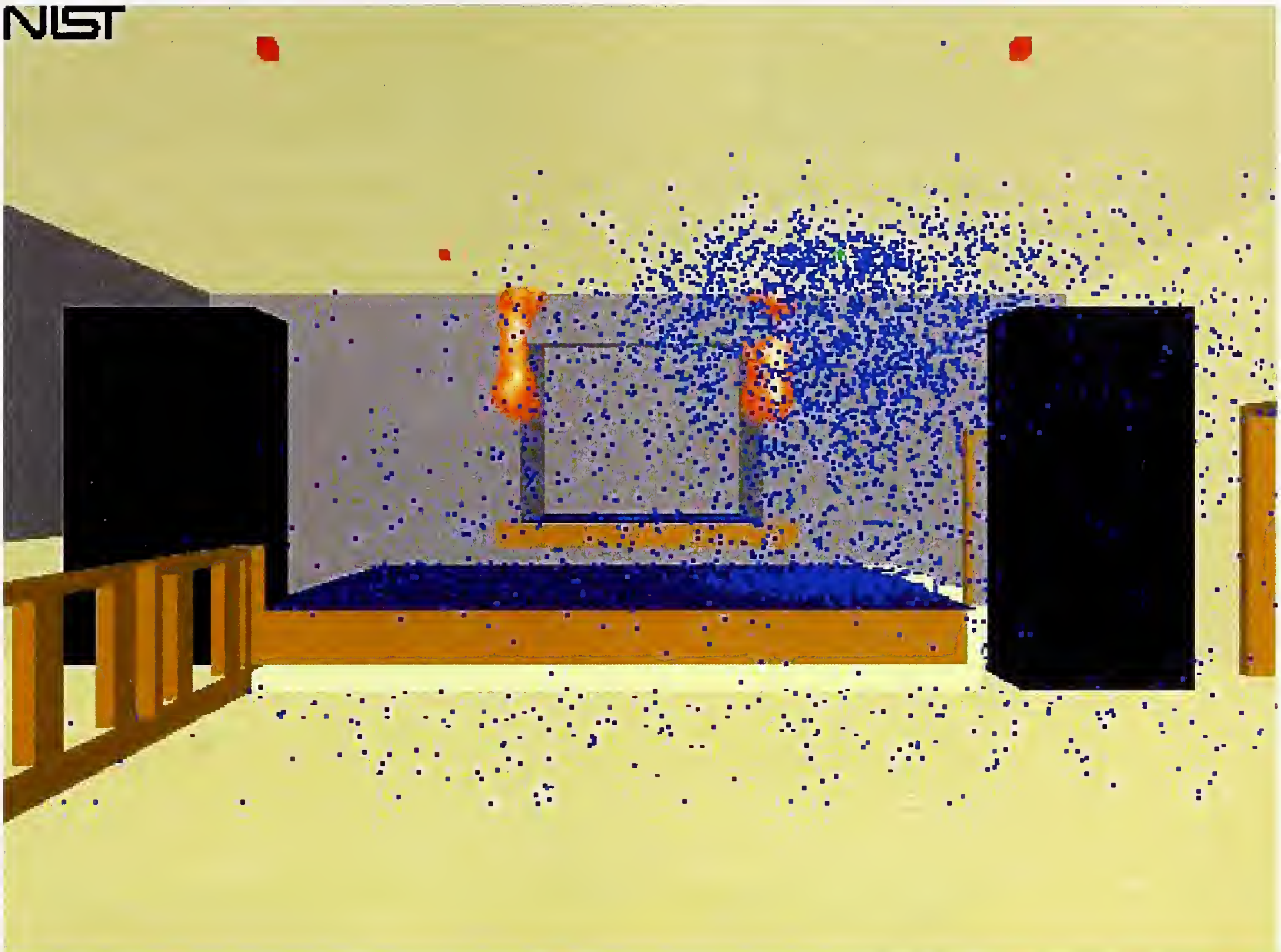


Figure 5-63b. Simulation of nightclub with sprinklers, 70 seconds to 150 seconds

Figure 5-64 provides another means of looking at the simulation. This image, rendered at 2 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.



Time: 18.0

Figure 5-64. Simulation of northwest sprinkler activation 18 seconds after ignition, showing water flow with smoke "turned off."

(ii) Numerical Output

In this section, predictions of heat release rate, temperature, and oxygen volume fraction from the FDS sprinklered incident simulation are presented and compared to the non-sprinklered simulation and tenability criteria.

Figure 5-65 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.

Isothermal plots are shown in Figures 5-66a and 5-66b to assess the tenability conditions based on temperatures that were predicted during the simulation of the fire. The figures show horizontal isothermal images 1.5 m (5 ft) above the floor from the time of ignition (t = 0) to 100 seconds at 10 second intervals, and an image at 150 seconds. Due to the rapid activation of the sprinklers (three sprinklers were operating by 30 seconds after ignition), the temperatures at the 1.5 m (5 ft) level remain well below the temperature tenability threshold of 120 °C (248 °F) [6].

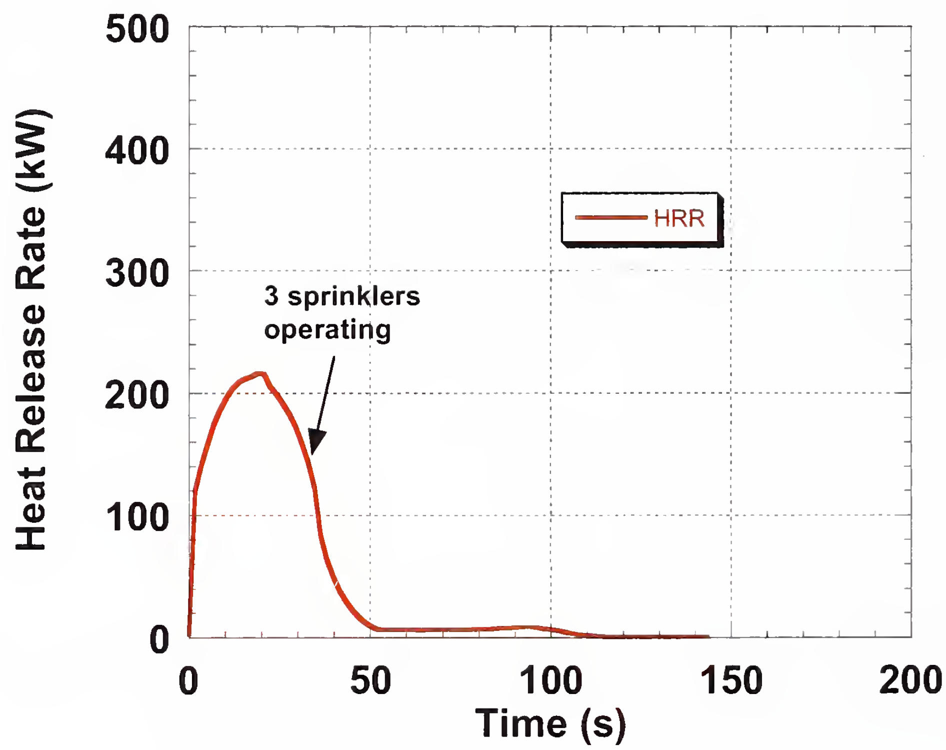


Figure 5-65. FDS predicted heat release rate for the sprinklered case.

The comparison between the temperatures 1.5 m (5 ft) above the floor in the non-sprinklered simulation (Figure 5-55) and in the sprinklered configuration (Figs. 5-66a and 5-66b) show dramatically different thermal conditions. (Note the large difference in color scales.) During the non-sprinklered simulation temperatures exceeded 1000 °C (1830 °F) in the platform and dance floor areas, and in the main bar room they exceeded 500 °C (930 °F) within 100 seconds. In the sprinklered simulation, the temperature exceeds 25 °C at head height only near the platform; following sprinkler activation around 20 seconds, the thermal environment remains close to ambient up until the time the fire is fully extinguished at 120 seconds.

Given the limited fire spread and the resulting tenable gas temperatures, the heat flux tenability criteria was never exceeded in the sprinklered case.

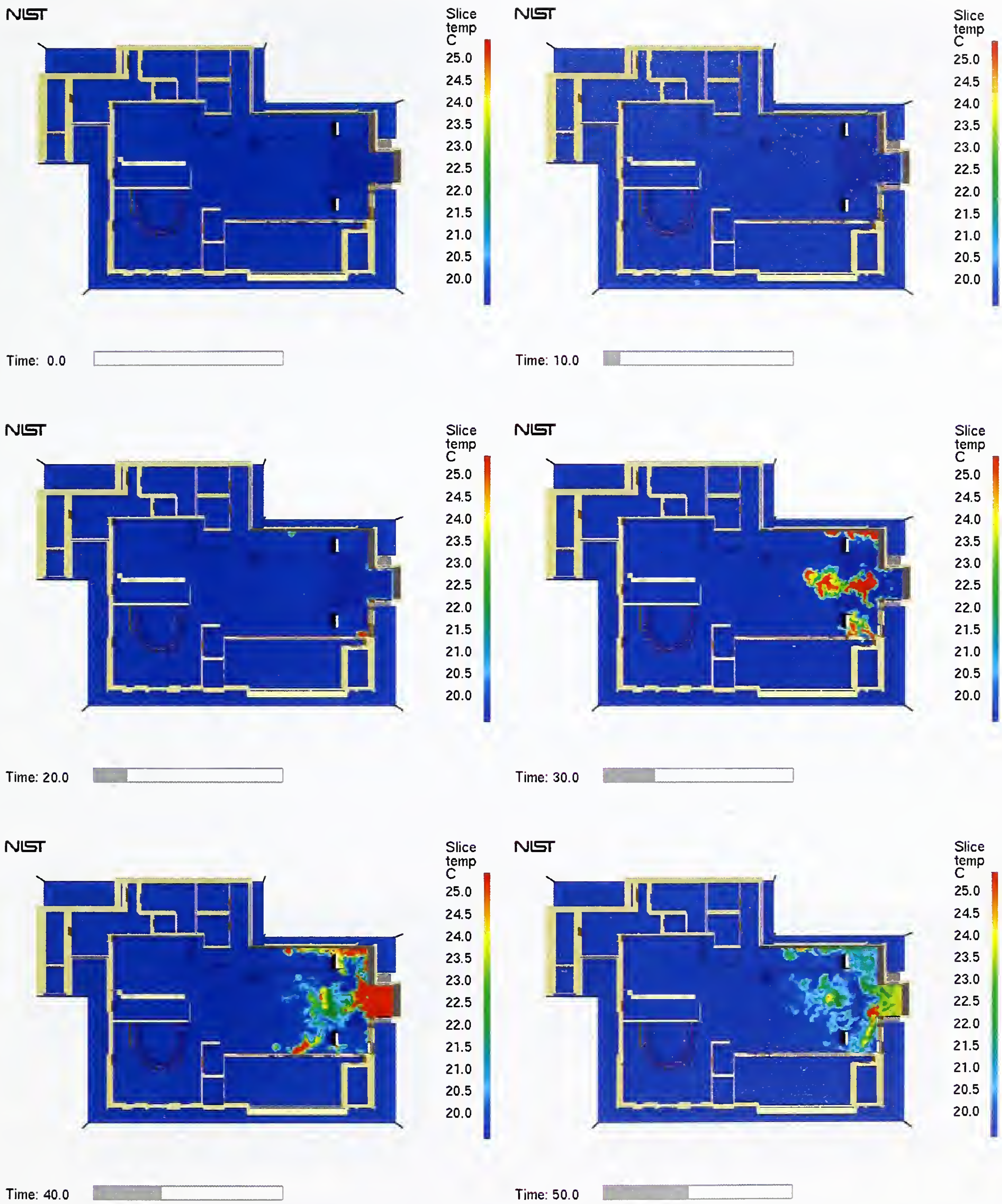


Figure 5-66a. Temperatures at 1.5 m (5 ft) above the floor, 0 seconds to 50 seconds

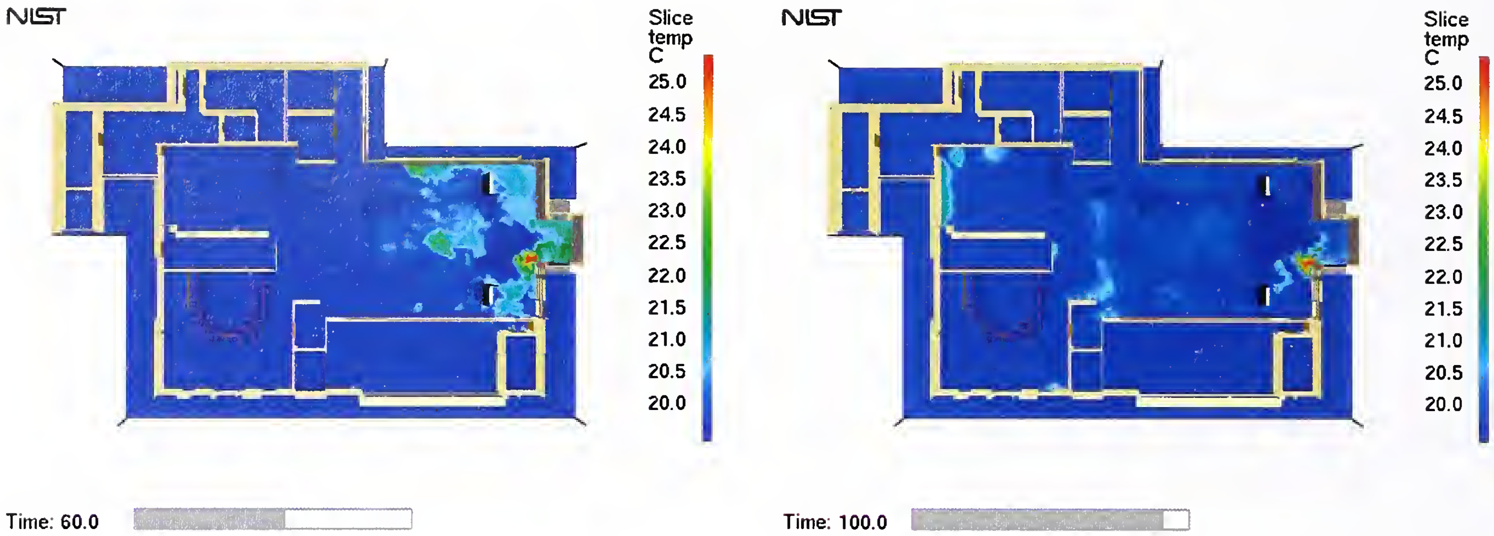


Figure 5-66b. Temperatures at 1.5 m (5 ft) above the floor, 60 seconds and 100 seconds

(iii) Oxygen

Oxygen volume fractions were also examined in the sprinklered simulation to assess the tenability conditions that existed during the evolution of the fire. Horizontal slices were taken at the 1.5 m (5 ft) level with the roof removed to examine the structure as a whole. The analysis utilized a volume fraction of 0.12 as the oxygen tenability threshold [6]. Based on that oxygen limit, Figures 5-67a and 5-67b demonstrate that the atmosphere remained tenable during the entire duration of the simulation. In contrast, the non-sprinklered simulation predicted oxygen levels below 0.12 at the 1.5 m (5 ft) elevation throughout the building at 100 seconds after ignition and then continuing at untenable concentrations during the remainder of the simulation.

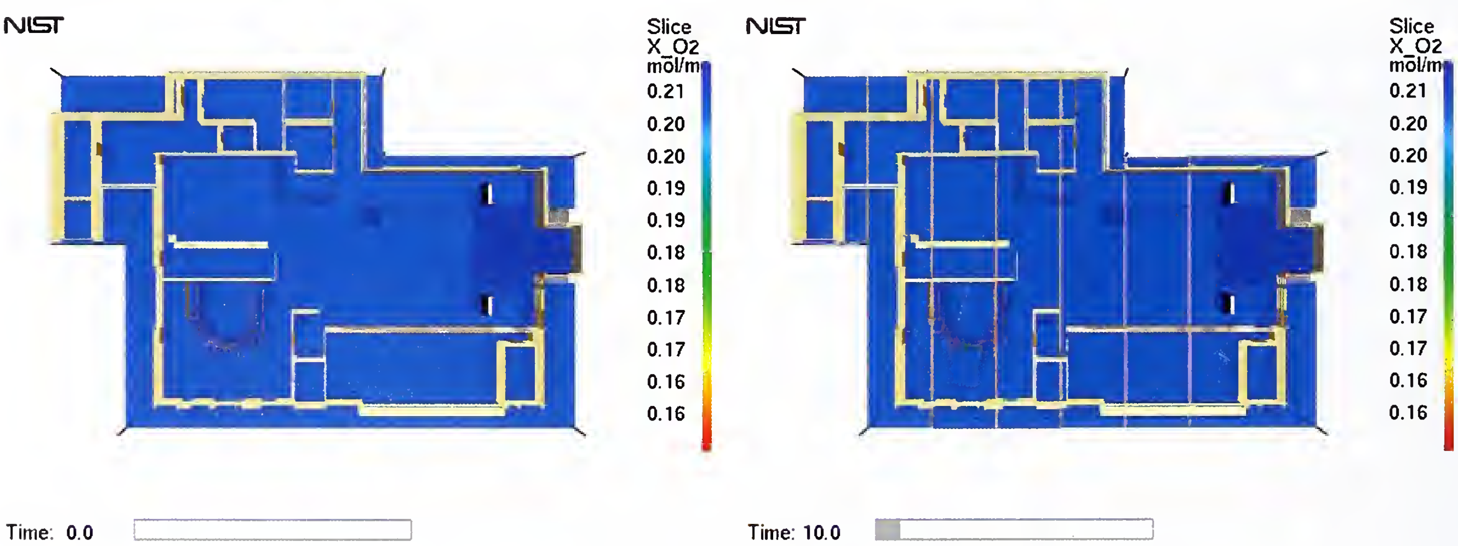


Figure 5.67a. Oxygen volume fractions at 1.5 m (5 ft) above the floor, 0 seconds and 10 seconds

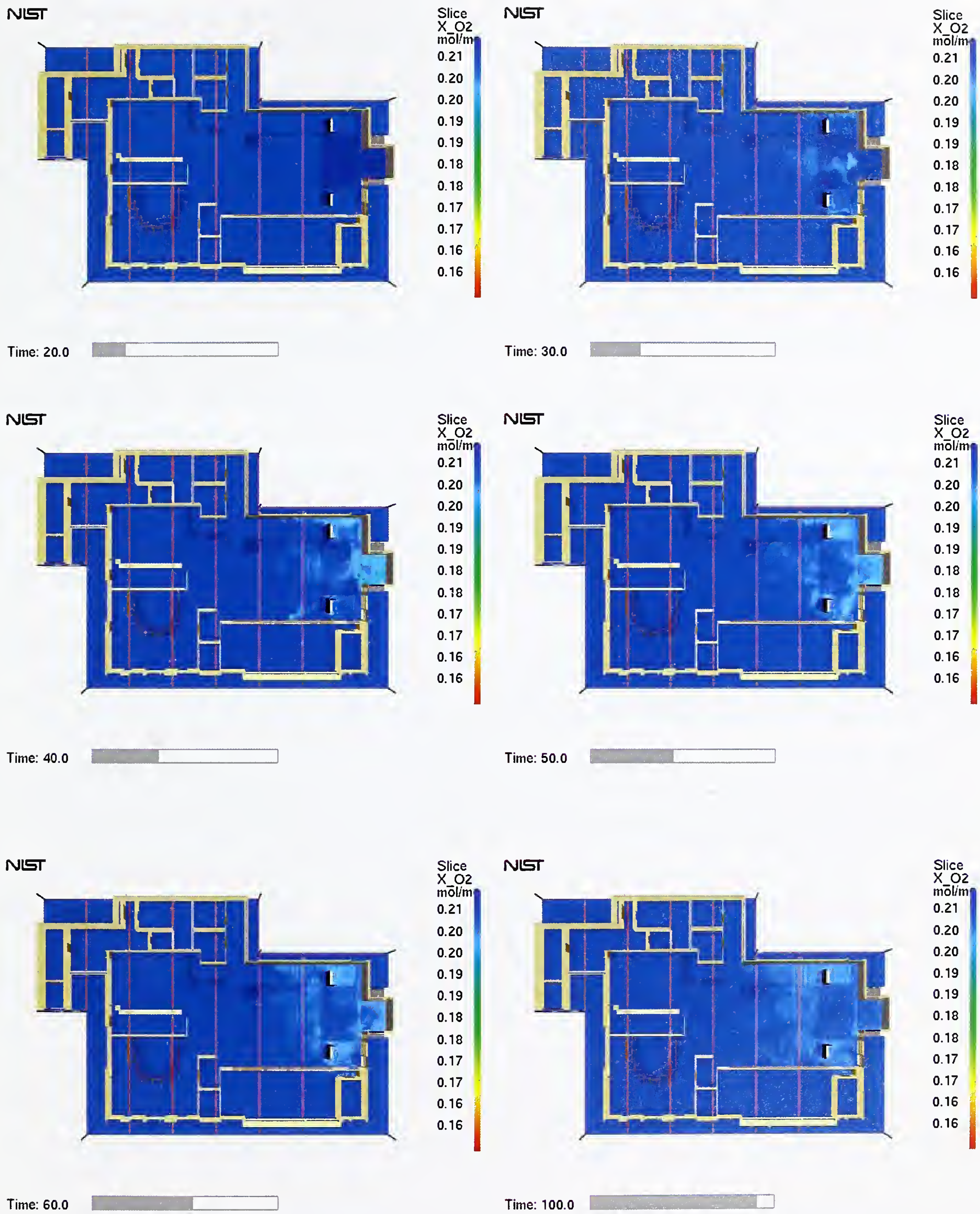


Figure 5-67b. Oxygen volume fractions at 1.5 m (5 ft) above the floor, 20 to 100 seconds

5.4 SUMMARY

Images from the WPRI video were utilized to develop model input to establish the location of the different interior finishes within The Station nightclub as well as used as a general resource for confirming the physical arrangement of the nightclub. The simulation was run for 300 seconds to examine the time period from ignition to the approximate time of flames throughout most of the nightclub as recorded by WPRI. The computation included simulated fire and smoke spread and potential temperatures, heat flux and oxygen concentrations that may have existed in the actual incident. Each of these parameters were compared to published tenability criteria.

Results from some of the bench-scale experiments described in Chapter 4 and existing data were used to develop the input properties for the interior finish materials. The key parameters were the combustion properties of the foam/plywood wall; i.e., ignition temperature, heat of vaporization, and maximum burning rate. The results from the cone calorimeter tests of the polyurethane foam were not used directly in the simulation because of the composite nature of the foam-plus-plywood fuel on the wall of the nightclub. (As a consequence, the differences in heat release rate of the polyurethane foam measured by NIST and ATF had no impact on the simulation results.)

The visual and numerical comparisons between the experiments and the FDS simulations of the experiments demonstrated reasonable agreement. The visual comparisons indicated a lag in fire development in the simulation relative to the experiments, but once the simulated fire grew large enough the growth rate and smoke development were consistent with the experiments. The temperature, heat flux, and the oxygen concentration comparisons show reasonable agreement between the experiments and the model in terms of both trends and range.

To gauge the accuracy of the full nightclub simulation results, they were compared with the WPRI video record of the incident and the map of victim locations. 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.

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 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 effects of an automatic sprinkler system on a fire were modeled to a useful degree by FDS and visualized with Smokeview. Both the experiment and the FDS simulation demonstrate that the sprinklers would prevent flashover and considerably mitigate the hazard from the fire in the test enclosure. However, the degree to which the fire is controlled is different between the experiment and the model. The simulation has more flame spread along the edges of the alcove ceiling after activation of the sprinklers. While the ability of FDS to predict fire suppression is simplified and cannot capture all of the physics involved in the process, FDS is able to predict the trends in reasonable agreement with the measured temperatures, heat fluxes and oxygen volume fractions.

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

5.5 REFERENCES FOR CHAPTER 5

[1] Nelson, H.E., "An Engineering Analysis of he Early Stages of Fire Development- The Fire at the Dupont Plaza Hotel and Casino- December 31, 1986", NBSIR97-3560, National Institute of Standards and Technology (formerly the National Bureau of Standards), Gaithersburg, MD, April 1987.

[2] Nelson, H.E., "An Engineering View of the Fire of May 4, 1988 in the First Interstate Bank Building, Los Angeles, California", NISTIR 89-4061, National Institute of Standards and Technology, Gaithersburg, MD, March 1989.

[3] Bukowski, R.W., and Spetzler, R.C., "Analysis of the Happyland Social Club Fire with HAZARD I", *Journal of Fire Protection Engineering*, Vol. 4, No. 4, pp117-131, 1992.

[4] Nelson, H.E., "Fire Growth Analysis of the Fire of March 20, 1990, Pulaski Building, 20 Massachusetts Avenue, N.W., Washington, DC", NISTIR 4489, National Institute of Standards and Technology, Gaithersburg, MD, June 1994.

[5] Bukowski, R.W., "Modeling a Backdraft: The Fire at 62 Watts Street.", *NFPA Journal*, Vol. 89, No. 6, National Fire Protection Association, Quincy, MA, pp85-89, November/December 1995.

[6] McGrattan, K.B., Hamins, A., and Evans, D.D., "Sprinklers, Vent and Draft Curtain Interaction – Modeling and Experiment", Fire Suppression and Detection Research Application Symposium, Research and Practice: Bridging the Gap, February 25-27, 1998, Orlando, FL Proceedings. National Fire Protection Research Foundation, Quincy, MA, 1998.

[7] McGrattan, K.B., and Forney, G.P., "Numerical Simulation of Sprinkler Performance", Fire Suppression and Detection Research Application Symposium, Research and Practice: Bridging the Gap, February 24-26, 1999, Orlando, FL. Proceedings. National Fire Protection Research Foundation, Quincy, MA, pp. 79-85, 1999.

[8] Madrzykowski, D., and Vettori, R.L., "Simulation of the Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999.", NISTIR 6510, National Institute of Standards and Technology, Gaithersburg, MD, April 2000.

[9] Madrzykowski, D., Forney, G.P., and Walton, W.D., "Simulation of the Dynamics of a Fire in a Two-Story Duplex-Iowa, December 22, 1999.", NISTIR 6854, National Institute of Standards and Technology, Gaithersburg, MD, January 2002.

[10] Sutula, J., "Applications of Fire Dynamics Simulator in Fire Protection Engineering Consulting", *Fire Protection Engineering*, No. 14, Society of Fire Protection Engineers, Bethesda, MD, Spring 2002.

[11] Rehm, R.G., Pitts, W.M., Baum, H.R., Evans, D.D., Prasad, K., McGrattan, K.B., and Forney, G.P., "Initial Model for Fires in the World Trade Center Towers", NISTIR 6879, National Institute of Standards and Technology, Gaithersburg, MD, May, 2002.

[12] Sutula, J., "Practical Applications of Fire Dynamics Simulator in Fire Protection Engineering Consulting", *Fire Protection Engineering*, No. 15, Society of Fire Protection Engineers, Bethesda, MD, Summer 2002.

[13] McGrattan, K.B., and Hamins, A., "Numerical Simulation of the Howard Street Tunnel Fire, Baltimore, Maryland, July 2001., NISTIR 6902, National Institute of Standards and Technology, Gaithersburg, MD, August 2002.

[14] Vettori, R.L., Madrzykowski, D., and Walton, W.D., "Simulation of the Dynamics of a Fire in a One-Story Restaurant – Texas, February 14, 2000.", NISTIR 6923, National Institute of Standards and Technology, Gaithersburg, MD, October 2002.

[15] McGrattan, Kevin; Forney, Glenn; "Fire Dynamics Simulator (Version 4) – User's Guide," National Institute of Standards and Technology, Gaithersburg, MD, NIST SP 1019, September 2004.

[16] Forney, G. P. and McGrattan, K.B., "User's Guide for Smokeview Version 4 - A Tool for Visualizing Fire Dynamics Simulation Data," NIST SP 1017, National Institute of Standards and Technology, Gaithersburg, MD, August 2004.

[17] McGrattan, K., ed., "Fire Dynamics Simulator (Version 4), Technical Reference Guide," NIST SP 1018, National Institute of Standards and Technology, Gaithersburg, MD, September 2004.

[18] Hietaniemi, J., Hostikka, S., and Vaari, J. "FDS Simulation of Fire Spread – Comparison of Model Results with Experimental Data", Technical Report VTT Working Paper 4, VTT Building and Transport, Espoo, Finland, 2004.

[19] Heskestad, G. and Bill, R.G., "Quantification of Thermal Responsiveness of Automatic Sprinklers Including Conduction Effects". *Fire Safety Journal*, 14:113-125, 1988.

[20] Putorti, A.D., Belsinger, T.D., and Twilley, W.H., Determination of Water Spray Drop Size and Speed from a Standard Orifice, Pendant Spray Sprinkler, National Institute of Standards and Technology, Gaithersburg, MD., Report of Test FR4003, May 1999.

[21] Purser, D.A., "Toxicity Assessment of Combustion Products." *SFPE Handbook of Fire Protection Engineering, 3rd ed.* DiNenno, P.J., et. al. (eds). NFPA Quincy, MA, 2002.

[22] Madrzykowski, D., and Vettori, R.L., "A Sprinkler Fire Suppression Algorithm," *Journal of Fire Protection Engineering, Vol. 4*, No. 4, 1992, pp 151-164.

Chapter 6
ANALYSIS OF BUILDING EGRESS

6.1 INTRODUCTION

Chapter 6 documents, to the extent possible, life safety egress features present in the building at the time of the fire on Feb. 20, 2003. A summary of previous incidents in which a significant number of lives have been lost is provided in Appendix C, as well as emergency evacuations that can be classified as successful.

A contract was let to Ove Arup & Partners Massachusetts, Inc. to help document the egress process and life safety features in the building. This chapter is based upon portions of their final report [1], although any conclusions and findings that are presented are solely those of NIST.

The analysis and observations presented depend primarily on the following sources:

- *Providence Journal* – all pertinent published documents;
- *Boston Globe* – all pertinent published documents;
- Town of West Warwick, RI, Building Department – public information on file at the Office of the Town Clerk;
- Town of West Warwick, RI, Fire Department – public information on file at the Office of the Town Clerk;
- National Fire Protection Association (NFPA) – published fire investigations, and historical Life Safety Codes, code handbooks and commentaries;
- International Code Council (ICC) – historical building codes and code commentaries; and
- Rhode Island Attorney General's Office – public information available regarding the indictments.

Additional information was provided by individuals directly to NIST via email, mail, and telephone calls in response to an appeal to the public.

6.2 ANALYSIS OF EVIDENCE

Chapter 2 of this report provides a timeline for the evacuation based upon the WPRI-TV video. Times taken from the video are accurate to within a few seconds, although some events being described had less specific starting or ending points. Additional photographic records, documents, and witness statements have been analyzed to gain a more complete picture of the egress process and associated activities.

6.2.1 Lighting

While the camera operator was evacuating, the fluorescent "black lights" mounted on the ceiling of the club remain on, as do various other lights that are visible on the video. Thus, main power within the club was still on when the camera reached the exterior. The video did not provide evidence as to when the lights inside the club went out. This information would have aided in coordinating some of the eyewitness statements provided later in Chapter 6.

Lights mounted on the eaves outside of the building were seen to be illuminated throughout the duration of the video up until 0:12:36 video time (0:06:14 fire time). The video did not depict these as illuminated after 0:12:36 video time (0:06:14 fire time). It is not clear if the circuit powering these lights turned off, or if individual fixtures turned off as a direct result of the fire in their vicinity.

6.2.2 Occupant Tracking

A great deal of analysis was carried out to attempt to track occupants as they evacuated the building. The goal was to determine if specific portions of the crowd were able to escape more readily than others and to gain insight as to the pile-up at the front door. The main sources for locating occupants within the building for this analysis were the WPRI video footage panning across the crowd facing the platform, video footage taken while the camera operator evacuated the facility, and video of occupants escaping through windows.

Efforts were made to track individuals from their location in the club when the fire ignited until they had evacuated. One male occupant, shown facing the camera in Figure 6-1, was tracked through evacuation. The time of this still frame is 0:06:51 video time (0:00:29 fire time). The occupant's face has been blurred in the figures below in order to preserve his anonymity; his facial features were not critical for the identification analysis.

After the ignition of the fire, the camera operator began reacting before most other occupants did. The camera captured the occupant shown in Figure 6-1 29 seconds after the ignition of the fire turning and beginning to move toward the door. At this point, the camera was approximately two rows of people behind this man (between him and the main exit). This occupant can be seen reaching and crossing the main exit at 0:07:31 video time (0:01:09 fire time), 39 seconds later, in Figure 6-2.

It appears that whether an occupant choosing to exit through the main exit was able to escape or not depended on a combination of two factors: (1) when the occupant decided to begin to evacuate, and (2) where the occupant was located when he/she decided to evacuate. Based on analysis of the video, it appears that the camera operator was located approximately three to six rows back from the platform, chose to evacuate 18 seconds after the ignition of the fire, and was able to exit safely 53 seconds later. The male occupant discussed above was farther away from the platform 29 seconds after the ignition. Because he was closer to the main exit at this point, he was able to complete his egress safely 39 seconds later. Clearly, the time to commence evacuation and the initial location at the beginning of one's evacuation effort both contribute to the outcome.

A number of people were seen early in the video within the club and, after the ignition of the fire, at the exterior. However, based upon the limited video footage of the crowd facing the platform at the start of the concert and during the evacuation, attempting to track other occupants initially located further inside the club was unsuccessful. This is mainly due to the fact that many of the occupants exiting through the vestibule were not originally located in the view of the camera.

6.2.3 Interruption of Flow Through Front Door

Although Figure 6-3 is of poor quality because the camera was in motion at the time, this video frame depicts a series of occupants evacuating through the main exit (note that the white surface at the lower right corner of the frame is one of the open exterior doors). The video time of this still frame is 0:07:33

Figure 6-1. Occupant at Start of Evacuation [2]

Figure 6-2. Occupant Exiting the Building [2]

Figure 6-3. Evacuating Occupants [2]

(0:01:11 fire time). A male and a female are visible near the center of the frame; however, occupants cannot be seen immediately behind them. It would be expected that the occupant density ahead of these individuals would be similar to the occupant density behind them, given that much of the crowd in the video frames leading up to this frame is noted to be moving towards this door. The lack of occupants visible behind these individuals suggests that some event may have occurred to slow or stop further egress. The camera angle shifts away from this door after 0:07:33 (0:01:11 fire time) and does not return to the front door until 0:08:04 (0:01:42 fire time). When the camera returns at 0:08:04 (0:01:42 fire time) a pile-up of occupants is visible. Details regarding how the pile-up occurred are not available from the WPRI-TV video; however, the interruption in flow of evacuating occupants apparent in Figure 6-3 supports the contention that the disruption may have initiated early during the 31 second period when the camera was pointed elsewhere.

6.2.4 Occupants Within Crowd-Crush

Attempts were made to relate individuals observed in the build-up at the main exit door to their locations at the start of the evacuation for the purpose of gaining additional information regarding how and when the pile-up occurred. Due to the limited views afforded by the WPRI video, most individuals could not be tracked. However, the male occupant shown in Figure 6-4 (attempting to evacuate) was also seen in the video near the bottom of the pile-up of occupants shortly later. This occupant was identified by the color of his clothing, gold chain and hairstyle. It appears that this occupant waited at the sidelight of the interior vestibule door (see Figure 6-4), so it is unclear when he was able to join the stream of evacuating occupants. There appears to be one person below him in the pileup of people, implying that he was directly behind or close to the first occupants who tripped or otherwise fell to the ground. According to an interview conducted with the *Providence Journal* [23], the person who appeared to be this occupant

> "got into entry hall, it was chaotic with people coming from two directions into foyer, like a funnel. The smoke came in. [The occupant] started pushing and shoving his way to front; 'I could feel myself walking over' people; he could feel the heat on his back. Front doors were open. He was almost out when he tripped over someone who had fallen, and was laying perpendicular to front door. [The occupant] caught himself but as he was halfway up, people behind him fell on top of him. 30-35 people on him. Half his body was out of the door. His waist was where the door was. [He] felt himself being yanked back in. Grabbed bottom metal bar [outside the main entrance]... Finally, [on the] third or fourth pull, [the occupant's] other shoe popped off and he came sliding out."

Forty-one seconds elapsed between Figure 6-4 (0:01:02 fire time) and when the occupant was first seen near the bottom of the pile. Because the camera operator moved to the side of the building immediately upon exiting through the main exit, it is not known when the individual shown in these figures reached the door and fell to that position.

A second survivor of the crowd-crush gave the following account, as reported by the *Providence Journal* [41]:

> "As the mass followed the most direct route to the doors, [the survivor] detoured around a free-standing wall, and rejoined the river of people on the other side. The force of the crowd behind him was growing. He almost made it to the exit. He tried to stay upright by putting his hands on the person in front of him, but the pressure from behind overwhelmed him. He fell to the floor, two feet from the door. He rolled over to his side and curled up into the fetal position. 'People were piling up on top of me and I could feel the press of people,' he said.... He could breathe in cool, fresh air. He wasn't even hot. But he couldn't move. 'It felt like a football pileup,' he said...'I didn't want to move

Figure 6-4 Occupant Attempting to Evacuate [2]

because I didn't want the pile to topple on me,' he said. 'I had air and I didn't feel any heat. I wasn't crushed or feeling crushed. I was in a relaxed state. I just felt calm and focused… I knew it was bad because we were stuck there, but I didn't know how bad,' he said. Finally, he felt the load above him lighten as firefighters searched for survivors. He saw a firefighter's boot and reached for it. The firefighter gripped him and wouldn't let go… It took a couple of tugs and [he] was freed."

6.2.5 Eyewitness Statements

Statements from approximately 30 individuals were reviewed for this analysis; those that are relevant to this project are summarized in the following sections. The accounts presented here are quoted from those compiled and published by the *Providence Journal, Boston Globe*, Associated Press, and various other sources. In addition, NIST provided an anonymous toll free hotline and an email address for voluntary input from the general public, which generated another 25 communications, none of which contradicted the published accounts.

(i) General accounts of the fire

The statements in this Section refer to the development of the fire and any occupant actions in response to the fire, other than evacuation.

Paul Vanner – Club Employee [3]

After the fire started on the sides of the stage, Vanner moved to the sound control booth towards the back of the concert space and picked up a fire extinguisher that was stored there: "I hit the pin, hit the trigger just to make sure I got something coming out of it. Then I'm heading for the stage. …a fire extinguisher has no chance against this. We've got to get out of here right now."

Vanner then exited via the kitchen exit, bringing several occupants along with him.

(Note: The *Providence Journal* reported that Kimberly Phillips, a club patron, recalls being hit on the leg by a fire extinguisher as a club employee carried it past her. It is not known if the employee was Vanner, but this confirms that at least one employee obtained a fire extinguisher and advanced towards the stage with it.)

Mario Giamei, Jr. – Former Club Employee [4]

Giamei described the actions of the club's manager in attempting to re-enter the building to help occupants: "He tried to run back in but he couldn't; he got knocked back with smoke."

Robert Riffe – Club Patron [5]

Riffe was attending the concert with a friend on the night of the fire: "I believe I heard someone screaming fire, and I recall someone in the band throw a cup of water on the flames, which of course did nothing."

Riffe also described the development of the fire that he observed as he evacuated: "Within about 5 seconds of us heading to the door, the flames were already about half way through the first room, and the black smoke had filled the entire club." It is expected that the "first room" Riffe refers to is the main event space where the stage is located.

(ii) General accounts of the evacuation

This section provides general eyewitness statements of the evacuation of The Station subsequent to the fire. The statements in this section do not refer to any specific portion of the building or its exit components.

Christopher Travis – Club Patron [6]

Travis was somewhere in the middle of the crowd when the fire started: "Nobody wanted to give up their spot. People felt like it would just be put out." Travis did not start to evacuate until after the lights in the club had gone out.

Andrea Stewart – Club Patron [7]

Stewart was in the crowd about ten rows back from the stage when the fire started: "It happened so fast. I saw the top of the stage catch on fire… People started to run. All of a sudden, bam! People were pushing me so hard." Stewart was knocked down and landed in the middle of a pile of people just before the lights in the club went out.

Mark Knott – West Warwick, RI, Police Officer [8]

Officer Knott was located near the club's main entrance door when people began to evacuate. He was pushed out of the door by the evacuating occupants, and subsequently radioed to the police dispatcher: "Stampede."

(iii) Accounts of evacuation via the main exit

Many of the occupants of The Station exited (or attempted to exit) through the main exit door at the front of the building. This Section provides several statements describing the evacuation at this location. The Providence Journal reported that 90 occupants exited through the main exit [9].

Robert Riffe – Club Patron [5]

Riffe was attending the concert with a friend on the night of the fire. Upon noticing the growing fire, he and his friend began to evacuate: "We both turned and headed for the main door, which…was the only door we knew of."

They made their way to the main door: "Just as we reached the point where the two hallways came to one, the thick black smoke just completely filled the room. I couldn't see, I couldn't breathe… As I got within inches from the front door way, I just came to a complete stop."

Once out of the building, Riffe attempted to assist others in evacuating: "I tried pulling on one man and could not get him to even budge the tiniest bit. I grabbed onto a woman who was trapped at the bottom, and could not get her to budge either."

He eventually left the area of the main entrance and observed the scene from the parking lot:

"…we could see people coming out of the windows…"

Raul Michael Vargas – Club Patron [10]

After deciding to evacuate the club, Vargas states that he encountered numerous people who were not moving and were still watching the stage: "I just picked people up as I went so I wouldn't trip over them."

It is unclear if by "picked people up" Vargas means that he got people to evacuate along with him, or if he encountered people who had fallen and lifted them from the floor.

(iv) Accounts of the evacuation via the exit by the main bar

An exit was provided in the main bar area of the club. Numerous eyewitness statements are available describing evacuation efforts in this area, as provided below. The *Providence Journal* reported that 46 occupants exited through the exit by the main bar [9].

Deborah Lemay – Club Patron [11]

Lemay had been in the club several times prior to the night of the fire, and knew of the exit door by the main bar. When the fire broke out, she decided to exit via this door. However, she claims to have experienced difficulty in opening this door. "There was no push bar and I'm looking for a handle and I remember there not being anything to open the door."

This is contrary to the statements of Robin Petrarca and the video taken inside the club before the fire.

Robin Petrarca – Club Patron [12]

Petrarca, who was a frequent patron of The Station, was located in the main bar area of the club when the fire started. She and a number of her friends escaped through the exit door near the main bar: "Only because we know where the door is…"

Petrarca did not imply that her friend had any trouble in opening this door. Petrarca was pushed out of the door and fell down some stairs: "So many people were just pushing that bodies started coming down the stairs on top of me."

Rick Sanetti – Club Patron [11]

Sanetti was among the occupants who chose to exit through the door near the main bar area: "It was totally pitch black and you had about 20 of us pushing, and you're in a state of panic pushing at that door, and it wouldn't open. The door was functional, but whoever it was [trying to open it] was having a problem getting it open. The door was jammed with people. Had it opened, I assure you, had it opened easily, another 30 or 40 people would have gotten out that door."

Jason Williams – Band Member of Opening Band *Trip* [13]

Upon noticing the fire, Williams, who had been near the main bar, moved towards the exit door in the main bar area. There, he encountered a crowd, and he attempted to calm people down: "I said something about Chicago, people getting trampled. People seemed to kind of relax for a second. Then, a flood of people came over the bar, flying toward me… the smoke came right behind them, just really fast."

In the above quote, Williams is referring to a February 18, 2003 incident in a Chicago nightclub in which 21 people were killed and 55 were injured attempting to evacuate through a single door.

Just after the lights in the club went out, Williams decided to back away from the door where people were bunching up, and covered his mouth until he saw an opening to the outside: "As soon as I saw a little glimmer of light, I ran for the door and made it through."

(v) Accounts of evacuation via the platform exit

A third exit door was located next to the performance platform in the club. The statements below describe evacuation efforts using this exit. The *Providence Journal* reported that 20 occupants exited through the platform exit [9].

Paul Vanner – Club Employee [3]

Vanner had warned band personnel against placing objects in the path to the door by the stage:

"…you've got to move this stuff. That's a fire exit."

Walter Castle – Club Patron [11]

Castle attempted to use the door by the stage early in the fire's development. His statement

indicates that he was told by a club employee that the exit was for band members only: "Come to find out it was a band exit....I ended up throwing him out of the way."

(vi) Accounts of evacuation via the kitchen exit

While technically not an exit per code, a door to the exterior was available in the kitchen area of the club, and several occupants (mostly employees) utilized this door during the evacuation. The statement below

describes this door. The *Providence Journal* reported that 12 occupants exited through the kitchen exit [9].

Mario Giamei, Jr. – Former Club Employee [11]

Giamei described the exit located near the club's kitchen: "It had an exit sign, but unless you're back in that area, you wouldn't know it. The way the club was shaped, it was out of the way."

(vii) Accounts of evacuation through windows

Numerous eyewitness statements suggest that a significant number of occupants escaped through the club's windows. The *Providence Journal* reported that 79 occupants exited through windows [9].

Anthony Bettencourt – West Warwick, RI, Police Officer [8]

Officer Bettencourt was pushed out of the main exit of the club by the initial rush of people. Once outside, he apparently heard people kicking at windows, and proceeded to break some of these windows with his baton. He and other officers helped numerous people, both conscious and unconscious, exit through the windows.

Eventually, the officers could no longer reach people immediately inside the windows, and began to call for occupants: "Come to the window."

According to Bettencourt, one occupant ran through one of the windows: "He opened up a nice hole."

Robert Riffe – Club Patron [5]

After being stopped at the main entrance by the build-up of people, he was able to struggle free from the pile and to get out of the building. He observed the scene from the parking lot.

"…we could see people coming out of the windows, and people scattered throughout the parking lot. Some…were all bloodied from jumping out of the windows and onto the pavement."

Paul Vanner – Club Employee [3]

After deciding against attempting to fight the fire with a fire extinguisher, Vanner evacuated through the kitchen door. He then moved around towards the front of the building.

"All of a sudden, I heard smash-smash-smash, people kicking out the windows. It was like black oozing smoke when they started kicking those windows out."

(viii) Accounts of when the lights failed

Several accounts suggest that the lighting failed after the pile-up occurred.

Andrea Stewart – Club Patron [7]

Stewart was in the crowd about ten rows back from the stage when the fire started.

Stewart was knocked down and landed in the middle of a pile of people just before the lights in the club went out.

Deborah Lemay – Club Patron [11]

Lemay had been in the club several times prior to the night of the fire, and knew of the exit door by the main bar. When the fire broke out, she decided to exit via this door.

"When the lights went off. I was almost at the door. I remember turning around and seeing the black smoke rolling in. Then I became engulfed in smoke."

6.2.6 Summary of Additional Evacuation Analysis Observations

The analyses of the WPRI video and the available eyewitness statements have generated numerous observations in addition to the fire and evacuation timeline presented above. These are summarized below.

- It is apparent that many people did not immediately move upon first noticing the flames. This may have occurred because people initially believed that it was "part of the show" or wished to maintain their locations within the crowd for the rest of the show. This may also have occurred because the occupants were apparently not instructed by the club's staff to begin evacuation. People appear to have initially felt that the fire would be controlled. These factors caused a delay in the evacuation of many occupants which, for an ordinary fire, would not be considered excessive.

- Some of the occupants knew of the existence of the side exit door near the main bar. The *Providence Journal* identified survivors of the February 20, 2003 fire at The Station [14]. According to this article, approximately 46 occupants used this exit. However, difficulty in opening this door, for unknown reasons, was reported by several survivors (but not all survivors that exited through this door reported difficulty). In the WPRI video, this door appears to have panic hardware and to swing in the direction of egress. Eyewitness statements confirm that occupants were able to evacuate through this door.
- Some occupants who used the side exit near the main bar reported falling down a series of stairs immediately after passing through the door. Video footage or photographs of the evacuation efforts at this location are not available; however, this door exits onto a landing with steps to grade.
- A small number of occupants (approximately 20 - mainly those associated with the band or the club, as reported by the *Providence Journal* [14] used the exit near the platform early in the fire. It is apparent from the WPRI video that this exit rapidly became impassable; the camera observed significant flames in the area of this door when the camera operator first made his way to the side of the building at 1 minute 25 seconds after the start of the fire. Thus, it is likely that smoke and flames blocked this exit within 1 minute 25 seconds of the start of the fire. At 4 minutes 30 seconds after the start of the fire, dense smoke and flames could be seen down to the floor level just inside of the platform exit.
- Multiple survivors described the evacuation as "panicked" or likened it to a "stampede," [6-8]; however, no evidence of panic was captured on the video.
- Many survivors indicated that they were not aware of any exit doors other than the main front door.
- Seventy-nine occupants exited the building through its windows. Many were assisted by individuals, including police officers, on the outside of the building.
- Some attempts were made at initiating manual extinguishment of the fire. One band member attempted to douse the flames with a bottle of water, while another ran for a fire extinguisher (but never actuated it). Based upon eyewitness statements and observations from the WPRI-TV video regarding the fire growth, manual extinguishment efforts when initiated were ineffective against the fire.

6.3 ESTIMATES OF OCCUPANT LOAD

Based upon the 2003 editions of the IBC and NFPA 5000 model building codes, the estimated permitted occupant load for a building similar to The Station in area and use varies (See Section 7.3.11), but is equal to 420 people when limited by egress from properly functioning doors at the main entrance, platform, and bar exits. (Refer to Figures 7-3 through 7-5 for the floor areas and to Table 7-6 for the door widths used to arrive at this estimated occupancy limit.)

Several public documents from the Town of West Warwick were found that referred to occupant loads in The Station or its previous incarnations. One, dated Nov. 21, 1981 [16], was an Application for Variation under the Fire Safety Code to omit completely enclosing the boiler room, which identified an occupant load of 225 for the building as it was being used at the time. The West Warwick Fire Department, in a memorandum dated Dec. 30, 1999 [17], identified the occupant load as 253 occupants; however, an allowance was given to increase the occupancy to 317 by removing tables and chairs from three lounge areas and providing standing room only in those areas. No other distribution for the memorandum is indicated on the document. A third document was an unsigned memorandum on blank bond without letterhead from the West Warwick Fire Department, dated Mar. 2, 2000 [18], addressed to Chief Peter Brousseau. Again, no other distribution is shown. The memorandum identified the occupant load as 258 when tables and chairs were set up in the four designated seating areas; however, an allowance was given to increase the occupancy to 404 by removing all tables and chairs. The memorandum also stated that a uniformed firefighter should be on the premises if this higher occupancy were to be applied. No explanation has been obtained for why the memorandum was written, nor does NIST know if either of the memoranda was made available to the owners of the building.

Published articles were reviewed in an attempt to develop estimates of the number of occupants at The Station during the incident. The *Providence Journal* identified the names of 100 people who died as well as the names of the survivors of the Feb. 20, 2003 fire at The Station [14]. Survivors are listed by source of identification. According to the *Providence Journal*, 208 survivors were interviewed; of those interviewed, 59 were identified by other survivors, 46 were identified by lawyers, 10 were identified by relatives, 5 were identified by hospital staff and two photographers were taking pictures in the club. The *Providence Journal* lists ages, town of residence, and state of residence for 274 of these people, list a total 430 occupants in October 2003 [14], 432 in December 2003 [9], and 440 in Feb. 2004 [40]. The Associated Press reported [42] that the Rhode Island Office of the Attorney General claimed that 458 people were inside the nightclub that evening.

To the degree possible, the WPRI-TV video taken in The Station on the night of the incident [2] was used to provide an alternative estimate of the actual number of occupants within the club; however, several factors limited the accuracy and comprehensiveness of the count:

- A camera has a limited view, or “cone of vision.” As the operator moved around, he was only able to capture occupants within the camera’s view; and thus, in many cases additional occupants at the periphery of the camera’s view were not recorded.
- A single sequence in which the camera pans in a full circle and thus shows the entirety of the club at a given time was not available. Thus, at any given time, the camera is only showing the occupants of one portion of the club, and the occupant load conditions in the rest of the club are unknown.
- The first part off the video was recorded over an unknown amount of time, and includes several “cuts” or stop points when the camera was turned off for an unknown portion of time. During such cuts, occupants were likely to have moved around the club, and new occupants likely entered.
- The dark conditions of the club through most of the evening created shadows in areas distant from the light of the camera. Occupants located in these shadows were generally not visible.

With the above limitations in mind, a series of still frames that provide a panning view of the club’s performance assembly area were obtained from the WPRI-TV video. These frames are shown in sequence in Figures 6-5 through 6-8 as the camera pans from right to left. The occupants shown in these still frames were counted in an effort to derive an approximate occupant load for the area shown. Orange dots have been used to represent counted occupants. The yellow lines in these Figures represent the boundaries where the frames overlap. A total of 144 occupants can be seen in these four figures. It is not clear at what time in relation to the start of the concert this video sequence was recorded. If it was recorded well before the main musical act, then it is likely that many occupants were located outside of the main platform viewing area at this time (i.e., many occupants may have been near one of the bars, in the pool room, or in the restrooms). Conversely, if this sequence was recorded immediately prior to the start of the primary musical act, then it is likely that the majority of the club's occupants would have moved towards the platform and into the performance assembly area. For these reasons it is not possible to extrapolate to a total building occupant load from this analysis. However, these figures can be helpful in estimating possible ranges of the number of occupants that may have been within the main platform viewing area.

6.4 LIFE SAFETY FEATURES

Multiple data sources were reviewed to assist in determining the life safety features present at The Station at the time of the fire on Feb. 20, 2003. The following section documents the results of this effort. The information is divided into three categories:

- Public Documentation Evidence: This includes data from Fire Department Inspections, Fire Alarm Company Sketches and Reports, and other publicly available documentation.
- Photographic Evidence: This includes information obtained from a review of the digital photographs and scanned images received from NIST.
- Video Evidence: This includes information extracted from the WPRI video footage of the incident.

6.4.1 Floor Surfaces

It has been claimed that floor surfaces in The Station were uneven [22]. NIST has no independent information to confirm or contradict this claim.

6.4.2 Exit Doors

Egress through the main entrance to the building was limited by a single interior door (LSF 6 in Figure 6-10) not the double doors that could be seen from outside the building.

The West Warwick Fire Department Inspection Report dated Nov. 10, 2001, commented that the exit door near the platform cannot swing inward [24]. The building owner was instructed to call when ready for re-inspection. Note that these comments were checked and deemed "OK"; however, the re-inspection signature is blank.

In a West Warwick Fire Department Inspection Report dated Nov. 20, 2002 [25], the following comments were made:

- Platform exit door swings in the wrong direction;
- Panic hardware on platform door is broken.

The building owner was instructed to call when ready for re-inspection. These comments were checked and deemed "OK"; however, the re-inspection signature is blank.

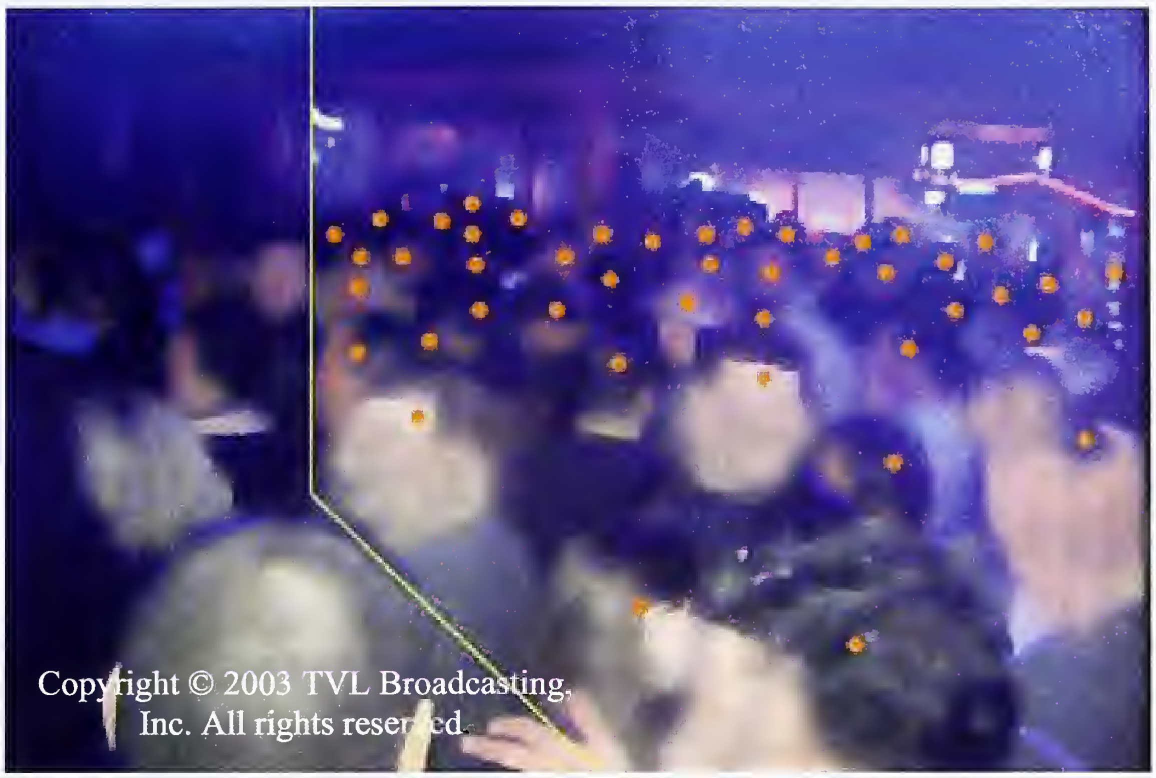


Figure 6-5. Occupant Load Count, Part1 – 45 Occupants

Figure 6-6. Occupant Load Count, Part 2 – 42 Occupants

Figure 6-7. Occupant Load Count, Part 3 – 37 Occupants

Figure 6-8. Occupant Load Count, Part 4 – 20 Occupants

6.4.3 Exit Signs

Numerous West Warwick Fire Department reports were issued to previous businesses on this site regarding the exit signs. In reports dated Sept. 25, 1993 [26], Nov. 17, 1994 [27], Oct. 2, 1995 [28], Sept. 25, 1996 [29], and Nov. 22, 1998 [30], the condition, arrangement, and operation of the exits signs were noted as “OK”. These reports did not require re-inspection.

The West Warwick Fire Department Inspection Report dated Nov. 10, 2001 [24], commented that the exit sign near main entrance needs bulbs. The building owner was instructed to call when the building was ready for re-inspection. Note that this issue was checked and deemed “OK”, although re-inspection signature on the report is blank.

The West Warwick Fire Department Inspection Report dated Nov. 20, 2002 commented that the exit signs were not working [25]. The building owner was again instructed to call when the building was ready for re-inspection. Note that these issues were checked and deemed “OK”, although the re-inspection signature is blank on this report as well.

6.4.4 Emergency Lighting

The West Warwick Fire Department inspected the emergency lighting within the building under previous ownership on numerous occasions. In Inspection Reports dated Sept. 25, 1993 [26], Oct. 2, 1995 [28], Sept. 25, 1996 [29], and Nov. 22, 1998 [30], the condition and operation of the emergency lighting within the building were noted as “OK” and re-inspection was not called for.

In a West Warwick Fire Department Inspection Report dated Nov. 17, 1994, the kitchen emergency lighting was noted as not working. The owner was instructed to notify the Fire Department when the repairs were completed; note that the re-inspection signature is blank [27].

The West Warwick Fire Department Inspection Report dated Nov. 10, 2001, commented that the emergency lighting units at main entrance and at platform were not working [24]. The building owner was instructed to call when the building was ready for re-inspection. These issues were rechecked and deemed “OK”, although the re-inspection signature on the report is blank.

6.4.5 Suppression

The West Warwick Fire Department carried out numerous inspections of the manual suppression equipment in businesses at this site. The Fire Department issued reports on Sept. 25, 1993 [26], Nov. 17, 1994 [27], Oct. 2, 1995 [28], Sept. 25, 1996 [29], and Nov. 22, 1998 [30], deeming the condition and location of the existing fire extinguishers “OK”, and re-inspection was not required.

The West Warwick Fire Department Inspection Report dated Nov. 10, 2001, commented that the fire extinguishers must be hung [24]. The building owner was instructed to call when the fire extinguishers were ready for re-inspection. This issue was rechecked and deemed “OK”, although the re-inspection signature on the report is blank.

6.4.6 Fire Alarm and Detection

(i) Fire alarm company information

An inspection report from RI-CONN Fire Systems, Inc. [31] verifies the testing of the following system components:

- four heat detectors in the kitchen and basement;

- two manual stations – one at the kitchen exit and one at the bar;
- the kitchen hood suppression system was also tested.

Fire alarm sketches prepared by New England Custom Alarms [32], indicate existing system devices and various device additions to upgrade the fire alarm system at The Station. This work was permitted on Mar.8, 2000; it appears that this work was completed.

The existing drawings located the following life safety devices:

- two heat detectors in the space between the Kitchen and the Employee Restroom Area;
- one heat detector in the Employee Restroom;
- an Ansul system in the kitchen (presumably protecting cooking appliances);
- one alarm horn near the kitchen door adjacent to the large bar;
- one alarm horn in the greenhouse near the pool tables;
- one alarm horn adjacent to the platform exit door;
- two heat detectors in the basement.

The upgrades included on the Mar. 6, 2000, drawings resulted in the following:

- a new Fire Alarm Control Panel inside the main entrance doors.
- one existing heat detector in the space between the kitchen and the employee restroom/prep area (one of the heat detectors was to be removed);
- one heat detector in the prep area (moved from the employee restroom);
- an existing Ansul system in the kitchen (presumably protecting cooking appliances);
- one new heat detector below the platform;
- one new heat detector above the platform;
- one new heat detector backstage;
- one existing alarm horn near the kitchen door adjacent to the large bar;
- one existing alarm horn in the greenhouse near the pool tables;
- one existing alarm horn adjacent to the platform exit door;
- one new alarm horn in the hallway to the restrooms.
- four new manual pull stations (inside front door, at platform door, at left side bar area door, and at light/sound control area);
- two existing heat detectors in the basement.

An NFPA 72 Inspection and Testing form [33] lists the following fire alarm system components:

- three manual stations;
- six heat detectors;
- one Ansul tie-in;
- four horns;

- five strobes;
- one speaker.

The device testing section of the same form [33] confirms that the following initiating and supervisory devices were inspected and tested:

- one heat detector in the Kitchen;
- one heat detector in the Prep Area;
- one heat detector in the Dining Area;
- one heat detector in the Employee Restroom;
- two heat detectors in the Basement;
- two pull stations (location is not specified);
- Ansul system was visually inspection and its operation was simulated.

6.4.7 Interior Finish

In letters dated May 22, 2003 [34] and May 23, 2003 [35], the West Warwick Fire Chief and the West Warwick Building Official, respectively, responded to the West Warwick Town Clerk regarding requests for permits or inspections from The Station for the use of decorative or acoustic materials. No information was found by either individual with regard to a request from The Station for permitting or inspection of decorative or acoustic material usage.

6.4.8 Identification of In-place Life Safety Features

Table 6-1 summarizes all identified life safety features within The Station prior to the fire. Refer to Figure 6-9 for the locations of these features within the building. Specific devices and features are shown in Figures 6-10 and 6-11, taken from video stills or photographs taken at the site on Feb. 22, 2003. (Large format copies of the photos are included in Appendix B.) Additional details, such as manufacturer names, model numbers, or other descriptions of the devices were not available.

Several additional observations were made regarding the main exit vestibule area and the exit door near the platform. Figure 6-12 provides an approximate representation of the orientation and layout of the main exit vestibule area. It also shows the video evidence that was used to formulate this representation. The notes provided with this Figure give some additional observations related to this exit. Figure 6-13 shows the exit door located in the vicinity of the platform. Based upon this video still and other frames from this portion of the WPRI video, it appears that this exit included two doors:

- an exterior door, which swung outward, or with the direction of egress travel, and
- an interior door, which swung inward, or against the direction of egress travel.

The presence of the interior door is evident from the inward-swinging hinges seen on the doorframe. The edge of this door is visible as well. As can be seen in Figure 6-14 the exterior door was equipped with panic hardware. The hardware installed on the interior door is unclear. Additional examination of this figure reveals what appears to be adhesive on the inside of the exterior door.

Table 6-1. Summary of Identified Life Safety Devices

Image ID	Description
LSF 1.	Main double doors with ramp and stairs. (Note that egress was limited by the single interior door (LSF 6), not the main double doors.)
LSF 2.	Exterior stairs from the left-side main bar area indicating location of exit door.
LSF 3.	Exterior stairs from the kitchen area indicating location of exit door.
LSF 4.	Exterior stairs from the platform area indicating the location of exit door.
LSF 5.	Site view indicating the location of the doorway from the main bar area to the ticket area.
LSF 6.	Door leading from the interior ticket area towards the outer vestibule.
LSF 7.	Exit door from the left side of the main bar area to the exterior concrete stairs. Panic hardware was provided on this door.
LSF 8.	Exit door adjacent to the platform to the exterior concrete stairs. Panic hardware was provided on this door. Note that it appears there was foam attached to this door and that there was an additional interior door that swung against the egress direction.
LSF 9.	Exit sign located near the rear bar; it appears to be pointing toward the kitchen exit door.
LSF 10.	Exit sign above the door that leads from the ticket area to the front vestibule.
LSF 11.	Exit sign above the platform door. Note that in this image the sign is clearly illuminated.
LSF 12.	Exit sign above the platform door on February 20, 2003. Note that in this image the sign does not appear to be illuminated. NOTE: This is a duplicate of LSF 12, but was included to show that the exit sign may not have always been illuminated.
LSF 13.	Two exit signs. One located in the main floor area with an arrow towards the ticket area and another above the ticket area doors leading to the front vestibule.
LSF 14.	Exit sign over the left side main bar area exit door.
LSF 15.	Exit sign located in the front vestibule above the main double exit doors. This location is based upon similar wall and ceiling features observed in the WPRI video.
LSF 16.	Emergency light located near the rear bar.
LSF 17.	Emergency light above and to the right of the platform exit door.
LSF 18.	Emergency light on the wall adjacent to the kitchen by the main bar facing into the main floor area.
LSF 19.	Emergency light above and to the right of the left side exit door from the main bar area.
LSF 20.	Fire extinguisher located behind the rear bar.
LSF 21.	Detector (heat) located above the lighting grid on the ceiling near the platform.
LSF 22.	Fire alarm strobe adjacent to the exit sign above the platform exit door.
LSF 23.	Fire alarm strobe on the ceiling to the left and in front of the platform.
LSF 24.	Fire alarm strobe on the wall adjacent to the exit sign in the main floor area pointing toward the ticket area.

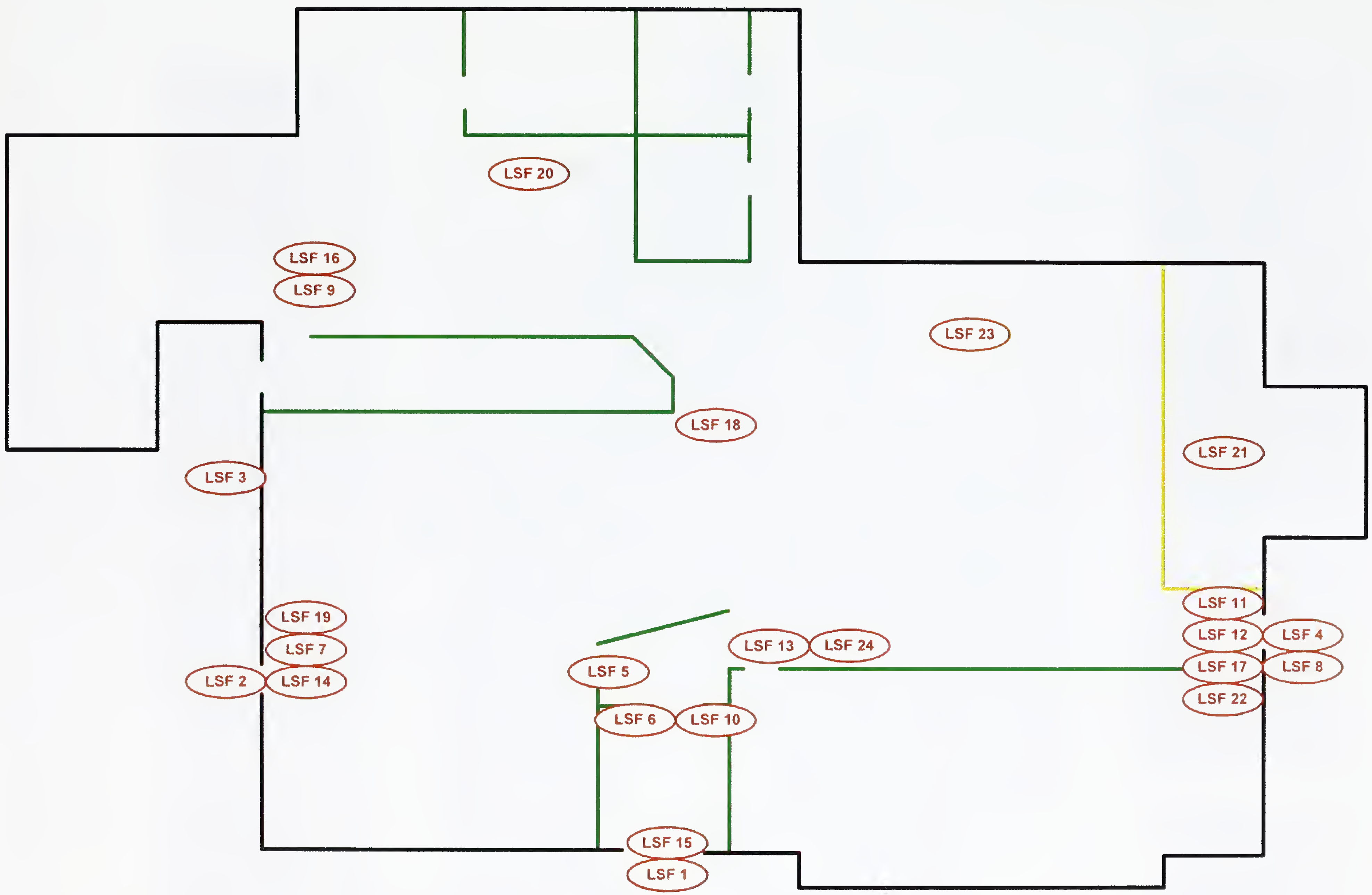


Figure 6-9. Locations of life safety features listed in Table 6-1.

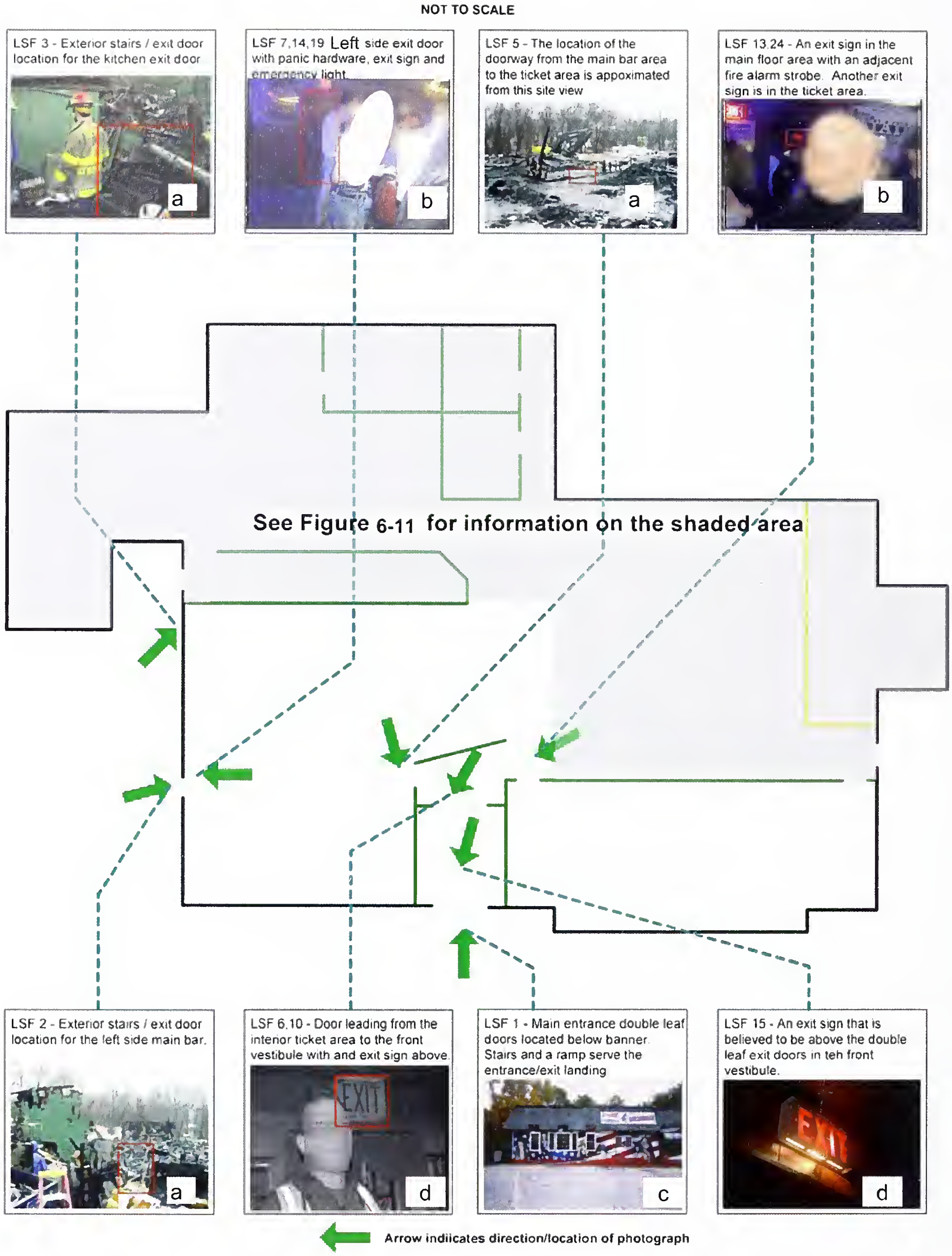


Figure 6-10. Summary of Life Safety Features – Part 1

a - photo by NIST; b - Copyright © 2003 TVL Broadcasting, Inc. All rights reserved.

c - photo with permission of A. Baldino, III; d - photo with permission of K. Corbin

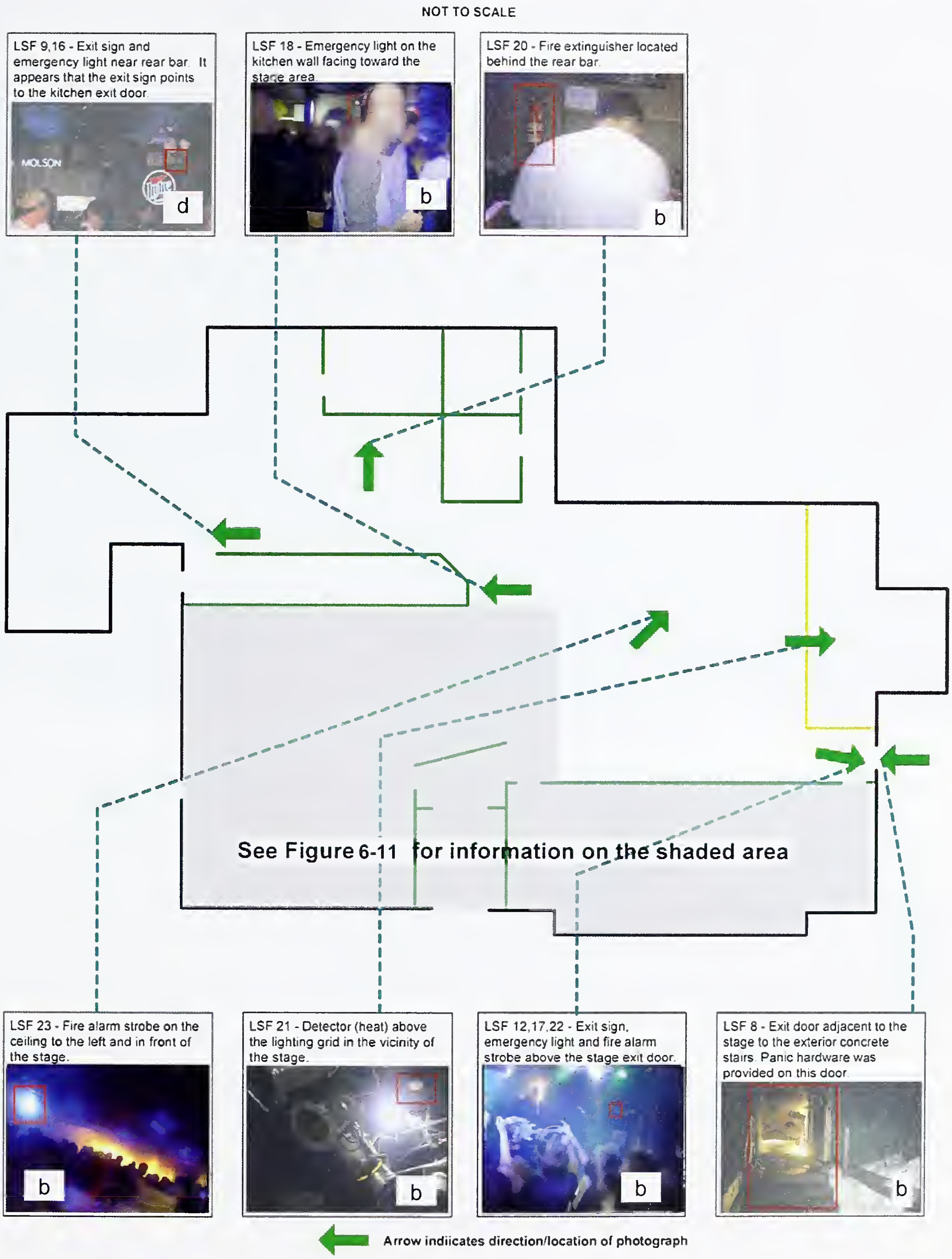


Figure 6-11. Summary of Life Safety Features – Part 2

d - photo with permission of K. Corbin

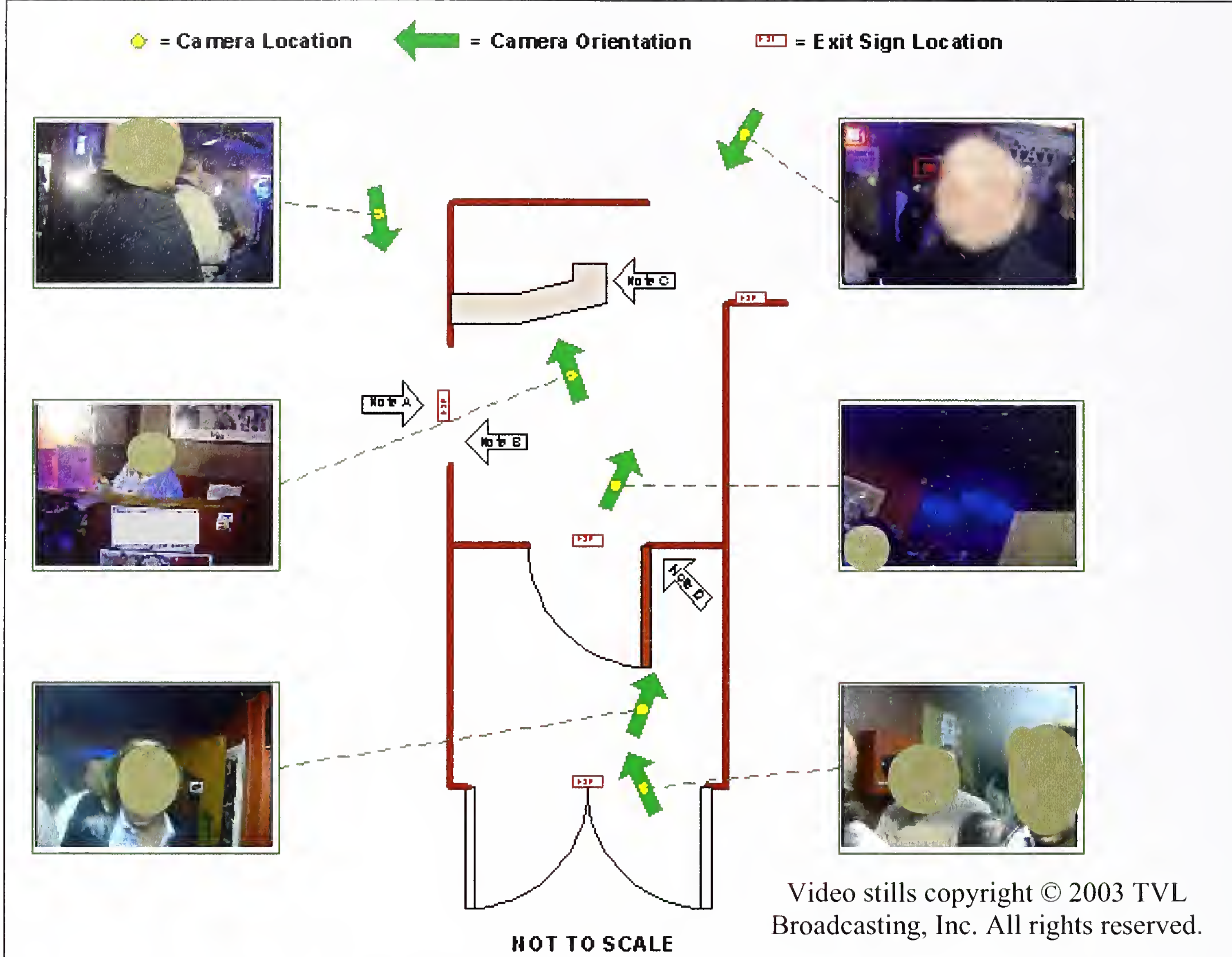


Figure 6-12. Detail of Main Exit Vestibule Area (Video frames copyright © 2003 TVL Broadcasting, Inc. All rights reserved)

Note A: The exact location of this exit sign above the secondary vestibule doorway was estimated from a reflection in the mirror behind the main bar observed in the WPRI video.

Note B: The exact location and size of the secondary vestibule doorway was approximated based upon the video evidence available.

Note C: The dimensions of the ticket counter were approximated based upon the video evidence available.

Note D: The dimensions of the associated sidelights are not known, although the orientation shown here is accurate based upon video evidence. Note that the single inner door provides the limit to egress, not the exterior double doors.

Note E: The diagram in Figure 6-12 is an approximation based upon the video available, and reflects approximate locations from where video was taken both before and during the fire. The video images in this Figure 6-12 were captured both before and during the fire.

The uncertainty in the transverse position of the camera is estimated to be +/- 1 ft; it is not possible to estimate the uncertainty in position of the camera along the direction of the arrow since the zoom setting is unknown.

Figure 6-13. Exit Door Near Platform [2]

6.5 EGRESS PATHWAYS AND THE LOCATION OF VICTIMS RECOVERED FROM THE SCENE

The *Providence Journal*, during interviews with some of the survivors and acquaintances of the occupants, was able to identify the exit path for 248 of the approximately 350 people who escaped from the building. Of the 169 occupants who indicated that they had escaped through a door (main, barroom, kitchen, and platform), 91 left through the main entrance in the front of the building. The windows in the main bar room and the sunroom appear to have become the secondary routes of escape once the main entrance became impassible, with 25 survivors escaping through the sunroom windows and 54 leaving through the windows in the main bar, accounting for 32 % of the successful evacuations documented.

The Rhode Island Attorney General's office released a diagram of the approximate location where the rescuers recovered the 96 people who died at the scene of the fire [36] (See Figure 6-14.); 58 of these were located in the main entryway, at the entrance to the main entryway, or trapped in the sunroom. Taken together with the 91 who escaped through the front door, this translates to 56 % of the occupants apparently selecting the main entrance as a route to safety. Including the people who chose the windows only after the main exit became impassable, one could argue that as many as 2/3 of the occupants attempted (at least initially) to leave through the main entrance in the front of the building. Only about 40% of those who successfully evacuated escaped through the main entrance.

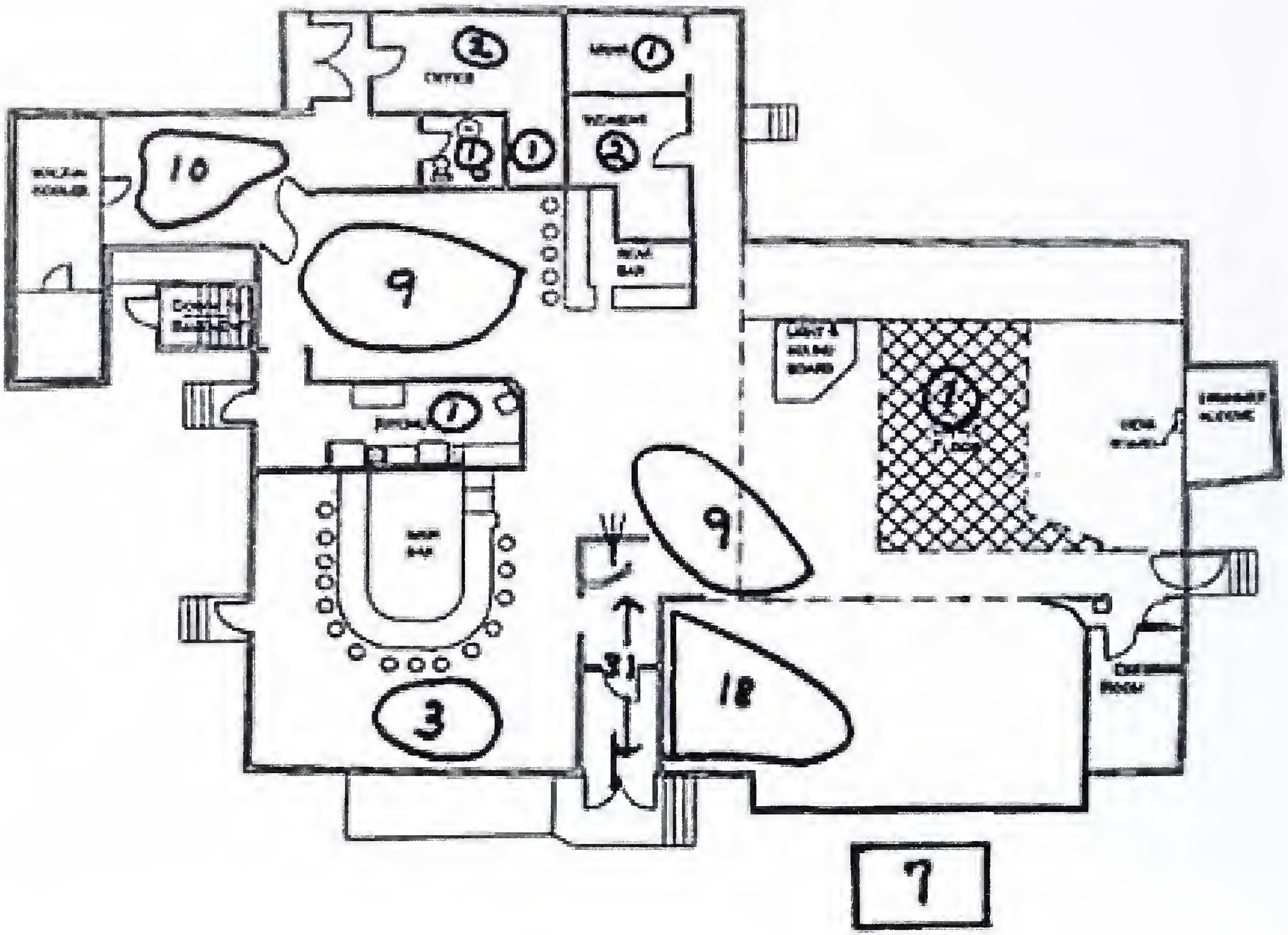


Figure 6-14. Location of Recovered People Who Died at Scene [36]

The small number of victims shown in Figure 6-14 who were found in the main bar room suggests that the main bar room exit door and windows provided open routes to escape for a time period about as long as it took to reach untenable conditions in that area of the building. By contrast, the high number of victims found in the sunroom relatively close to the windows suggests that the environment there became untenable quickly, eliminating the option of a secondary route through the sunroom windows once the platform door and main entrance became unusable. Both of these conclusions are consistent with the environmental conditions predicted in the FDS simulations discussed in Chapter 5.

Twenty-three victims were found in the dart room, storage area, and office, suggesting either that they were unfamiliar with the building and hoped to find a safe exit in that region, or that they became disoriented while heading for the side exit of the main bar room (or possibly the kitchen exit). It is unclear whether the seven people identified in Figure 6-14 as being recovered from the front of the building outside of the sunroom died as they escaped or were pulled from the sunroom by rescuers.

6.6 ALTERNATIVE SIMULATIONS OF NIGHTCLUB EVACUATION SCENARIOS

The following questions were posed by the investigation team regarding the evacuation from the nightclub:

1. How long would it take to evacuate a building similar to The Station with no fire present assuming exit numbers, exit widths, and occupancy limits were consistent with current national model building codes (see chapter 7 for details)?
2. How long would it have taken to evacuate The Station assuming the platform door became impassable in 30 seconds and the main entrance in front became blocked in 90 seconds?
3. How long would it take to evacuate a building similar to The Station assuming that the doorway near the ticket-taker was the same width as the double doors leading to the outside and that it did not become blocked, but that the platform door became impassable in 30 seconds?

The first question is important to answer since it yields the minimum time that could be expected. The second question is a challenge to our ability to predict reality when it comes to an emergency evacuation. The third question provides insight into the effectiveness of a possible change in model code requirements.

The Station had four exit paths: through the main entrance, the main barroom, the kitchen, and the platform area. Based upon current model codes, the kitchen door was not accessible to the patrons. As mentioned in Chapter 6.3 and discussed in more detail in Chapter 7.3, the occupancy limit based upon current model code provisions for safe egress from the building as it was used on Feb. 20, 2003, was calculated to be roughly 420. With these data as input, and the floor plan from Chapter 1, the evacuation time was estimated using two commercial software packages, Simulex [36, 37] and buildingEXODUS [38].

To run these models it was necessary to distribute the 420 occupants throughout the building. It was assumed that the dance floor and area around the platform were at the maximum density permitted by the current national model codes described in chapter 7, 2.17 persons/m^2 (5 ft^2/person), that the sunroom and raised area around the dance floor had a density of 1.56 persons/m^2 (7 ft^2/person), that the main barroom and back room were populated at 0.72 persons/m^2 (15 ft^2/person), and that the 36 remaining occupants were scattered about the kitchen, behind the bar, restrooms, storage area, dressing room, and corridor.

Simulex and buildingEXODUS also needed to have a pre-movement time assigned as well as an algorithm for selecting exits. In a more conventional fire situation for a building of this type, pre-movement times can range from less than a minute to several minutes. For all cases examined here, for simplicity, the pre-movement time was assumed to be zero since the primary intent was only to examine the changes in egress time associated with different evacuation scenarios; as a result, the times calculated are non-conservative and shorter than what one would expect under even a non-emergency evacuation.

The occupants were instructed to always select the closest exit. While there are other algorithms that could have been chosen, it was felt that this simple approach was sufficient to assess the differences in the evacuation scenarios. Building EXODUS is designed to handle open and closing of exits during the simulation; Simulex is not. For the scenarios that called for the platform area door to be closed 30 seconds into the simulation, we first calculated the number of occupants who would potentially leave through the platform door before 30 seconds, which totaled 39, and then instructed only these 39 simulated occupants that the platform door was a viable exit; this door was unavailable to the rest of the crowd.

Table 6-2 summarizes the results of the simulations. (Refer to Appendix L for a complete listing of input data for both models and all scenarios examined.) The scenario number in column one corresponds to the questions posed above. The total times to evacuate and the number of people through each of the available doors are listed in the other columns, corresponding to the scenarios and the simulation model used in column 1. For a building meeting current national model code requirements at maximum

Table 6-2. Summary of calculated evacuation times* (seconds) and total occupants out each exit

Scenario	Total Evacuation Time	Occupants to Front Door	Occupants to Platform Door	Occupants to Kitchen Door	Occupants to Main Bar Door	Total Remaining at 90 s
1 (Simulex)	188 s	213	184	3	20	166
1 (EXODUS)	202 s	214	180	4	22	208
2 (EXODUS)	330 s	91	32	3	273	271
3 (Simulex)	198 s	358	39	3	20	173
3 (EXODUS)	194 s	363	33	4	20	201
2* (Simulex)	308 s	356	39	3	22	256
2* (EXODUS)	341 s	364	32	4	20	274

* Note that evacuation times are based upon instantaneous reaction of the occupants to the fire; an appropriate pre-movement time must be included in a proper design calculation.

occupant load (scenario 1), the time needed to evacuate with no fire or smoke present was calculated to be 195 seconds ± 7 seconds for the two simulations. The flow through the various exits was about the same for both calculation methods, with just over 50 % of the occupants evacuating through the front door.

Only buildingEXODUS was used to evaluate the scenario in question 2, in which the *platform door became impassable in 30 seconds and the front entrance became blocked at 90 seconds*. (The technique described above for "closing" a door while using Simulex would not have worked for the front entrance because it was also necessary to trap the occupants in the vestibule once the front door was closed.) Scenario 2 was the closest to the condition that occurred on Feb. 20, recognizing that the simulations did not account for any impairment of movement associated with high temperatures, smoke and toxic gas levels that were produced in the actual fire. The time for total evacuation increased to 330 seconds, with the bulk of the people forced to evacuate through the only (known) exit in the main barroom. (No provision was made to allow escape through broken windows). In this case, only 91 people used the front entrance and 35 used either the platform door or the kitchen door, numbers that were consistent with those reported by the *Providence Journal*. The total number of people evacuated in this scenario was only 399 since it was assumed that the 21 occupants who were in the entrance corridor when it became blocked at 90 seconds were trapped.

Scenario 3 investigated the impact of *doubling the width of the most restrictive element at the front entrance*. Figure 6-15 is one frame grabbed from the Simulex computer simulation indicating the initial population and distribution of patrons and employees. (This was typical of the initial conditions for all of the simulations.) The purpose was to see how this affected the evacuation time in the event that one of the other exits became blocked (e.g., due to construction, negligence or a criminal act). Simulex and

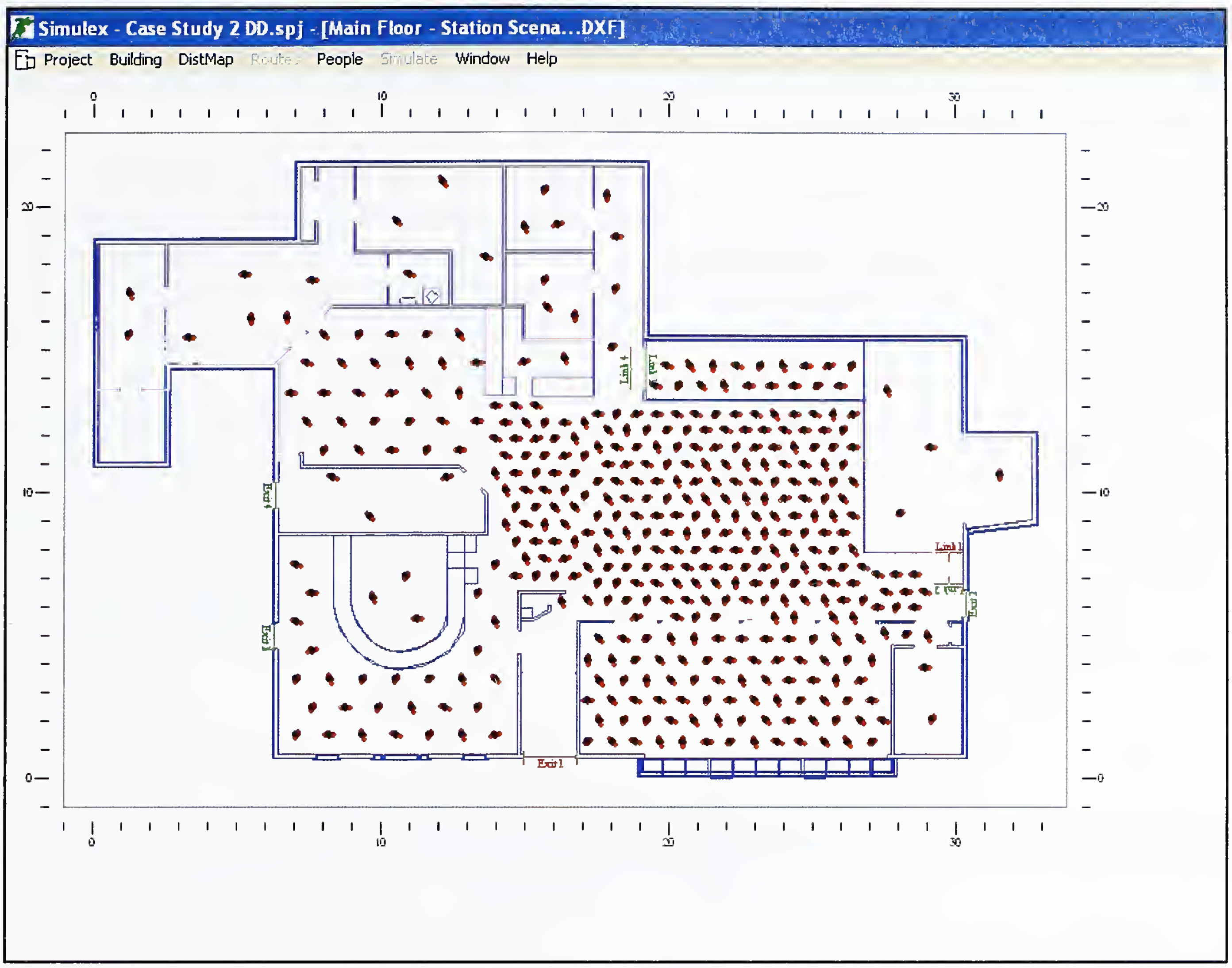


Figure 6-15. Initial distribution of 420 simulated nightclub patrons and employees

buildingEXODUS calculated a total egress exit time of 196 seconds ± 2 seconds, almost identical to the baseline case in scenario 1. The main difference in the outcome for scenario 3 was the larger number of occupants using the front entrance to escape, about 87 % of the total. Assuming that doubling the width of the restrictive front entrance would also have reduced the possibility for a crowd crush to develop, this change would bring the level of safety equivalent to what was implied by the current model codes.

The last row in Table 6-2 applies to a modified form of scenario 2 (Scenario 2*), in which it was assumed that *the main door did not become blocked by the crush of the crowd (in spite of the single door width at the entrance to the ticket taker area), and that the platform door became impassable after 30 seconds.* (Because the front door did not close and trap the occupants, Simulex, as well as buildingEXODUS were capable of simulating Scenario 2*.) It is interesting to see that while the distribution of occupants through the different doorways is essentially the same as was calculated for scenario 3, the total evacuation time increased to between 308 seconds and 341 seconds. This results from the decision algorithm that required occupants to choose the closest exit, even if the queue was long. One could argue that many of the people waiting to go out the front door would have chosen the barroom door (which remained clear for most of the evacuation period) as a logical alternative, even though it may have been a bit more distant. The counter argument is that the barroom exit sign could have been obscured by smoke, making that door a reasonable alternative only for those familiar with the nightclub.

Figures 6-16 and 6-17 compare the cumulative population that was evacuated as a function of time for the scenarios described above, based upon the results of buildingEXODUS [39] and Simulex [37, 38] respectively. If one draws a vertical line up from the time scale at 90 seconds, the total number of people who remained in the nightclub at that time can be determined.

Ninety seconds had significance on Feb. 20 because that was about the time the front entrance became blocked and, according to the fire dynamics simulations, was a point where the conditions were becoming untenable throughout the building. The last column in Table 6-2 lists the population remaining for both the buildingEXODUS and Simulex simulations. Note that buildingEXODUS, when compared to Simulex, consistently provided a more conservative (i.e., a slower) rate of egress, which is consistent with the conservative flow rates chosen for the exit doors in buildingEXODUS.

Somewhere between 166 and 208 people were calculated to remain in the building 90 seconds after the fire began for the scenario in which the building met current national model code requirements. This number jumped to 271 for scenario 2, with the platform door blocked (recall that the front door remained open during the first 90 seconds). Doubling the entrance door width in scenario 3 brought the number of people remaining in the building 90 seconds into the fire back down to the range calculated for scenario 1. Finally, since the crowd-crush had not occurred prior to 90 seconds, the calculation for the 2* scenario is essentially the same as for scenario 2.

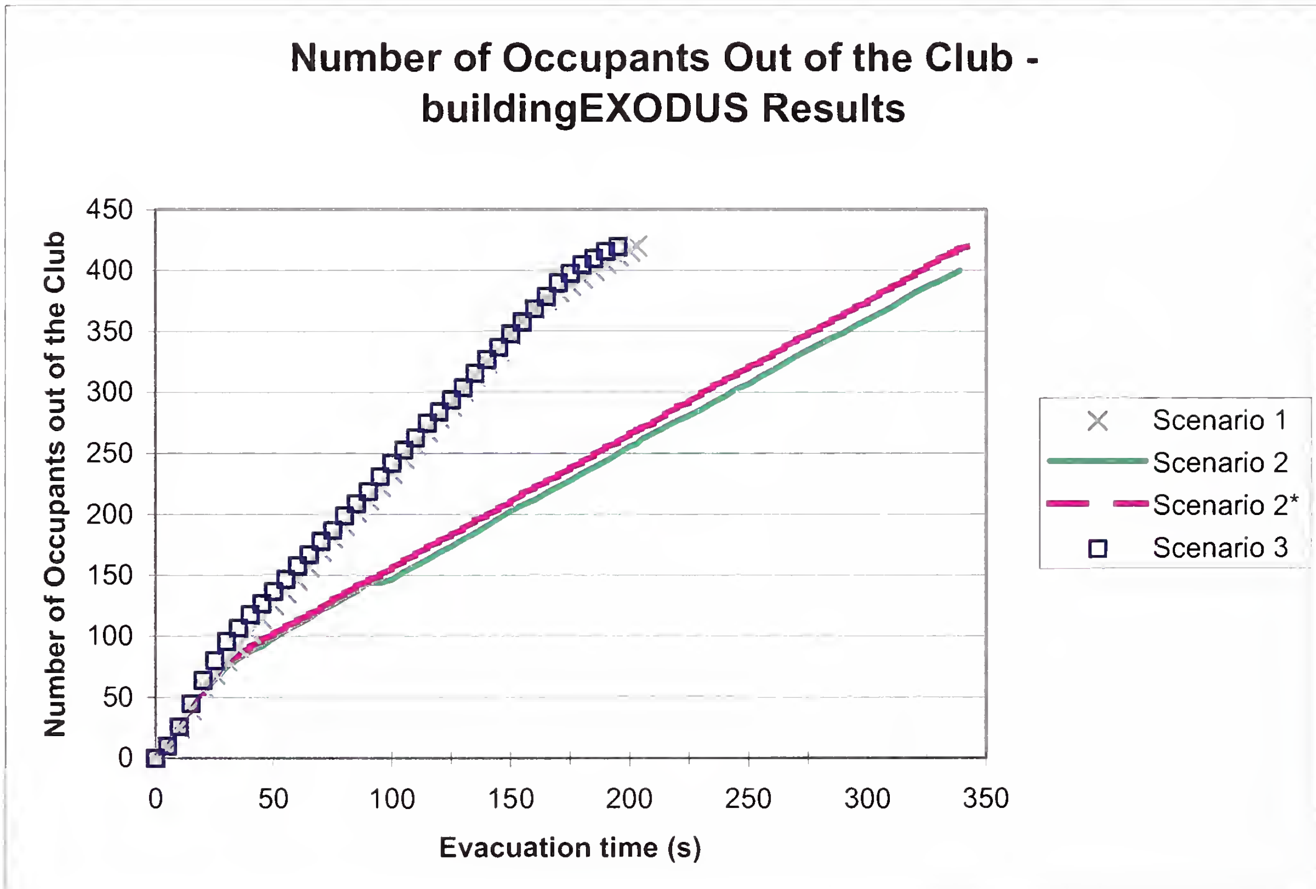


Figure 6-16. Cumulative plot of evacuation from building for different scenarios calculated from buildingEXODUS [39]. (Note that a non-zero pre-movement time would shift the curves to right.)

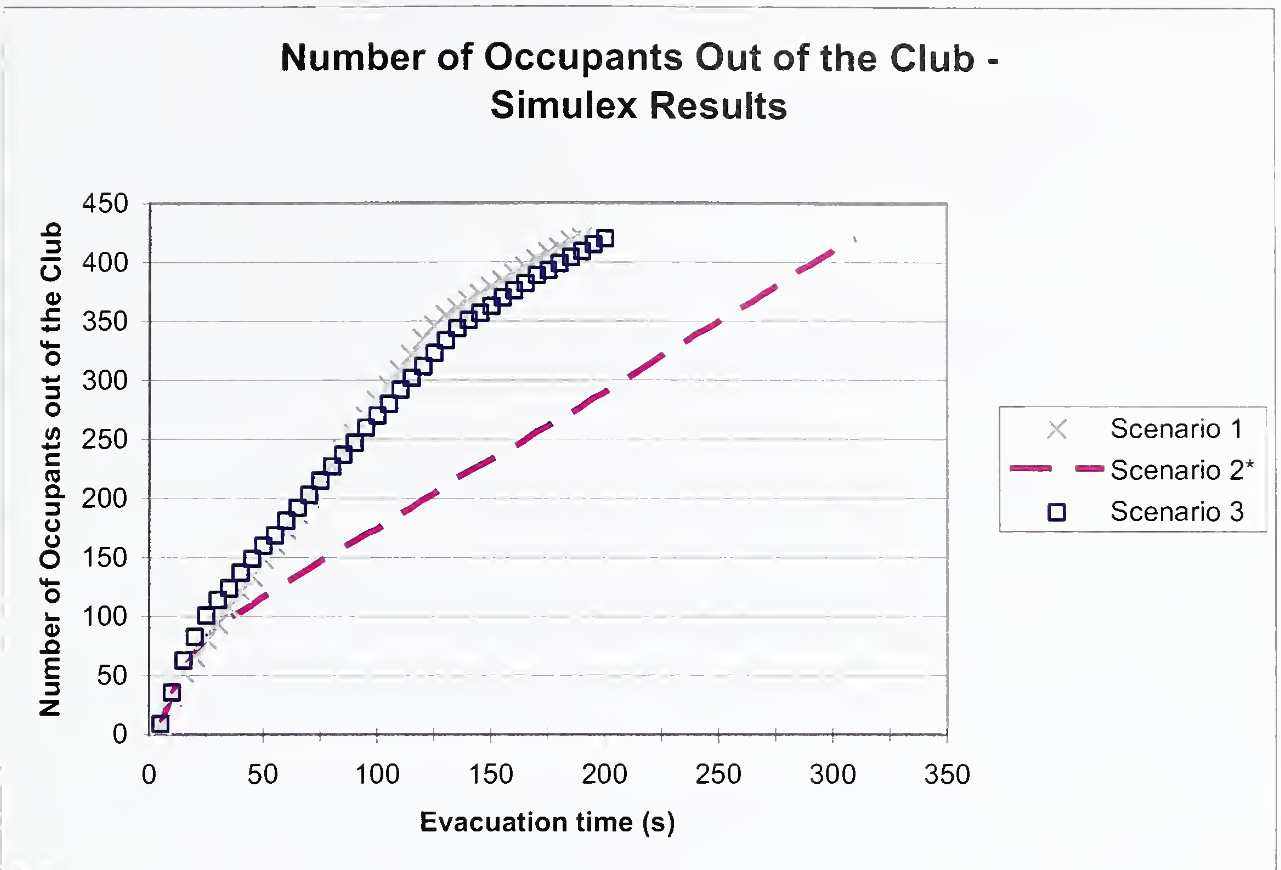


Figure 6-17. Cumulative plot of evacuation from building for different scenarios calculated from Simulex [37, 38]. (Note that a non-zero pre-movement time would shift the curves to right.)

6.7 REFERENCES FOR CHAPTER 6

[1] "Evaluation of Limitations to Egress through Doorways in Emergency Situations," vol. 1, Ove Arup & Partners Massachusetts Inc., Job number 32979, Westborough MA, Feb. 18, 2004.

[2] Butler, Brian, Video by WPRI-TV, Channel 12, Feb. 20, 2003.

[3] Parker, P.E. and Anderson, E. "Stage manager: Pyrotechnics not unusual at club." *Providence Journal*, Feb. 26, 2003.

[4] Parker, P.E., Levitz, J., and Anderson, E. "Witness describes placement of fireworks just before blaze." *Providence Journal*, Feb. 27, 2003.

[5] Riffe, R. "A first-person account from a survivor." *Providence Journal,* Feb. 24, 2003.

[6] Patinkin, M. "You just make plans for the end." *Providence Journal,* Feb. 23, 2003.

[7] Carbone, G. "Survivor reflects on life: Tell those you love, I love you." *Providence Journal*, Mar. 4, 2003.

[8] Mooney, T. "Saving lives at the open gates of hell." *Providence Journal,* Apr.13, 2003.

[9] Corkery, M. and Parker, P.E. "Forged by Fire, Day 7: Life and Death." *Providence Journal,* Dec. 21, 2003.

[10] Crowley, C. "A survivor's story: Saved by a pileup." Providence Journal, Mar. 10, 2003.

[11] Levitz, J. and Breton, T. "No easy way to escape." Providence Journal, May 5, 2003.

[12] Bramson, K. "Friends lost during frantic escape." Providence Journal, Feb. 23, 2003.

[13] Anderson, E. "Opening band: A 'little button' set off sparks that started fire." *Providence Journal*, Feb. 28, 2003.

[14] *Providence Journal*, "In the Fire." Oct. 5, 2003.

[15] "Analysis if Model Building and Fire Codes and Practices," Koffel Associates, Inc., Ellicott City, MD, 2004.

[16] Application for Variation under the Fire Safety Code, submitted to the State of Rhode Island by D. S. Kelly, Triton Industries, Inc. Nov. 21, 1981.

[17] Larocque, D., letter to Chief P. Brousseau of West Warwick Police Department, dated Jan. 30, 1999, signed by D. Larocque, West Warwick Fire Marshal.

[18] Letter from West Warwick Fire Department to Chief P. Brousseau of West Warwick Police Department, dated Mar. 2, 2000.

[22] Horgan, Daniel J., Ralph J. Monaco, John J. Nazzaro & Robert I. Reardon, Jr. United States District Court District of Connecticut, Civil Action Indictment. June 5, 2003.

[23] database compiled by *Providence Journal,* provided to NIST, Jan. 23, 2004.

[24] West Warwick Fire Department Inspection Report, dated Nov. 10, 2001, signed by D. Laroque.

[25] West Warwick Fire Department Inspection Report, dated Nov. 20, 2002, signed by D. Laroque.

[26] West Warwick Fire Department Inspection Report, dated Sept. 25, 1993, signed by R. Ouellette.

[27] West Warwick Fire Department Inspection Report, dated Nov. 17, 1994, signed by Capt R. Ouellette.

[28] West Warwick Fire Department Inspection Report, dated Oct. 2, 1995, signed by BC R. Ouellette.

[29] West Warwick Fire Department Inspection Report, dated Sept. 25, 1996, signed by R. Ouellette.

[30] West Warwick Fire Department Inspection Report, dated Nov. 22, 1998.

[31] RI-CONN Fire Systems, Inc. Inspection Report, dated Apr. 3, 1991 by inspector #9776.

[32] New England Custom Alarms, Fire Alarm Sketches, dated Mar. 6, 2000.

[33] New England Custom Alarms NFPA 72 Inspection and Testing Form, dated Mar. 3, 2000, completed by J LaFontaine (License #BF 09863).

[34] West Warwick Fire Chief, letter regarding requests for permits or inspections for the use of decorations or acoustic materials, dated May 22, 2003.

[35] West Warwick Building Official, letter regarding requests for permits or inspections for the use of decorations or acoustic materials, dated May 23, 2003.

[36] Rhode Island Attorney General's Office, Aug. 2004.

[37] IES, "Simulex User Manual, Evacuation modeling software," Integrated Environmental Solutions, Inc., Glasgow, UK, Mar. 2001.

[38] IES, "Simulex Technical Reference, Evacuation modeling software," Integrated Environmental Solutions, Inc., Glasgow, UK, Nov. 2000.

[39] Galea, E.R., Gwynne, S., Lawrence, P.J., Filippidis, L., Blackshields, D., and Cooney, D., "buildingEXODUS V4.0 User Guide and Technical Manual," Fire Safety Engineering Group, University of Greenwich, London, UK, 2004.

[40] *Providence Journal*, "In the Fire," p. B4, Feb. 20, 2004.

[41] Crowley, C.F., The Station Nightclub Disaster - A survivor's story: Saved by a pileup; *Providence Journal*. Providence, R.I.: Mar 10, 2003. pg. A.01

[42] Associated Press, March 28, 2005.

Chapter 7 MODEL CODES, STANDARDS AND PRACTICES

7.1 INTRODUCTION

A contract was issued to Koffel Associates, Inc. of Ellicott City, Maryland, to identify the current model building and fire codes that were available for application to a structure such as The Station nightclub, as well as to identify the model building codes in place at the time modifications were made to the structure. This chapter reproduces information supplied NIST by the contractor [1], much of it verbatim and without further attribution, although any conclusions and findings that are presented are solely those of NIST.

7.2 CODE HISTORY

Since the 1946 original construction of the building at 211 Cowesett Avenue in West Warwick, RI, numerous model codes have come and gone. Prior to 2000, most model codes were limited to regional adoption. Tables 7-1 and 7-2 summarize the model fire and building codes that were relevant to the structure over its history.

From the 1940's through the 1960's, the prevalent regional model building code in Rhode Island was the National Board of Fire Underwriters, later the *American Insurance Association (AIA) National Building Code (NBC)*, last published in 1976. AIA also published the *Fire Prevention Code (FPC)*, which was the prevalent model fire code in the region.

From the 1970's through the end of the century, the Building Officials and Code Administrators (BOCA) building code was the leading model code in the region. The BOCA fire code dominated during this period. The BOCA codes were originally named the *Basic Building Code (BBC)* and *Basic Fire Prevention Code (BFPC)*. In the 1980's, BOCA purchased the rights to the AIA codes. BOCA renamed their codes the *National Building Code (NBC)* and the *National Fire Code (NFC)*. While the names were that of the AIA codes, the content was that of the BOCA documents.

In 2000, the International Code Council (ICC) published the first *International Building Code (IBC)* and first *International Fire Code (IFC)*, both now published in 2003 editions [2, 3]. The ICC was formed by the merger of the three regional code writing organizations. As such the IBC replaced the NBC and the IFC replaced the NFC. From 2000 until the appearance of the NFPA building code, the IBC was the only model building code that was being developed and maintained in the United States.

The *Life Safety Code*, published by the National Fire Protection Association (NFPA) as *NFPA 101* [7[, deals with the aspects of life safety from fire as would a model building code. This code, with its predecessor document dating back to 1913, addresses requirements for both new and existing construction. *NFPA 101*, unless amended when adopted, does not permit existing conditions that pose a serious safety risks to remain unabated. Typically, building codes only regulate conditions that came into existence after the code was adopted. *NFPA 101* mandates a minimum level or standard of care for all buildings. In many cases, *NFPA 101* will require improvements to existing buildings.

NFPA has published a fire code since 1971 and began publishing a building code in 2003. The NFPA fire code, originally named the *Fire Prevention Code*, was renamed the *Uniform Fire Code* for the 2003 edition [4]. The NFPA building code, Building Construction and Safety Code, is a second model code

Table 7-1. Applicable Model Fire Code

Bldg. Permit Date	Description of Work	BOCA: Fire Code	NFPA 101	NFPA 1
July 27, 1967	Install paneling; rebuild two porches; install new sign	Basic Fire Prevention Code 1965	Life Safety Code 1967	
May 18, 1970	Roofing Paneling ect	Basic Fire Prevention Code 1970	Life Safety Code 1970	
October 18, 1971	Alterations and remodeling	Basic Fire Prevention Code 1970	Life Safety Code 1970	
November 15, 1974	Interior paneling and partitions	Basic Fire Prevention Code 1970	Life Safety Code 1973	
April 29, 1975	Exterior Alterations and Renovations	Basic Fire Prevention Code 1975	Life Safety Code 1973	
July 1, 1975	Addition 330ft^2	Basic Fire Prevention Code 1975	Life Safety Code 1973	
November 21, 1981	Request of Variation Under Building Code, not enclose stair to basement	Basic Fire Prevention Code 1981	Life Safety Code 1981	
Feburary 20, 1985	Remodel and renovation to existing restaurant	Basic/National Fire Prevention Code 1984	Life Safety Code 1985	Fire Prevention Code 1982
December 9, 1999	Notice of Construction without a permit	National Fire Prevention Code 1999	Life Safety Code 1997	Fire Prevention Code 1997
June 19, 2001	Repair front from car	National Fire Prevention Code 1999	Life Safety Code 2000	Fire Prevention Code 2000

Table 7-2. Applicable Model Building Code

Building Permits Dates	Description of Work	BOCA Building Code
July 27, 1967	Install paneling; rebuild two porches; install new sign	1965 Basic Building Code
May 18, 1970	Roofing Paneling ect	1970 Basic Building Code
October 18, 1971	Alterations and remodeling	1970 Basic Building Code
November 15, 1974	Interior paneling and partitions	1970 Basic Building Code
April 29, 1975	Exterior Alterations and Renovations	1975 Basic Building Code
July 1, 1975	Addition 330ft^2	1975 Basic Building Code
November 21, 1981	Request of Variation Under Building Code, not enclose stair to basement	1981 Basic Building Code
Feburary 20, 1985	Remodel and renovation to existing restaurant	1984 Basic/National Building Code
December 9, 1999	Notice of Construction without a permit	1999 National Building Code or IBC 2000
June 19, 2001	Repair front from car	1999 National Building Code or IBC 2000

developed and maintained in the United States. As such, it is included in the code analysis. The Building Construction and Safety Code is commonly known as *NFPA 5000* [5].

The older editions of the BOCA building code treated restaurants and nightclubs differently. To many, a restaurant and a night club may seem to pose similar risks; however, prior to 2000, the codes viewed restaurants and night clubs differently. Even though the codes classified nightclubs and restaurants in different occupancies, it is not always easy to distinguish between restaurants and nightclubs. Below are BOCA definitions of class A-1 and class A-2 structures [6]:

> **303.3 Use Group A-2 structures**: This use group includes all buildings and places of public assembly, without theatrical *stage* accessories, designed for occupancy as dance halls, nightclubs and for similar purposes, including all rooms, lobbies and other spaces connected thereto with a common *means of egress* and entrance.
>
> **303.4 Use Group A-3 structures**: This use group includes all buildings with or without an auditorium in which persons assemble for amusement, entertainment or recreation purposes as well as incidental motion picture, dramatic or theatrical presentations, lectures or other similar purposes without theatrical *stage* other than a raised *platform*; and which are principally occupied without permanent seating facilities, including art galleries, exhibition halls, museums, lecture halls, libraries, restaurants other than nightclubs, and recreation centers; and buildings designed for similar assembly purposes, including passenger terminals.

Facilities that have seating at tables and chairs for all patrons and serve food are typically considered as restaurants. Facilities that may have some seating and food service, but offer standing and gathering space are typically considered to be nightclubs. Either occupancy may have entertainment and a dance floor. As a tool to assist in determining if an establishment is a nightclub or restaurant, historically, local jurisdictions have compared amounts of food and alcohol served. The ratio of food to alcohol to be classified as one or the other varies between localities.

Converting from one to the other would trigger the change of occupancy provisions of the codes. Historically, the change of occupancy provisions of the BOCA codes required that the building meet the intent of the code for the new occupancy and not pose a greater hazard.

The 1955 National Building Code made no distinction between restaurants and nightclubs. The Code stated the following: "The provisions of this code based on occupancy also apply to conversions of existing buildings and structures or portions thereof from one occupancy classification to another, which would not apply to change from restaurant to nightclub."

It is clear that the proper classification of The Station at the time of the fire was as a nightclub. However, as of the writing of this document, the Town of West Warwick has not made either the historical, or most current, use and occupancy permit for the bar available. It is not possible to determine how the facility was being regulated. Also, it is not possible to determine how the facility was classified when changes occurred to the building. Without accurate knowledge of how the building was classified, assumptions regarding occupancy classification could lead to incorrect conclusions.

7.3 MODEL CODE ANALYSIS

The model code analysis was based upon the *International Building Code (IBC)* 2003 [2] edition and *Building Construction and Safety Code (NFPA 5000)* 2003 edition [5]. A comparison of the relevant sections of these codes is included as Table K-1 in Appendix K. In areas were the codes had dissimilar requirements the impact of both requirements were evaluated.

The *Life Safety Code (NFPA 101)* 2003 edition [7] is a code that addresses life safety issues primarily through regulation of egress and fire safety systems. The provisions of new construction in *NFPA 101* aligned with the requirements of *NFPA 5000*. (Note that the analysis did not include a comparison to *NFPA 101* for existing buildings) The *International Fire Code (IFC)* [3] and the *Uniform Fire Code (NFPA 1)* [4] are compared section by section in Appendix K, Table K-2.

Details on the changes to *NFPA 101*, the *Uniform Building Code*, the *Standard Building Code*, and the *BCMC* over the life of The Station and its previous incarnations were also tabulated in the final report from Arup Fire [8].

NIST's technical investigation did not focus on compliance or non-compliance with the specific state or local regulations in effect at the time of the fire, nor did it seek to find fault. Rather, the focus was on model codes and standards and how the design and operation of The Station compared with the guidance provided within them. The findings and recommendations from the NIST investigation are expected to be useful across the nation.

Relevant aspects of the national model building codes are discussed in this section, followed by comments (in italics) on the conditions in The Station that were documented during the analysis. ***It should be noted that the building code evaluation utilizes current building code requirements, which generally are not applied to existing buildings.***

7.3.1 Administration

IBC §105.1 mandates permits for enlarging, altering, repairing, or changing of the occupancy of any building. NFPA 5000 §1.7.6.1.1.1 maintains similar requirements.

> *Comment: Over the life of this building, it was rehabilitated numerous times. A number of the projects were permitted. Typically, descriptions of work included on building permits included Roofing Paneling [9], Alterations and remodeling [10], Addition 30.6 m^2 (330 ft^2) [11]*

Both IBC §109.1 and NFPA 5000 §1.7.6.6.1.3 demand any work that is required to have a permit issued to be inspected.

> *Comment: Limited inspection records for the building were available for review. The inspection records are of fire department inspections, not inspection records for the building department. The reports appear to be from inspections related to renewal of the bar's liquor license.*

NFPA 5000 §1.7.6.6.4 requires the records be maintained for each inspection. IBC §104.7 also mandates that reports of inspections be maintained for the period of time required for public records by the local authority.

7.3.2 Occupancy Classification

IBC §303.1 classifies the occupancy as a Group A-2. NFPA 5000 §3.3.371.1 classifies the space as an Assembly Occupancy.

> *Comment: The use of The Station is consistent with the IBC and NFPA 5000 occupancy classifications of Group A-2 and Assembly, respectively.*

7.3.3 Construction Type

IBC §602.5 classifies the building as Type VB construction. NFPA 5000 §7.2.6 classifies the building construction as Type V (000).

Comment: The construction of the building was unprotected wood frame.

The requirements, IBC Table 602 and NFPA 5000 Table 7.3.2.1, for fire resistance rating of exterior walls are consistent in both codes. In instances were the building is more than 3.05 m (10 ft) from the property line, exterior walls are not required to have a fire resistance rating. For a separation distance between the building and the property line of less than 3.05 m (10 ft), the codes require the exterior wall to have a 1-hour fire resistance rating.

Comment: The building was more than 3 m (10 ft) from the property line.

7.3.4 General Building Heights and Area

Both codes regulate the height and area of buildings based on occupancy of the building and construction type. IBC Table 503 limits the area of the Group A-2 Type VB buildings to 557 m^2 (6000 ft^2) and one story. NFPA 5000 Table 7.4.1 limits Assembly occupancies with occupant loads greater than 300 and less than 1000 persons of Type V (000) construction to 511 m^2 (5500 ft^2) and one story.

Comment: West Warwick tax records indicate the main floor of the building was 416 m^2 (4484 ft^2) and the basement was 78 m^2 (840 ft^2) [12]

Both codes allow an increase in the area based on open perimeter. The IBC also allows an increase in the height of the building based upon sprinkler protection. NFPA 5000 does not allow the increase in height for sprinklers in this instance.

Comment: The building was not sprinkler protected.

7.3.5 Interior Finish

Both model codes regulate interior finish materials based upon flame spread, smoke production, location in the building, and type of use or occupancy of the space. The IBC, Chapter 8 contains interior finish provisions; in NFPA 5000, they are contained in Chapter 10. ASTM E-84 [13] (or NFPA 255 [14]) is the principal test method used by both codes to characterize flame spread and smoke development. Both codes also allow for large scale testing of interior finishes in lieu of E-84. Tests such as NFPA 286 [15] meet the requirement for large scale testing.

IBC Table 803.6 and NFPA 5000 §16.3.3.3 require interior finishes such as wood paneling, wood sheathing boards, and bead board to have a flame spread rating equal to or less than 75 and a smoke development index equal to or less than 450. In sprinkler protected buildings, both codes allow the flame spread index to go up to 200.

In the IBC, plastics used as interior finish are regulated by IBC §2604. In NFPA 5000, cellular or foamed plastics used as interior finish are regulated by §10.4.3. The IBC requires foam plastics used as interior finish to be labeled, to have a flame spread index not to exceed 75, to have a smoke development index not to exceed 450, and to pass full scale testing. The large scale testing shall be related to the actual use configuration.

NFPA 5000 §10.4.3.1 requires large scale fire tests for foam plastic insulation. The tests must be representative of actual use conditions.

In 1949, no combustible wall or ceiling finish was permitted in public buildings and places of assembly and exits there from that would "spread flame over its surface more rapidly than over one-inch (nominal) wood boards covered with ordinary paint or varnish." This rather loose standard was replaced in the 1955 NBC by the E-84 test discussed above.

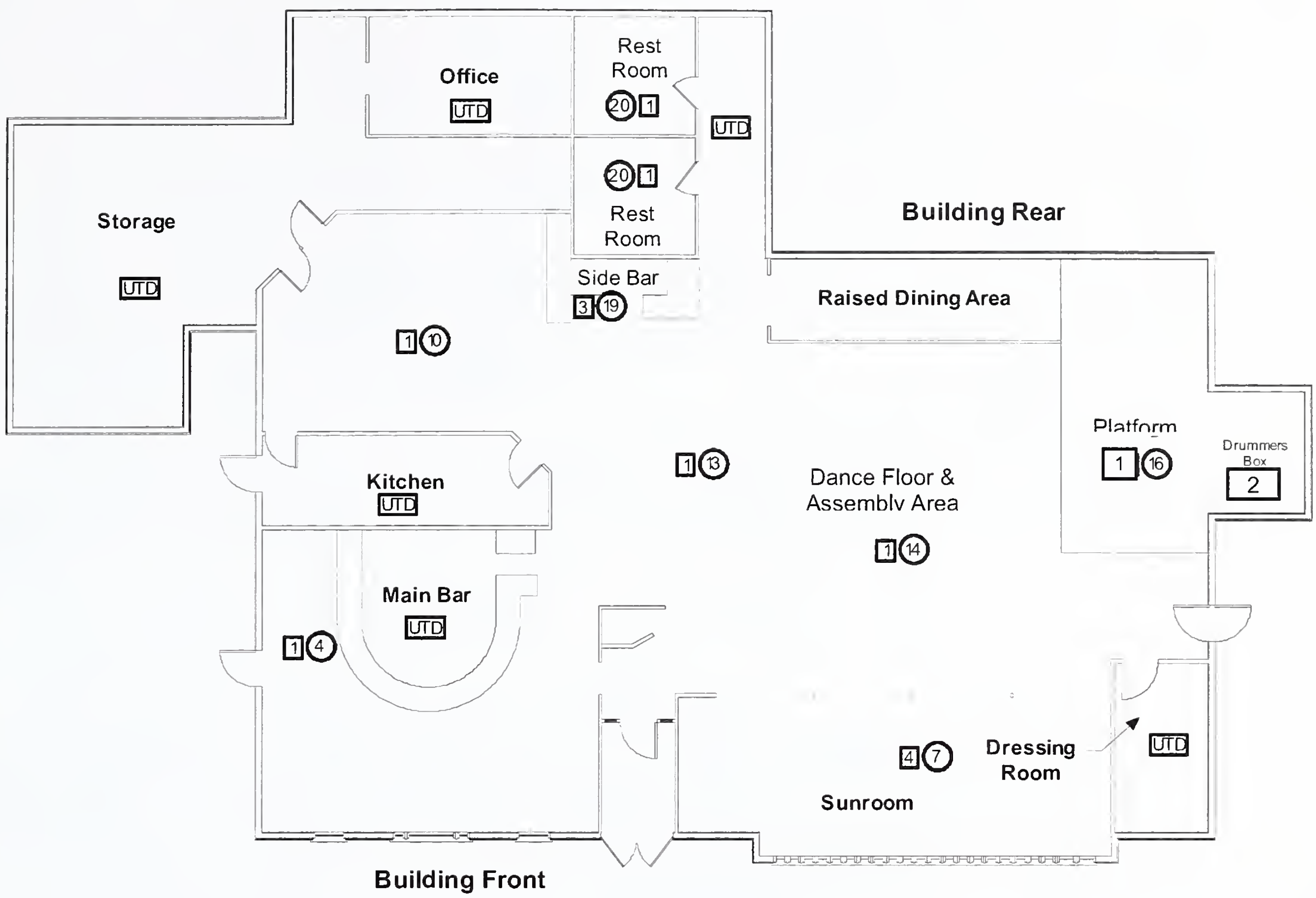
The interior finish requirements have changed little since the 1955 edition. The most significant change in 1967 tightened a previous exception for business occupancies by reducing the allowable flame spread in rooms or spaces less than 139 m^2 (1500 ft^2). In 1976, the allowable flame spread of exits in assembly occupancies was reduced, and dwellings were regulated for the first time. A separate section was added on floor coverings based upon a "flame propagation index". Neither smoke production nor toxicity has been regulated.

> *Comment: As would be expected, the interior finish materials of the building varied greatly. The interior finish material was mapped and is shown in Figures 7-1 and 7-2. The interior wall finishes included wood paneling, bead board, painted gypsum, wafer board, and ceramic tile. Interior finishes were identified from photographic and video records. The finishes identified were estimates based on a video and photographs taken in the building. The finishes referred to as painted gypsum may be either gypsum wall board or plaster. Neither samples of products nor model and manufacture information were available. Accordingly, conclusions regarding flame spread ratings are based upon broad product categories. The ceramic tile and gypsum do not pose potential interior finish flame spread issues.*
>
> *It appears that there were multiple types of wood paneling installed in the building. Portions of the wood paneling and bead board were painted. Wood paneling is manufactured with different flame spread ratings ranging from Class A to Class C. Many wood panelings are plywoods. Flame spread indexes for plywood range from 70 to 160 [16, 17]. Without knowledge of the specific paneling installed, it is not possible to determine the interior finish classification of the wood paneling at its time of installation. The natural aging and surface treatments applied after installation can dramatically affect the flame spread index of products. The bead board is subject to the same variations in flame spread index due to aging and surface treatments. Without samples to test the class of the interior finish, the flame spread index cannot be definitively stated for either the bead board or paneling. Untreated red oak flooring has a Class C interior finish rating (100 flame spread index).*
>
> *The walls surrounding the platform and the wall to the left of the platform were covered in expanded foam plastic insulation. Additionally, a portion of the ceiling over the platform and the ceiling in front of the platform were covered with expanded foam plastic insulation. The model codes allow foam plastic installation as an interior finish only after large scale testing has been conducted and successfully completed.*

7.3.6 Plastics

IBC regulates plastics in Chapter 26. Chapter 26 has provisions that complement the interior finish provisions in Chapter 8. NFPA 5000 Chapter 48 regulates all plastic materials used in or on buildings.

> *Comment: The tie between Chapters 48 and 10 is not as concise as with IBC. The provisions of IBC and NFPA 5000 are the same. The organization of these codes differ; however, the requirements are the same.*



*	Refer to Appendix _ for details
**	Blank Indicates No Wall Exists
***	UTD - Unable To Determine

Legend

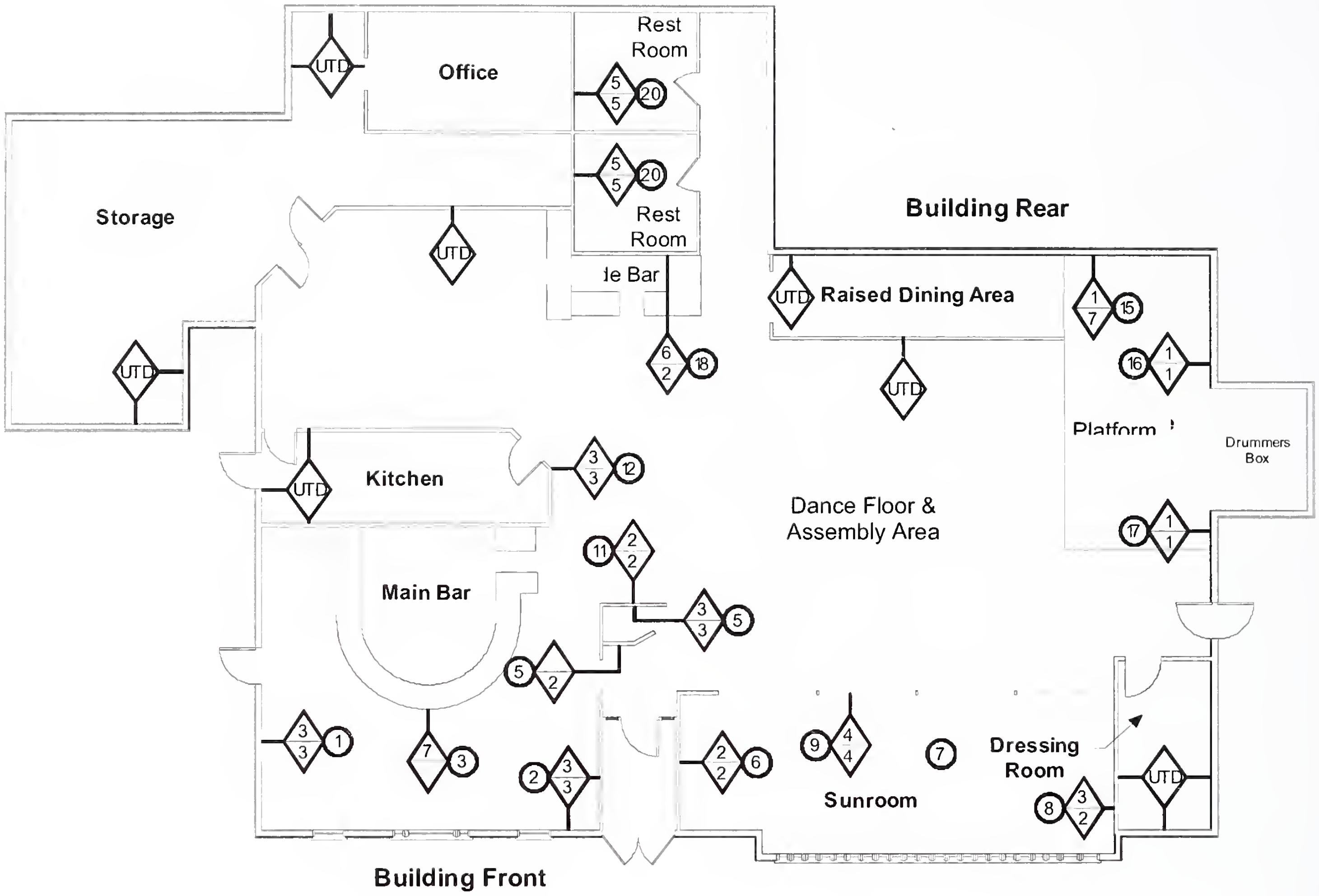
Ⓧ Bibliography of Photos

☒ Indicates Ceiling Type*

Legend of Ceiling Types

1 Acoustical Ceiling Tile
2 Foam
3 Wood Lattice
4 2x4 Rafters

Figure 7-1. Station Night Club Ceiling Interior Finish



*	Refer to Appendix _ for details
**	Blank Indicates No Wall Exists
***	UTD - Unable To Determine

Legend

- Ⓧ **Bibliography of Photos**
- Top portion of wall** / Bottom portion of wall** — **Indicates Wall Type***

Legend of Wall Types

1	Foam
2	Paneling
3	Gypsum
4	Waffer Boards
5	Ceramic Tile
6	Stucco
7	Bead Board

Figure 7-2. Station Night Club Wall Interior Finish

Foam plastic used as an interior finish shall be the tested in accordance with NFPA 286. During the NFPA 286 test, the room may not flashover nor may flames exit the enclosure. Additionally, total smoke production (a measure of the total surface area of the smoke particles per kg of fuel consumed) shall not exceed 1000 m^2. In the IBC, the requirements for foam plastic to be used as an interior finish are found in §2604.1. §2604.1 requires testing in compliance with §2603.8. §2603.8 requires large scale testing and compliance with Chapter 8 flame spread provisions. NFPA 5000 §48.4.4 contains the same provisions as IBC §2603.8.

Comment: The model codes prohibit the use of foam plastic insulation as an interior finish that does not pass a large scale test replicating end-use conditions. There is no indication that the foam used on the walls of The Station was tested.

7.3.7 Automatic Sprinkler System

For new construction, IBC §903.2.1.2 requires Group A-2 uses to be protected by automatic sprinklers if any of the following are exceeded:

- fire area > 1114 m^2 (12,000 ft^2)
- occupant load > 300 persons
- fire area located on other than the floor of exit discharge

NFPA 5000 §16.3.5.1.1 mandates automatic sprinkler protection for assembly occupancy serving more than 300 persons. Several exceptions are allowed. None of the exceptions are relevant to The Station.

Comment: The model codes trigger sprinkler protection for buildings based on a combination of factors including occupancy, building area, construction type, building height, location relative to exit discharge, and occupant load. ***For new construction*** *of this type of building, the model codes require sprinklers for an occupant load. in excess of 300 persons. The building was not equipped with an automatic sprinkler system.*

The BOCA National Building Code would have required sprinkler protection ***(for new construction)*** *based on the area and construction type of the building. The largest Type 5B Use Group A-2 building the BOCA National Building Code would have allowed is 390 m^2 (4200 ft^2), which is less than the area of The Station.*

7.3.8 Fire Alarm

IBC §907.2.1 requires manual fire alarm systems in Group A occupancies with occupant loads exceeding 300 persons. IBC §907.2.1.1 requires voice notification for Group A occupancies with occupant loads greater than 1000 persons.

NFPA 5000 §16.3.4 requires manual fire alarms in Assembly occupancies with occupant loads exceeding 300 persons. The fire alarm shall be activated by manual pull station, smoke detectors, the sprinkler system, and heat detectors in hazardous locations.

Comment: The building was equipped with a manual fire alarm. Manual pull stations were located adjacent to Door 3 and behind the main bar. Heat detectors were located in the area behind the kitchen. Heat detectors were present above and below the platform area. Fire alarm horns were located behind the main bar and in the front room near the pool tables.

7.3.9 Festival Seating

NFPA 5000 §3.3.474.1 defines "Festival Seating" as a form of audience/spectator accommodation in which no seating, other than a floor or ground surface, is provided for the audience/spectators gathered to observe a performance. NFPA 5000 §16.2.4.1 allows festival seating for assembly occupancies with less than 1000 occupants. IBC uses the term "standing room" rather than"festival seating."

> *Comment: At the time of the fire, the nightclub was arranged for festival seating, permitting more occupants than had the building been arranged for fixed seating.*

7.3.10 Exits

There were four exit routes from the building, as numbered in Figure 7-5: (1) the front main exit, (2) the main bar exit on the side, (3) the kitchen exit, and (4) the platform exit. The model codes govern their number, size, placement, and other details of design, as discussed in this section

(i) Doors

Doors shall provide a clear opening of at least 0.81 m (32 in), IBC §1008.1.1 and NFPA 5000 §11.2.1.2.4. Doors shall swing in the direction of egress travel when serving spaces with more than 50 persons, IBC §1008.1.2 and NFPA 5000 §11.2.1.4.2.

> *Comments: All doors exceeded the 0.81 m (32 in) minimum, and all door leaves swing in the direction of egress travel with the exception of the interior leaf at exit 4. (See Fig. 7-5.)*

(ii) Panic Hardware

IBC §1008.1.9 and NFPA 5000 §16.2.2.2.3 mandate panic hardware on doors that have locks or latches in the means of egress for assembly occupancies with an occupant load greater than or equal to 100 persons.

> *Comments: When viewed from the exterior, the right leaf of the front doors was not equipped with panic hardware. There was no visible hardware on either door. As of this writing, the type of hardware on the swinging door immediately inside the double exterior doors is undetermined. (See Fig. 7-5.)*
>
> *The door to exit 2 was equipped with panic hardware. As of this writing the type of hardware with which the door at exit 3 was equipped has not been determined. The inward swinging leaf of the door at exit 4 was fitted with standard knob style hardware. The outward swinging door was equipped with panic hardware.*

(iii) Floor Level and Landings

IBC §1008.1.4 and NFPA 5000 §11.2.1.3 mandate that the floor level on both sides of a door shall be at the same level. IBC §1008.1.5 and NFPA 5000 §11.2.2.3.2 also requires that the landing be at least as wide as the stair or door being served and the door when fully open may not reduce the required width of the landing by more than 0.18 m (7 in).

> *Comments: Based on photographic evidence and review of the video, the floor was level on both sides of the main door at exit 1. It could not be determined if the floor was level on both sides of the doors at exits 2 and 3. The floor was not level on both sides of door at exit 4. The first riser was in line with the plane of the closed door.*

There was not a landing at the exterior of exit 4. The photos of exit 2 indicate a landing outside the door, however, it cannot be determined if a step existed at the door. The photos indicate a stair at Door 3, but it could not be determined if a landing or risers were present at the door.

(iv) Exit Signs

Exit signs are required at exits other than obvious main exits, and at other locations where exit access is not obvious, per IBC §1011.1 and NFPA 5000 §11.10.1.4.

Comments: The nightclub was equipped with exit signs over each of the four doorways.

(v) Travel Distance

Both IBC §1018.1 and NFPA 5000 §16.2.6 require the travel distance to exits (the maximum distance from any place in the building to an exit) not exceed 61 m (200 ft). In the 1955 NBC travel distance in assembly occupancies was increased to 45.7 m (150 ft), up from 30.5 m (100 ft). In 1967 it was changed back to 30.5 m (100 ft).

Comment: The travel distance in this building was less than 61 m (200 ft).

(vi) Common Path of Travel

IBC §1013.3 states the common path of travel shall not exceed 22.8 m (75 ft). NFPA 5000 §16.2.5.1.2 limits the common path of travel to 6.1 m (20 ft) or less. Common path of travel is the portion of the means of egress that must be traversed until such a point that at least two independent means of egress to at least two exits are available.

Comment: If all doors to the exterior were considered exits, all areas complied with the model codes' common path of travel provisions.

If exit 4 is not considered an exit, over 50% of the sun room and dance floor area have a common path of travel greater than 6.1 m (20 ft).

Not considering exit 3 as an exit does not create additional common path of travel issues.

(vii) Exit Separation

NFPA 5000 §11.5.1.4 and IBC §1014.2.1 requires the exits to be separated by at least one half the length of the maximum overall diagonal dimension of the building area served.

Comments: The diagonal of the area served was 25.3 m (83 ft). The model codes require a separation of 12.6 m (41.5 ft). If all doors to the exterior were considered exits, the separation of exists in The Station would have been consistent with the model code provisions. Only Door 1 and Door 2 were consistent with the model code definition of an exit, and they were separated by 10.4 m (34 ft)t. Accordingly, when considering Doors 1 and 2 as the only exits the separation of exits was less than required in the model codes.

(viii) Dead Ends

IBC §1016.3 states that dead ends in relation to corridors shall not exceed 6.1 m (20 ft). NFPA 5000 §16.2.5.1.3 has the same limit.

While the passage way to the restrooms created a dead end 7.6 m (25 ft) long and the access aisle to the raised seating area was a dead end 7.3 m (24 ft) in length, neither were associated with corridors. No other dead ends existed.

7.3.11 Occupant Load Limits

The model codes compute the occupant load limits in two ways: based upon area, and based upon egress capacity. If the occupant load calculated via area exceeds the capacity of the egress system, the codes require the egress system to be expanded. The egress capacity must always exceed the occupant load.

(i) Area Basis

Occupant load factors are expressed in terms of square meters (feet) per person. Dividing the area of the space by the occupant load factor yields the allowable occupant load. The model codes use occupant load factors to determine the allowable number of persons given an area. The relevant occupant load factors from IBC Table 1004.1.2 and NFPA 5000 Table 11.3.1.2 are detailed in the following table.

Table 7-3. Occupant Load Factors, m^2/person (ft^2/person)

Occupancy/Use	IBC Table 1004.1.2 Occupant load factor	NFPA Table 11.3.1.2 Occupant load factor
Assembly, Concentrated (chairs only not fixed)	0.65 (7) net	0.65 (7) net
Assembly, Stand space	0.46 (5) net	0.65 (7) net
Assembly, Unconcentrated (tables and chairs)	1.39 (15) net	1.39 (15) net
Business area	9.28 (100) gross	9.28 (100) gross
Kitchens commercial	18.6 (200) gross	9.28 (100) gross
Stages and Platforms	1.39 (15) net	1.39 (15) net
Warehouse	46.4 (500) gross	based upon maximum probable number of occupants present

IBC §1004.2 allows the occupant load to be increased above the calculated number provided the other egress provisions are met and the occupant load does not exceed 0.46 m^2/person (5 ft^2/person). NFPA 5000 §11.3.1.3 and 16.1.6 contains similar provisions.

Both model codes allow the occupant load to be based on capacity of the means of egress provided each person has 0.46 m^2 (5 ft^2) of floor space. NFPA 5000 §16.1.6 limits the increased occupant density to 0.46 m^2/person (5 ft^2/person) net floor space for buildings up to 930 m^2 (10,000 ft^2) and to 0.65 m^2/person (7 ft^2/person) net floor space for buildings that are larger.Note that net space excludes restrooms, passageways, and space assigned for other uses such as the space behind the bars and the kitchens.

Comment: Refer to Figure 7-3 and Figure 7-4 for the use of spaces within the Station as defined by the model codes. Based upon those uses, the maximum load for each space is computed in Table 7-4. The total maximum occupancy of a building similar to The Station, according to IBC,

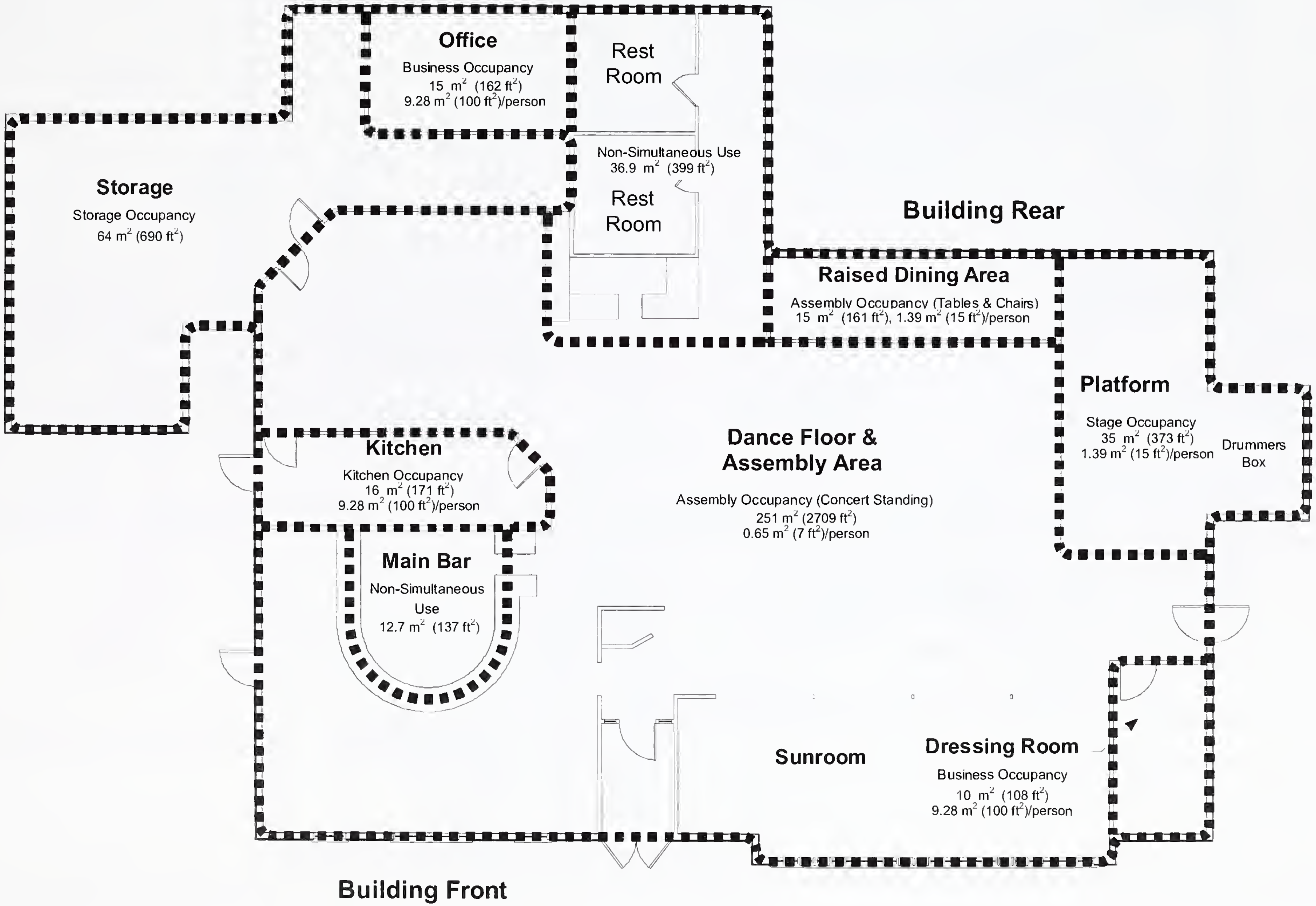


Figure 7-3. Station Nightclub (NFPA 5000) Use Area Designations

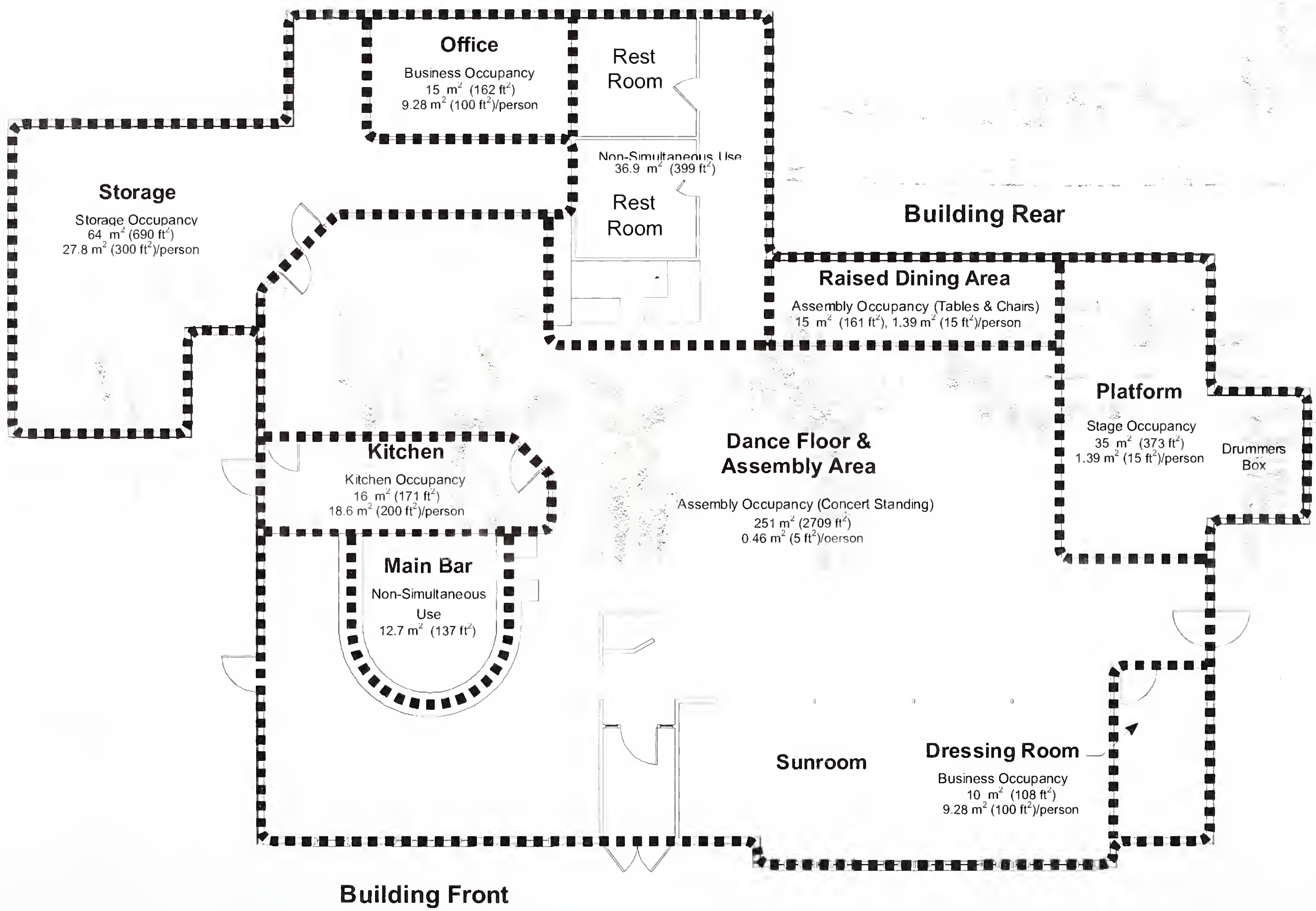


Figure 7-4. Station Night Club Fire (IBC) Occupancy Area Designations

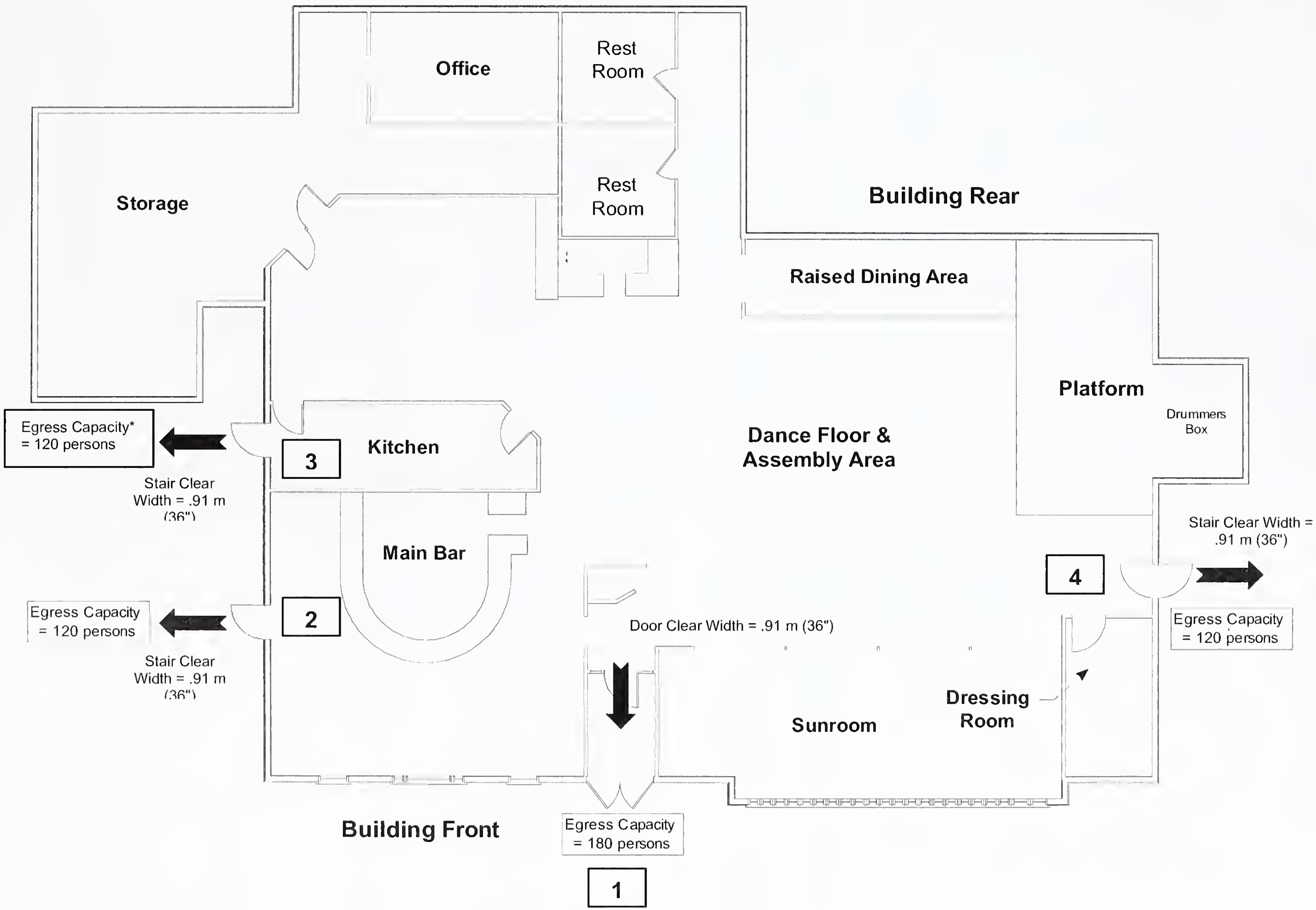


Figure 7-5. Station Nightclub Egress Capacity (*Note that model codes exclude exiting through a kitchen when calculating occupancy limit.)

Table 7-4. Computed Occupant Loads Based Upon Model Codes and Areas Shown in Figures 7-3 and 7-4

Use	Area, m^2 (ft^2)	IBC capacity*	NFPA 5000 capacity*
Assembly Standing	251 (2709)	542	387
Business	25 (270)	3	3
Platform	35 (373)	25	25
Kitchen	16 (171)	1	1
Storage	64 (690)	3	3
Assembly T/C	15 (161)	11	11
Total	**406 (4374)**	**585**	**430**

* Note that conversion between metric and common units can lead to a variation of about 1 % in capacity

would have been 585 persons; a similar calculation based upon the NFPA 5000 occupant load factors yields a total maximum population of 430 persons. The significant differences arise from NFPA 5000 allowing the use of 0.65 m^2/person (7 ft^2/person) for concentrated assembly occupancy. IBC uses 0.46 m^2/person (5 ft^2/person) for standing assembly space. NFPA 5000 does have a provision that allows the occupant load to be increased to match the available egress capacity. Typically, the table value of 0.65 m^2/person (7 ft^2/person) is used. Both codes would allow these occupant loads, if the exit capacity were available.

(ii) Egress Basis

Egress capacity factors are related to the minimum clear width required for exit pathways in order to ensure timely egress, and are expressed in terms of mm/person (in/person). The egress capacity factors for level egress components and ramps are smaller than factors for stairways. The smaller this factor, the more occupants the egress component is given credit to manage. IBC Table 1005.1 and NFPA 5000 Table 11.3.3.1 contain the capacity factors for egress elements. Clear widths are divided by egress capacity factors to yield the maximum capacity for that particular egress element. The IBC reduces the required width when a building is fully sprinkler protected, as shown in Table 7-5. IBC and NFPA 5000

Table 7-5. Egress Capacity Factors

Occupancy	Without Sprinkler System, mm/person (in/person)		With Sprinkler System, mm/person (in/person)	
	IBC Table 1005.1	NFPA 5000 Table 11.3.3.1	IBC Table 1005.1	NFPA 5000 Table 11.3.3.1
Level Components and Ramps	5.1 (0.2)	5.1 (0.2)	3.8 (0.15)	5.1 (0.2)
Stairways	7.6 (0.3)	7.6 (0.3)	5.1 (0.2)	7.6 (0.3)

[a] Dimensions estimated from photographs to the nearest 1/2 in (12 mm)

[b] Model codes exclude exiting through a kitchen when computing occupancy limit

[c] Small increases within the uncertainty of our estimates of the sizes of the clear width of the stairs and doors could increase the total capacity to 426.

require the number of occupants to be less than the capacity of the available egress width, and both codes require two means of egress for buildings with a total occupant load of less than 501 persons. IBC §1008.1.2 and NFPA 5000 §11.2.1.4.2 contain requirements that doors swing in the direction of egress travel in the path of egress from assembly occupancies serving occupant loads of greater than 50 persons.

Comments: The building was not sprinkler protected.

See Table 7-6 and Figure 7-5 for capacities of each exit. As required by both model codes, the element with the smallest capacity in each path of egress was considered to be the limiting element. The limiting element dictated the capacity of each egress path. For the main entrance, exit 1, the interior 914 mm (36 in) door was the limiting element, resulting in a capacity of 180 persons for the main entrance exit. For exit 2, the side door out of the main bar area, the exterior stairs leading from the door were the limiting element, resulting in a capacity of 120 persons. Exit 3, from the kitchen, was also limited by an exterior stair; however, both codes prohibit egress by patrons through the kitchen (IBC §1013.2 and NFPA 5000 §11.5.2.1) Exit 4 adjacent to the platform had two doors installed on the same jam, one swinging in the direction of egress travel and one swinging opposing the direction of travel. Excluding the kitchen exit and including the exit adjacent to the platform, the occupancy limit based upon egress capacity would have been 420 according to both model codes. (See Table 7-6.)

Table 7-6. Egress-limited Occupant Load Calculations (IBC and NFPA 5000)

Element	Width,[a] mm (in)	Clear Width,[a] mm (in)	Capacity Fac., mm/person (in/person)	Capacity[c], persons	Limiting Element
Exit 1 - main					
Front Door	1829 (72)	1727 (68)	5.1 (0.2)	340	no
Interior Door	914 (36)	914 (36)	5.1 (0.2)	**180**	**yes**
Stairs (4 risers)	2540 (100)	2438 (96)	7.6 (0.3)	320	no
Ramp	2540 (100)	2438 (96)	5.1 (0.2)	480	no
Exit 2 - bar					
Side Door	914 (36)	914 (36)	5.1 (0.2)	180	no
Stairs (4 risers)	1016 (40)	914 (36)	7.6 (0.3)	**120**	**yes**
Exit 3 - kitchen[b]					
Side Door	*914 (36)*	*914 (36)*	*5.1 (0.2)*	*180*	*no*
Stairs (4 risers)	*1016 (40)*	*914 (36)*	*7.6 (0.3)*	*120*[b]	*yes*
Exit 4 - platform					
Side Door	914 (36)	914 (36)	5.1 (0.2)	180	no
Stairs (4 risers)	965 (38)	914 (36)	7.6 (0.3)	**120**	**yes**
			total egress limit	**420**[c]	

7.4 REFERENCES FOR CHAPTER 7

[1] "Code Analysis of the Station Nightclub," KA 03732-004, Koffel Associates, Inc., Ellicott City, MD, June, 2004.

[2] *2003 International Building Code,* International Code Council, Inc., Falls Church, VA.

[3] *2003 International Fire Code,* International Code Council, Inc., Falls Church, VA.

[4] *NFPA 1, Uniform Fire Code*, National Fire Protection Association, Quincy, MA, 2003.

[5] *NFPA 5000, Building Construction and Safety Code*, National Fire Protection Association, Quincy, MA, 2003.

[6] *The BOCA National Building Code/1993, Twelfth Ed.,* Building Officials and Code Administrators, Inc., Homewood, IL.

[7] *NFPA 101, Life Safety Code*, National Fire Protection Association, Quincy, MA, 2003.

[8] "Evaluation of Limitations to Egress through Doorways in Emergency Situations," vol. 2, Ove Arup & Partners Massachusetts Inc., Job number 32979, Westborough MA, Feb. 18, 2004.

[9] West Warwick, Rhode Island, Building Permit May 18, 1970.

[10] Building Permit October 18, 1971.

[11] Building Permit July, 1, 1975.

[12] West Warwick, Rhode Island Commercial /Industrial Property Record Card May 30, 2001.

[13] *ASTM E84-00a, Standard Test Method for Surface Burning Characteristics of Building Materials*, American Society for Testing & Materials, West Conshohocken, PA, 2001.

[14] *NFPA 255, Standard Method of Test of Surface Burning Characteristics of Building Materials*, National Fire Protection Association, Quincy, MA, 2002.

[15] *NFPA 286, Standard Methods of fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*, National Fire Protection Association, Quincy, MA, 2002.

[16] American Wood Council. Design for Code Acceptance. awc.org/publications/dca/dca1/dca1.pdf

[17] Canadian Wood Council. Cwc.ca/design/tech_topics/fire/spread_ratings.html

Chapter 8
SUMMARY, FINDINGS AND RECOMMENDATIONS

8.1 SUMMARY OF INVESTIGATION

Under the authority of the National Construction Safety Team Act, a team was formed by the NIST Director on Feb. 27, 2003 to investigate the failure seven days earlier of The Station nightclub in West Warwick, Rhode Island. The objectives of the investigation were the following:

- to establish the likely technical cause or causes of the building failure;
- to evaluate the technical aspects of evacuation and emergency response procedures;
- to recommend, as necessary, specific improvements to building standards, codes, and practices based on the findings made pursuant to the duties listed above; and
- to recommend any research and other appropriate actions needed to improve the structural safety of buildings, and improve evacuation and emergency response procedures, based upon the findings of the investigation.

The following activities were undertaken by the team to reach the first two objectives and to establish the basis for the remaining two:

- identification of technical issues and hypotheses requiring investigation through consultations with experts in fire protection engineering, emergency evacuation, and members of other teams investigating The Station fire;
- data collection from local authorities, contractors and suppliers, building and fire protection design documents, records, plans, and specifications, video and photographic data, telephone and radio transmissions, field data, a limited number of interviews and other oral and written accounts from building occupants and emergency responders, and other witnesses as reported by the news media;
- analysis and comparison of national model building and fire codes and practices, as well as review and analysis of practices used in operation of the building;
- simulation and analysis of phenomena (with associated uncertainties), including fire spread, smoke movement, tenability, occupant behavior and response, evacuation issues, and operation of active and passive fire protection systems; and
- testing to provide additional data and validate computer simulation predictions.

The previous seven chapters of this final report describe the methodology used to conduct the investigation, detail what occurred on the night of Feb. 20, 2003, review the history of the building and the model codes and standards that would have applied to a building of this type, and present the results of testing and simulations. The key findings from the investigation are summarized in the following section. Recommendations for improving model building and fire standards, as well as codes, and practices are listed in Section 8.3; Section 8.4 describes actions already taken by local authorities and code making organizations. Research recommendations and other appropriate actions are provided in Section 8.5.

8.2 FINDINGS

During the course of the investigation NIST examined relevant model building and fire codes; previous incidents with some similar aspects that occurred in places of assembly; the life safety systems that were part of the building design; the materials used as part of the structure, as finish products and as building contents; the egress process; and the response of the fire department to the incident. NIST developed new information or confirmed published reports as to the initiating event, the reasons for the very rapid spread of fire and smoke, the difficulties encountered by the occupants during egress, and the mass casualty situation confronted by the fire department. Many of the findings summarized in this section had a direct bearing on the tragic outcome of this specific event (these are highlighted below in bold); others had a more peripheral role but are important to capture because of the potential to positively influence the outcome of future events.

8.2.1 Model Codes and Standards

Appendix C recounts dozens of other tragedies in nightclubs and places of assembly where adherence to U.S. model building and fire codes could have prevented the failure of the building. Of most relevance to the current incident are the Happy Land Social Club fire [17], the Gothenburg Dance Hall fire [18], the Café de Hemel fire [19], and the E2 Nightclub crowd crush incident [20]. These events killed between 14 and 87 people each, with the root causes related to limitations on exits, overcrowding, an unanticipated initiating event, and (except for E2) building contents and materials -- all conditions that are inconsistent with the 2003 model building and fire codes.

The following is the primary finding of the investigation regarding model codes and standards:

- **The investigation concluded that strict adherence to 2003 model codes available at the time of the fire would go a long way to preventing similar tragedies in the future. Changes to the codes subsequent to the fire made them stronger. By making some additional changes – and state and local agencies adopting and enforcing them – we can strengthen occupant safety even further.**

8.2.2 Materials

The hazardous mix of materials present in The Station were key contributors to the failure of the building. Specific findings regarding the foam on and in the walls and the pyrotechnics used in the performance are listed below:

- **A non-fire retarded foam sample purchased by NIST ignited within 10 seconds when exposed to a pyrotechnic device (15x15 gerb) in an arrangement similar to the set up on the platform of the nightclub. When a plywood panel with fire retarded polyurethane foam was exposed in a similar manner to a 15 x 15 gerb, no ignition of the panel occurred, nor did the plywood ignite with no foam present.**
- **As could be seen in the WPRI video, flames spread rapidly over the foam in the nightclub, generating smoke and enough heat (estimated to be almost 60 MW at its peak) to ignite the wood paneling underneath and adjacent to the foam. The wood paneling in the nightclub was estimated to contain over 95 % of the fuel load, so that once most of the foam was consumed (estimated to be around two minutes after ignition of the foam), the fire transitioned to a wood frame building fire, with a steady heat release rate estimated to be around 45 MW.**

- **There was no fire resistant barrier between the interior of the nightclub and foam thermal insulation which had been installed in the stud space on the interior side of external walls of the drummer's alcove.**
- **In the reconstruction of the *platform area fire* conducted at NIST, within 90 seconds after ignition of the non-fire retarded polyurethane foam conditions near the middle of the dance floor at head height (1.5 m, or 5 ft, above the floor) were lethal. (Temperature exceeded 460 °C (860 °F), carbon monoxide volume fractions reached 1 percent, hydrogen cyanide levels exceeded 0.07 percent, oxygen volume fraction fell to 9 percent, and radiant heat flux exceeded 40 kW/m^2.)**
- **NIST could not obtain samples of the foam that actually had been applied to the nightclub walls to conduct a chemical analysis to determine if the polyurethane material contained fire retardants; however, the ignition behavior of the foam exhibited on the WPRI video was consistent with the behavior observed in the NIST testing with a non-fire retardant foam.**
- Model codes require that foamed plastic material used as an interior finish pass large-scale fire tests that substantiate the combustibility characteristics of the material related to the actual end use.
- Model codes permit the use of pyrotechnic devices in nightclubs if certain precautions are taken and with the approval of the authority having jurisdiction.
- The average heat flux from the gerbs purchased by NIST impinging on a surface was determined to be much less than the average heat flux from the fire to the foam surface, once ignition of the foam had occurred.
- The heat release rate from foam samples found at the site and representative materials purchased by NIST ranged between about 250 kW/m^2 and 1100 kW/m^2 when exposed to radiant fluxes between 20 kW/m^2 and 70 kW/m^2 in a cone calorimeter.
- The carpet and furnishings contributed a relatively small amount to the fire, and the ceiling tiles a negligible amount.

8.2.3 Fire Protection Systems

An inadequate capability to suppress the fire during its early stage of growth was another direct contributor to the large loss of life. The following was found regarding the installation and operation of fire suppression and other safety systems applicable to the building:

- **Experiments conducted at NIST in a reconstruction of the platform area fire demonstrated that a water sprinkler system installed in the test room in accordance with NFPA 13 [1] was able to control the fire initiated in non fire retarded polyurethane foam panels and maintain tenable (survivable) conditions at head height in the test room for the duration (over five minutes) of the experiment. This was in contrast to the reconstruction of the platform area fire with no sprinklers present, which led to likely fatal conditions at head height in the test room in about 1-1/2 minutes. A computer simulation of the full nightclub with and without sprinklers led to a similar positive result for the sprinklered scenario.**

- **Automatic fire sprinklers were not installed in The Station nightclub, nor were they required for such existing structures under the 2003 editions of the model codes.**
- **A heat detection/fire alarm system was installed in The Station nightclub, which activated (sound and light strobe) 41 seconds after ignition of the polyurethane foam, by which time the crowd had already begun to move toward the exits.**
- Several hand-held fire extinguishers were located on the premises, at least one of which was used in an attempt to extinguish the fire on the platform.
- Standard exit signs were located above each exit.
- The building was equipped with emergency egress lighting.
- The kitchen was equipped with a dry powder fire suppression system above the stove.

8.2.4 Occupant Load and Egress

The inability of the exits to handle all of the occupants in the short time available for such a fast growing fire was the third major contributor to the substantial loss of life in The Station. Specific findings regarding the occupant load and egress process are presented here.

- **The first patrons recognized the fire danger about 24 seconds after ignition of the foam; the bulk of the crowd began to evacuate shortly after that, around the time the band stopped playing (30 seconds).**
- **The rate of egress from the main entrance at the front of the building was limited by the single doorway inside the vestibule, not the double doors visible from the outside.**
- **Between 56 percent and 66 percent of the occupants appear to have attempted to leave through the single main entrance in the front of the building; many were unsuccessful.**
- **Prior to 1-1/2 minutes into the fire, a crowd-crush occurred in the front vestibule which almost entirely disrupted the flow through the front exit. The precise event which led to the crowd-crush likely was related to the arrangement of the single interior door with merging streams of traffic and the pressure to escape the rapidly deteriorating conditions in the main area of the nightclub.**
- **Measurements of temperature, heat flux and gas species in a reconstruction of the platform area fire at NIST and computer models of the NIST experiment and the full nightclub suggest that the conditions around the platform, dance floor, sunroom, and dart room would have led to severe incapacitation or death within about 1-1/2 minutes after ignition of the foam for anyone remaining standing, and for not much longer even close to the floor.**
- **The number of building occupants at the time of the fire was reported by the Providence Journal to be 440 [2]; as reported by the Associated Press [42], the prosecutor's office claimed that 458 occupants were present.**
- The Station had three doors suitable for exit by occupants.
- The main area of the nightclub around the platform was open with very few chairs, stools or tables, consistent with a festival seating arrangement. Based upon the arrangement, number

and , geometry of the exits, the occupant limit for a similar building would be 420 persons according to both NFPA 5000 [3] and the International Building Code [4].

- For more than a minute into the fire, the crowd moved in an orderly fashion at an egress rate estimated to be a bit faster than 1 person/second through the main entrance of the building.
- It was reported by the Providence Journal that a little over half of all people who successfully escaped via the doors (main entrance, main bar, kitchen and platform doors) exited via the main entrance.
- The windows in the main bar room and the sunroom became the secondary routes of escape once the main entrance became impassible, and, according to reports, they accounted for over 1/3 of the successful evacuations.
- The high number of victims found relatively close to the windows in the sunroom suggests that the environment became untenable more quickly than the victims were able to find a secondary route (e.g., through the sunroom windows) once the platform door and main entrance became unusable.
- The small number of victims found in the main bar room suggests that the main bar room exit door and windows provided open routes of escape up to the point where conditions in that area of the building became untenable.
- A computer model of The Station nightclub fire suggests that the conditions in the main bar area near the floor may have been survivable for more than three minutes after ignition, which is consistent with the WPRI video that showed people being assisted through the main bar windows up to 4 minutes after the start of the fire.
- A significant number of victims were found in the dart room, storage area, and office near the back of the building, suggesting that they (1) were unfamiliar with the building and hoped to find a safe exit in that region, (2) did not realize that an exit existed inside the kitchen, or (3) became disoriented while heading for the side exit of the main bar room.
- An interior door which opened inward was located at the platform exit, but the orientation of the door did not play a role in delaying the evacuation process since the rapid fire growth in that vicinity discouraged patrons from attempting to escape via the platform door exit.
- A preexisting exit adjacent to the lavatories at the back of the structure had been eliminated during some previous construction.
- The Team found no evidence of a written emergency action plan, a written fire prevention plan, or employee training to assist safe and orderly evacuation.
- No evidence was found that a uniformed firefighter was on the premises at the start of the fire; however, two off-duty West Warwick police officers were known to be present, including one who called in the fire from within the building.

8.2.5 Emergency Response

Given the hazardous mix of materials in The Station and the lack of installed sprinklers, nothing that the fire department could have done that night would have saved the building from the fast growing fire. Based upon the findings below, however, there are still things to learn from the incident regarding emergency response procedures:

- The first 911 call reporting a fire was before 11:09 pm, less than 40 seconds after ignition of the foam.
- **West Warwick police officers on the scene reported the fire about one minute after ignition of the foam, leading to the dispatch of four engines with six fire fighters and three fire officers, a tower-ladder truck with two fire fighters, a rescue unit with two attendants, and a battalion chief.**
- **The first fire engine, staffed with one firefighter and a fire officer, was confirmed on-scene less than five minutes after the first 911 call was received, which was well within the limits of the NFPA standard [5] that states the fire department should be able to respond to a call within six minutes at least 90 percent of the time.**
- NFPA standards [5] recommend a minimum staffing level of four firefighters on both engine and truck companies, which was not achieved. Additional firefighters on scene at the crucial initial phase of the response would have benefited the rescue and firefighting efforts, although NIST is unable to say how the outcome might have been altered.
- Rhode Island's fire/rescue, emergency medical services and law enforcement agencies were confronted with the largest life loss fire incident in the State's history.
- Mutual aid agreements with neighboring jurisdictions were effective in bringing the necessary resources (equipment and emergency responders) to the scene of the incident.
- A mass casualty plan was implemented capably within about 10 minutes of arrival of the first engine on the scene, such that within two hours of the start of the fire, all occupants needing medical attention had been evacuated from the scene and transported to medical facilities.
- Because of the ongoing criminal investigation, the medical examiner's reports that may have revealed the likely causes of death of the 100 victims of the fire were not available to NIST.
- Communications challenges resulting from limited radio equipment capabilities and the high volume of traffic substantially hampered the Incident Command's effective coordination of fire ground and triage operations, as well as the routing of responding EMS units to area hospitals.

8.2.6 Public Building Record-keeping Practices

Inspections and record-keeping practices are an integral part of a community fire safety program. Findings related to this area that are relevant to The Station fire include the following:

- Records were not found of the initial building design. Records of modifications -- when located -- lacked sufficient detail to track the changes to the structure.
- Neither the historical nor most current use and occupancy permit for the building was located; however, the use of The Station was consistent with the IBC and NFPA 5000 occupancy classifications of "Group A-2" and "Assembly," respectively.
- The main deficiencies of the building identified during the history of inspections by the Town of West Warwick related to the location of the fire extinguishers, non-functioning exit signs and emergency lights, broken panic hardware on an exit door, and the direction of swing of an exit door.

- On numerous reports, deficiencies identified by the inspectors were later annotated as "OK," but with no official re-inspection signature.
- No Town of West Warwick or State of Rhode Island documents prior to Feb. 20, 2003, were located that mentioned foam materials on the walls of the nightclub, nor the use of pyrotechnics similar to those used on Feb. 20, 2003.

8.2.7 Referenced Codes and Standards

Tables 8-1, 8-2, and 8-3 list, respectively, the model codes and standards in the areas of materials, fire protection systems, and occupant load and egress that relate to the findings of the NIST investigation team. Table 8-4 summarizes the issues surrounding applications of the code, and building and fire safety practices. References are to the appropriate sections/paragraphs in the current International Building Code [4], the Life Safety Code [7], NFPA 5000 [3], and the standards contained therein. (The relevant sections in the International Fire Code and the Uniform Fire Code can be linked to the corresponding sections in the International Building Code and NFPA 5000 through the Tables provided in Appendix K.) The last column indicates the relevance of the issue to the outcome on Feb. 20, 2003. Based upon the computer simulations and other findings from the investigation, an "H" was assigned to issues that, properly addressed, were highly relevant and would almost certainly have reduced substantially the loss of life (these are also highlighted in bold); an "L" implies a low likelihood that addressing the issue would have reduced the loss of life for this particular incident; and "M" implies moderate relevance to the specifics of this particular incident. Consideration by the model code organizations and the building and fire safety professions for those actions marked as "L," while not linked tightly to the outcome of The Station fire, is still warranted. In some cases, actions may be called for that are not even addressed in the model codes as currently written; the code sections identified in Tables 8-1 through 8-4 are not meant to be inclusive.

Table 8-1 Findings Concerning Materials Relevant to Model Codes and Standards

Issue	References	Relev. H	M	L
Polyurethane foam used as sound insulation on platform and walls. Foam thermal insulation unprotected in back platform wall.	**ASTM E84 [9]**	X		
	NFPA 255 [11]	X		
	NFPA 286 [10]		X	
	IBC:2604 [4]		X	
	5000:10.4.3.1 [3]		X	
Pyrotechnic devices were used as part of the theatrics. **Little guidance provided to AHJ* regarding appropriate use of pyrotechnics.**	**NFPA 1126 [12]**	X		
Unknown fire rating on wood paneling.	IBC:803.6 [4]			X
	5000:16.3.3.3 [3]			X

* Authority Having Jurisdiction

Table 8-2 Findings Concerning Fire Protection Systems Relevant to Model Codes and Standards

Issue	References	Relev. H	M	L
Automatic sprinklers not required for existing structures.	**101:13.3.5.1 [7]**	X		
	5000:16.3.5.1.1 [3]	X		
	IBC:903.2.1.2 [4]	X		
	101.12.3.5.1 [7]			X
Fire alarm system unable to alert people to hazard quickly enough to avoid trapping occupants in building.	IBC:907.2.1 [4]		X	
	5000:16.3.4 [3]		X	
Portable fire extinguishers ineffective/not used early in fire.	NFPA 10 [8]		X	

Table 8-3 Findings Concerning Occupant Load and Egress Relevant to Model Codes and Standards

Issue	References	Relev. H	M	L
Main entrance did not have capacity to handle 50% of the occupants on the night of the fire, and 50% would have been insufficient to safely evacuate all occupants in time (1-1/2 minutes).	**IBC:1024.2 [4]** **5000:16.2.3.3 [3]** **101:12.2.3.3 [7]** **101:13.2.3.3 [7]**	X		
Festival seating overloaded the exit capacity.	**5000:16.2.5.4.1 [3]** **101:12.2.5.4.1 [7]** **101:13.2.5.4.1 [7]** **5000:16.2.4.1 [3]**	X X X X		
Trained crowd managers not required for occupant loads < 1000.	101:12.7.5 [7] 101:13.7.5 [7]		X X	
Higher occupant load factor permitted in IBC.	IBC:1004.2 T [4] 5000:11.3.1.2 T [3]		X X	
Lower egress capacity factor permitted in IBC if sprinklers are installed.	IBC:1005.1 T [4] 5000:11.3.3.1 T [3]		X X	
Location of alternative exits not obvious to patrons unfamiliar with nightclub, in spite of proper exit signs above doors.	IBC:16.4.7.5 [4] 5000:11.10.1.4 [3]		X X	
Longer common path of travel allowed in IBC.	IBC:1013.3 [4] 5000:16.2.5.1.2 [3]		X X	
Interior leaf of platform door did not swing in direction of egress.	IBC:1008.1.1 [4] 5000:11.2.1.4.2 [3]			X X
Stairs and landings at side exits may not have been at same level on both sides of doors.	IBC:1008.1.4 [4] 5000:11.2.1.3 [3]			X X
Main entrance double doors not equipped with panic hardware.	IBC:1008.1.9 [4] 5000:16.2.2.2.3 [3]			X X

Table 8-4 Findings Relevant to National Practices

Issue	References	Relev. H	M	L
Automatic sprinklers not required in many existing structures.	**IBC:903.2.1.2 [4]** **5000:16.3.5.1.1 [3]**	X X		
Polyurethane foam used as sound insulation on platform and walls.	**education, practice**	X		
Model codes can provide a meaningful level of safety only when adopted, practiced, and enforced by local jurisdictions.	**policy, practice**	X		
Model codes attempt to deliver reasonable safety but do not guarantee safety of occupants in all anticipated situations.	policy		X	
Criteria for optimum allocation of resources among routine inspections, prevention programs, and emergency response not established.	policy, practice, research		X	
Inspection reports not maintained.	101:12.7.1 [7] 101:13.7.1 [7]		X X	
	IBC:104.7 [4] 5000:1.7.6.6.4 [3]			X X
Portable fire extinguishers ineffective/not used early in fire.	training, practice			X
Stairs and landings at side exits may not have been at same level on both sides of doors.	IBC:1008.1.4 [4] 5000:11.2.1.3 [3]			X X
Main entrance double doors not equipped with panic hardware.	IBC:1008.1.9 [4] 5000:16.2.2.2.3 [3]			X X
Details of work not included in permits, or permits not obtained.	IBC:105.1 [4] 5000:1.7.6.1.1 [3]			X X
No indication that building was inspected following completion of work.	IBC:109.1 [4] 5000:1.7.6.6.1.3 [3]			X X

8.3 RECOMMENDATIONS FOR IMPROVING MODEL STANDARDS, CODES, AND PRACTICES

The general public expects that the model code upon which their community depends will protect them in public buildings from severe hazards (that can be anticipated). The investigation concluded that strict adherence to 2003 model codes available at the time of the fire would go a long way to preventing similar tragedies in the future. Changes to the codes subsequent to the fire made them stronger. By making some additional changes – and state and local agencies adopting and enforcing them – we can strengthen occupant safety even further. It is important to note that neither of the 2003 model codes were required to be followed at the time of The Station fire, and that NIST did not examine the code actually in force in West Warwick on Feb. 20, 2003, because the goal of the investigation was to understand how the incident happened, how it progressed, and how changes could be made in standards, codes and practices to avoid similar outcomes.

Adoption of a model code, in and of itself, is not sufficient to guarantee the safety of a building, however, since the source of a building failure that leads to significant loss of life usually can be traced to a breakdown in one or more of the following key assumptions upon which the model codes are based:

(1) that the building designer, constructor, owner, operator, staff and patrons adhere to all applicable code provisions; (2) that the authorities having jurisdiction (AHJs) properly interpret and aggressively enforce the code provisions; and (3) that the historical record is a reliable predictor of worst case events.

Recognizing this, model codes need to be robust and more redundant to minimize the chances of loss of life caused by the failure of a building that is out compliance, or is operating out of compliance, with code provisions. Adequate performance of the structure should be ensured even when one of the protective systems is compromised by uncertain behaviors of the building owner or occupants such as the following:

a) installing building decorations or temporary features that greatly exceed flame spread or fire load provisions;

b) exposing the building to strong ignition sources;

c) exceeding the posted occupancy limits;

d) temporarily blocking an exit; and

e) disabling sprinklers or other life safety systems for maintenance.

Recommendation 1

The findings presented above and the recommendations that follow raise a number of issues concerning model codes and standards, and the practices surrounding their adoption, application, and enforcement. NIST will work with the major organizations representing state and local officials – including mayors, state legislators, and county executives, as well as building and fire officials—to encourage them to seriously consider the recommendations of this report. As a starting point, state and local jurisdictions need to establish a sufficient building code infrastructure.

NIST recommends that all state and local jurisdictions:

a) adopt a building and fire code covering nightclubs based on one of the model codes (as a minimum requirement), and update local codes as the model codes are revised;

b) implement aggressive and effective fire inspection and enforcement programs that address: (i) all aspects of those codes; (ii) documentation of building permits and alterations; (iii) means of egress inspection and record keeping; (iv) frequency and rigor of fire inspections, including follow-up and auditing procedures; (v) and guidelines on recourse available to the inspector for identified deviations from code provisions; and

c) ensure that enough fire inspectors and building plan examiners are on staff to do the job and that they are professionally qualified to a national standard such as NFPA 1031 [14].

Recommendation 2

The results of the investigation clearly demonstrated the value of an NFPA 13 compliant automatic fire sprinkler system in extending the time the nightclub remained tenable. Recommendation 2 mirrors the action already taken by NFPA to strengthen the requirement for sprinklers in new and existing nightclubs and festival seating venues.

NIST recommends that model codes require sprinkler systems, and that state and local authorities adopt and aggressively enforce this provision:

a) for all new nightclubs regardless of size, and

b) for existing nightclubs with an occupancy limit greater than 100 people.

Recommendation 3

Limitations on the flammability of materials used as finish products in nightclubs are included in both model codes, with specific references to NFPA 286, ASTM E-84, and/or NFPA 255. These standards and the sections of the codes that refer to them are the focus of recommendation 3.

In relation to the fire performance of finish materials and building contents, NIST recommends:

a) that state and local authorities adopt and aggressively enforce the existing provisions of the model codes;

b) that non-fire retarded flexible polyurethane foam, and other materials that ignite as easily and propagate flames as rapidly as non-fire retarded flexible polyurethane foam, (i) be clearly identifiable to building owners, operators, contractors, and authorities having jurisdiction (regulatory agencies)[1]; and (ii) be specifically forbidden, with no exceptions, as finish materials from all new and existing nightclubs;

c) that NFPA 286 be modified to provide more explicit guidance to building owners, operators, contractors, and authorities having jurisdiction for when large-scale tests that are covered in NFPA 286 are required to demonstrate that materials (other than those already forbidden in b above) do not pose an undue hazard for the use intended; and

d) that ASTM E-84, NFPA 255, and NFPA 286 be modified to ensure that product classification and the pass/fail criteria for flame spread tests and large-scale tests are established using the best measurement and prediction practices available.

Recommendation 4

Most pyrotechnic devices produce temperatures high enough to ignite certain materials, including non-fire retarded flexible polyurethane foam, if the device is in close proximity to the material. NFPA 1126, *Use of Pyrotechnics before a Proximate Audience*, is a model standard that provides "requirements for the protection of property, operators, performers, support personnel, and the viewing audiences where pyrotechnic effects are used..." [12] The provisions in NFPA 1126 are designed to prevent an incident such as the one that occurred in The Station nightclub on Feb. 20, 2003. Because it is not possible for the authority having jurisdiction to continuously monitor what materials are brought into a nightclub, and where they may be placed relative to a pyrotechnic device, the model code should be unequivocal on those situations in which pyrotechnic devices are simply not permitted.

NIST recommends that NFPA 1126 be strengthened as described below, and that state and local authorities adopt and aggressively enforce the revised standard:

a) Pyrotechnic devices should be banned from indoor use in new and existing nightclubs not equipped with an NFPA 13 compliant automatic sprinkler system.

b) NFPA 1126 should be modified to include a minimum occupancy and/or area for a nightclub below which pyrotechnic devices should be banned from indoor use, irrespective of the installation of an automatic sprinkler system.

c) Plans for the use of indoor pyrotechnics in new and existing nightclubs should be posted on site; and in addition to the items listed in para. 4.3.2 of NFPA 1126, should describe the

[1] For example – all non-fire retarded polyurethane foam could be formulated with bright red or orange coloring to indicate that it is not a fire retarded product and may ignite easily and propagate flames rapidly.

measures that have been established to provide crowd management, security, fire protection, and other emergency services.

d) Section 6.6.2 of NFPA 1126 should be modified to require a minimum clearance between

(1) the nearest fixed or moveable contents, and

(2) any part or product (igniter, spark, projectile, or debris) of a pyrotechnic device permitted for indoor use in new and existing places of assembly,

to be twice the designed projection of the device, until such time that studies show that a smaller minimum clearance can guarantee safe operation in spite of the possibility that building decorations or temporary features that greatly exceed flame spread or fire load provisions of the fire code may occur.

Recommendation 5

The rationale for changes in egress provisions includes the realization that the impact of smoke, heat, and gases on human behavior during evacuation is not known; that mobility challenged persons take longer to evacuate; that other fire safety systems may be non-functional; and that threats other than fire can require rapid evacuation. Given the uncertainty in human behavior, and uncertainties in fire hazard calculations and egress analysis during an emergency, the code should ensure that the margin of safety on the time required to evacuate a nightclub accounts for the maximum reasonable uncertainty in these predictions. NIST found the conditions in The Station to be untenable in less than 1-1/2 minutes.

NIST recommends that the factor of safety for determining occupancy limits of all new and existing nightclubs be increased in the model codes in the following manner, and that state and local authorities adopt and aggressively enforce these provisions:

a) Within the model codes, establish the threshold building area and occupant limits for egress provisions using best practices for estimating tenability and evacuation time; and, unless further studies indicate another value is more appropriate, use 1-1/2 minutes as the maximum permitted evacuation time for nightclubs similar to or smaller than The Station.

b) Compute the number of required exits and the permitted occupant loads assuming at least one exit (including the main entrance) will be inaccessible in an emergency evacuation.

c) For nightclubs with one clearly identifiable main entrance, increase the minimum capacity of the main entrance to accommodate 2/3 of the maximum permitted occupant level (based upon standing space or festival seating, if applicable) during an emergency.

d) Eliminate trade-offs between sprinkler installation and factors that impact the time to evacuate buildings.

e) Require staff training and evacuation plans for all nightclubs that cannot be evacuated in less than 1-1/2 minutes.

f) Provide improved means for occupants to locate emergency routes -- such as explicit evacuation directions prior to the start of any public event, exit signs near the floor, and floor lighting -- for when standard exit signs become obscured by smoke.

Recommendation 6

Portable fire extinguishers, if readily available to someone properly trained, can be effective early in a fire and delay fire spread in the event the sprinkler system is not functioning.

NIST recommends that a study be performed to determine the minimum number and appropriate placement (based upon the time required for access and application in a fully occupied building) of portable fire extinguishers for use in new and existing nightclubs, and the level of staff training required to ensure their proper use.

Recommendation 7

As in all mass causality events, especially those where the window of opportunity for rescue is extremely limited, effective and efficient communications within and among the various responding agencies is imperative. Developing effective interoperable communications requires addressing numerous factors, including frequent use of interoperable communications equipment and procedures, formal governance and collaboration, formal standard operating procedures, appropriate technology, and multi-agency training and exercises. Tools and best practice models addressing many of these success factors, including a statewide communications interoperability planning methodology, are available though the Department of Homeland Security's SAFECOM Program [24], and through model standards such as those listed below.

To ensure an effective response to a rapidly developing mass casualty event, NIST recommends that state and local authorities adopt existing model standards on communications, mutual aid, command structure and staffing, such as:

a) NFPA 1221, Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems [15]

b) NFPA 1561, Standard on Emergency Services Incident Management Systems [16]

c) NFPA 1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments [5]

d) NFPA 1720, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments [13]

8.4 ACTIONS ALREADY TAKEN

The magnitude of the incident at West Warwick invoked a swift response by code developing organizations as well as by the State of Rhode Island. A number of the most critical recommendations from NIST presented above already have been enacted, either on a temporary emergency basis or as a permanent change to the codes. Some NIST recommendations have been addressed only partially, while aspects of others have been proposed and rejected by code bodies. Table 8-5 provides a cross-walk between the recommendations from NIST and the actions already taken that are discussed below.

(i) National Fire Protection Association

The Standards Council of NFPA held hearings to consider Tentative Interim Amendments (TIAs) to address certain life safety issues raised by The Station fire. The TIAs dealt with sprinklers, occupancy levels, crowd management, and means of egress. The following TIAs, and the NFPA Code section to which they apply, were approved in July 2003:

- Sprinkler existing nightclub type facilities and festival seating venues with occupant loads greater than 100 (TIA #739R, 101: 13.3.5.1 [7])
- Sprinkler new nightclub type facilities and festival seating venues (TIA #741R, 101:12.3.5.1 [7], and TIA #743R, 5000: 16.3.5.1.1 [3])
- Require trained crowed managers for existing and new assembly occupancies (TIA #738, 101:12.7.5 [7] and 101:13.7.5 [7])
- Restrict festival seating in new and existing facilities if occupant load is greater than 250 unless life-safety evaluation conducted (TIA #737R, 101:12.2.5.4.1 [7] and 101:13.2.5.4.1 [7]; and TIA #740R, 5000:16.2.5.4.1 [3]).
- Require of owner means of egress inspection and record keeping (TIA #742R, 101:12.7.1 [7] and 101:13.7.1 [7]).

(ii) International Code Council

A number of proposals for code changes related to The Station fire incident were submitted to the ICC at its September 2003 public hearing. One proposal, to require foam plastics covered with a textile or vinyl facing to pass a flame spread test (proposal FS108-03/04) [4], was approved.

Several proposals were aimed at increasing the capacity of the main entrance and the area requirement per occupant:

- Proposal E101-03/04 to eliminate 300 occupant minimum before requiring 50% capacity for main entrance, and increasing capacity requirement to 67%
- Proposals E102-03/04 and E103-03/04 to increase capacity of main entrance to 75% and 67%, respectively.
- Proposal E11-03/04 to increase area required per occupant from 0.47 m^2 (5 ft^2) to 0.65 m^2 (7 ft^2)
- Proposal E13-03/04 to eliminate sprinkler trade-offs with egress width requirement

These proposals were disapproved, primarily due to lack of technical justification to substantiate the change. The recommendations for research presented later in this chapter were made to address this issue.

(iii) State of Rhode Island

The State of Rhode Island acted quickly to examine its own building and fire codes. A special legislative commission was formed, held hearings, and delivered its report to the governor on June 5, 2003 [21]. Quoting from the letter of transmittal, five actions were identified to improve building standards, codes, and practices:

- "Require the use across the board of up-to-date fire safety codes -- this will require the elimination of the 'grandfather clause'-- and the coordinated administration of fire safety building codes.

Table 8-5. Actions taken by model code bodies and State of Rhode Island

NIST Recommendation	Related Action Taken	Comments
1. Adopt and enforce model codes	RI adopted NFPA 1 and NFPA 101	
	NFPA TIA #742R	NFPA action encompassed within broader NIST recommendation, needs formal proposal
	RI strengthened fire marshal's enforcement power	critical aspect of NIST recommendation
2. Strengthen requirement for sprinklers	NFPA TIA #739R NFPA TIA #743R	NIST recommendation mirrors NFPA modification
	RI strengthened regulation requiring sprinklers	based upon occupant load of 150 rather than 100, some exemptions
3. Strengthen restrictions on foam plastic finish materials	ICC FS108-03/04	ICC action deals with one aspect of foam plastic finish materials; NIST recommendation is broader, needs formal proposal
4. Strengthen restrictions on use of pyrotechnics	RI strengthened restrictions on pyrotechnics	same objectives as NIST recommendation, needs formal proposal
5. Increase factor of safety on egress	NFPA TIA #737R NFPA TIA #738	NIST recommendation is broader, based upon egress time rather than occupant load; some research required before formal proposal is submitted

NIST Recommendation	Related Action Taken	Comments
6. Conduct portable fire extinguisher study	RI increased number required in stage areas	Study needs to be conducted before formal proposal can be prepared
7. Adopt and practice communication, response, command structures, and staffing guidelines already established	no code modifications needed	more local and state jurisdictions should consider adopting and practicing guidance already in model codes and standards
8. Conduct research to understand human behavior better in emergency situations	none	multi-agency effort needed
9. Conduct research to understand fire spread and suppression better	none	work ongoing at NIST and elsewhere
10. Conduct research to refine computer-aided decision tools	none	work ongoing at NIST and elsewhere

- Prohibit the use of pyrotechnics in places of assembly such as nightclubs and strictly regulate their use in large venues...that can accommodate them safely.
- Mandate sprinklers in nightclubs with an occupancy of 150 or greater and in all Class A and B places of assembly, except places of worship and state and municipal buildings used for government purposes and place other requirements on nightclubs as high risk places of assembly.
- Provide greater enforcement powers to fire marshals to assure their ability: a) to make inspections, b) to require immediate abatement of conditions that pose an imminent threat to public safety or property and when necessary to order a premises vacated, and c) to inspect of nightclubs and other places of assembly during their actual hours of operation.
- Establish comprehensive planning requirements to identify in the future the weaknesses in Rhode Island's approach to fire safety and to recommend actions needed to improve fire safety."

The Fire Safety Code of the State of Rhode Island was amended significantly by The Comprehensive Fire Safety Act of 2003 [22] to address these five items and other issues discussed in the June 5 Report. Among the most significant changes was the adoption by Rhode Island of the Uniform Fire Code (NFPA 1) [5] and the Life Safety Code (NFPA 101) [7], which now includes the provisions of TIAs #737R, 738R, 739R, 740R, 741R, 742R, and 743R. All new and existing places of assembly in Rhode Island with a capacity greater than 300 will be required to be completely protected by an approved automatic sprinkler as of July 1, 2005. For new and existing buildings similar to The Station nightclub with occupancy less than 301 but greater than 150, the deadline for installing sprinklers is July 1, 2006. Additional provisions in The Comprehensive Fire Safety Act of 2003 include the requirement for two 20 pound fire extinguishers in stage areas and the strengthening of inspection authority for the Fire Marshal.

8.5 RESEARCH RECOMMENDATIONS AND OTHER APPROPRIATE ACTIONS

This investigation focused on The Station nightclub. Several recommendations in this report relate directly to nightclub structures, and other recommendations apply more broadly. Model building code organizations as well as state and local regulatory authorities should review the results of this investigation and consider the findings regarding sprinklers, egress, and materials flammability as they make revisions to their codes.

The acceptance by the model code and standards organizations of the recommendations being made by NIST and the adoption of modified provisions of the national model codes into the local code depend upon the strength of the technical evidence when weighed against the economic impact of implementing the change. There are a number of areas where the benefits may be obvious and the costs of implementation to the property owner and community can be computed easily. In those areas, to apply a particular provision of the code or not becomes a local policy decision that is not necessarily hindered by a lack of information available to the decision-maker.

There are other areas in which the basis for making the change is unsupported by data or technical rigor. Research is often needed in order to gain new knowledge and collect the data necessary to ensure that such changes are adopted if justified, or rejected if not. Research results also serve as the basis for setting thresholds or pass/fail criteria.

8.5.1 Recommendations for Research

NIST is required, under the NCST Act, to identify areas of research needed to support improvements to model building codes, standards and practices. Based upon the findings of this investigation and the resultant recommendations presented in section 8.3, additional research is recommended in three general areas:

- human behavior and people movement,
- material behavior and fire spread, and
- decision aids.

Recommendation 8

A basic tenet of our model codes is that public buildings should be designed and operated in a manner that assures there is enough time for occupants to evacuate safely for an anticipated worst case fire. In addition, we need to determine the desired behavior of occupants when faced with an unanticipated extreme event. Crowd-crush as observed in The Station fire also occurred in the E-2 [18] nightclub in Chicago the week prior to The Station incident, killing 21 people even though there was no fire, or even a real threat to the occupants. There is a need to understand better the behavior of people and crowds in emergency situations to pinpoint the factors that lead to crowd crush. This would enable sensible changes in building design to minimize the possibility of crowd crush, and improved ways to communicate to the crowd in emergency situations that go beyond the code, in direct support of recommendation 5.

NIST recommends that research be conducted to better understand human behavior in emergency situations, and to predict the impact of building design on safe egress in fires and other emergencies (real or perceived), including the following:

a) ***the impact of fire products (gases, heat, and obscuration) on occupant decisions and egress speeds;***

b) ***exit number, placement, size and signage;***

c) ***conditions leading to and mitigating crowd-crush;***

d) ***the role of crowd managers and group interactions;***

e) ***theoretical models of group behavior suitable for coupling to fire and smoke movement simulations; and***

f) ***the level of safety that model codes afford occupants of buildings.***

Recommendation 9

The behavior of people in a fire emergency and the time they have to escape depend upon the speed at which the fire spreads. Significant progress has been made in our ability to model the dynamics of a fire moving through a building, as evidenced by the simulations of The Station fire presented in this report. However, the state of the technology is insufficient to *accurately* model, in general, the spread of fire over common composite structures such as foam insulation on plywood, fabric covered foam furnishings, or gypsum covered wood frames. The detailed mechanisms for the formation of toxic products and smoke are extremely complex and are not amenable for inclusion in predictive fire models. Instead, it is necessary to rely on scientific experiments and real-scale fire testing of products and room geometries that are similar to what existed in the actual event to develop the empirical data required as input to computer fire models. This can be an impossible task for a fire that has occurred in a very large space, or when the fire totally destroys the structure along with the key evidence necessary for a reasonable recreation.

The time available for safe egress is influenced by the building geometry and ventilation system, the materials of construction and furnishings, and actions to suppress the fire. Predicting sprinkler activation and suppression and the influence of fire fighting activities on the spread of the fire is another aspect of the problem that cannot be done today to any but the grossest level of precision.

NIST recommends that research be conducted to understand fire spread and suppression better in order to provide the tools needed by the design profession to address recommendations 2, 3, and 5, above. The following specific capabilities require research:

a) prediction of flame spread over <u>actual</u> wall, ceiling and floor lining materials, and room furnishings;

b) <u>quantification</u> of smoke and toxic gas production in realistic room fires; and

c) development of generalized models for fire suppression with fixed sprinklers and for firefighter hose streams.

<u>Recommendation 10</u>

New knowledge, data, and predictive methods generated in the above research will lead to new technologies and improved fire standards. The selection among alternative fire safety technologies or building design options, and the setting of threshold values in the model codes, can have significant economic ramifications. New tools are needed that can be tailored to the individual stakeholder that rigorously account for cost in a manner transparent to competing interests. This research would be of particular value to implementing recommendations 1 and 7, above.

NIST recommends that research be conducted to:

a) refine computer-aided decision tools for determining the costs and benefits of alternative code changes and fire safety technologies, and

b) develop computer models to assist communities in allocating resources (money and staff) to ensure that their response to an emergency with a large number of casualties is effective.

8.5.2 Impact of Research

Completing the research recommended will put a sound technical foundation under the changes to codes, standards and practices that have already been made or are suggested. Specifically, a comprehensive research program would lead to an ability to:

- evaluate the impact of changing egress capacity and occupant load factors on the minimum time available for safe evacuation;
- quantify the value of increasing the size of the main entrance to handle a greater fraction of the occupant load;
- determine the relationship between flame spread rating on finish materials and fire spread in actual buildings;

- predict the smoke and toxic gas levels to a much greater level of precision, and the ramification of these fire products on occupant movement;
- quantify the value of sprinklers in places of assembly with different occupant loads, and compare the performance of alternative designs;
- investigate different strategies for managing crowds under various threat types and levels;
- supplement training for firefighters, fire marshals, other emergency responders, code officials, and crowd managers; and
- educate building owners, their employees and the general public on approaches to remain safe in places of assembly.

8.6 REFERENCES FOR CHAPTER 8

[1] *NFPA 13, Standard for the Installation of Sprinkler Systems*, National Fire Protection Association, Quincy, MA, 2002.

[2] *Providence Journal*, "In the Fire," p. B4, February 20, 2004.

[3] *NFPA 5000, Building Construction and Safety Code*, National Fire Protection Association, Quincy, MA, 2002

[4] *2003 International Building Code*, International Code Council, Inc., Country Club Hills, IL, 2002.

[5] *NFPA 1710, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, National Fire Protection Association, Quincy, MA, 2001.

[6] *NFPA 1, Uniform Fire Code*, National Fire Protection Association, Quincy, MA, 2003.

[7] *NFPA 101, Life Safety Code*, National Fire Protection Association, Quincy, MA, 2003.

[8] *NFPA 10, Standard for Portable Fire Extinguishers*, National Fire Protection Association, Quincy, MA, 2002

[9] *ASTM E84-00a, Standard Test Method for Surface Burning Characteristics of Building Materials*, American Society for Testing & Materials, West Conshohocken, PA, 2001.

[10] *NFPA 286, Standard Methods of fire Tests for Evaluating Contribution of Wall and Ceiling Interior Finish to Room Fire Growth*, National Fire Protection Association, Quincy, MA, 2002.

[11] *NFPA 255, Standard Method of Test of Surface Burning Characteristics of Building Materials*, National Fire Protection Association, Quincy, MA, 2002.

[12] *NFPA 1126, Use of Pyrotechnics before a Proximate Audience*, National Fire Protection Association, Quincy, MA, 2002

[13] *NFPA 1720, Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments,* National Fire Protection Association, Quincy, MA, 2001.

[14] *NFPA 1031,Professional Qualifications for Fire Inspector and Plan Examiner,* National Fire Protection Association, Quincy, MA, 2003.

[15] *NFPA 1221, Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems,* National Fire Protection Association, Quincy, MA, 2002.

[16] *NFPA 1561, Standard on Emergency Services Incident Management Systems,* National Fire Protection Association, Quincy, MA, 2002.

[17] *NFPA Alert Bulletin*, "Social Club Fire Bronx, New York". Number 90-2, May 1990.

[18] *NFPA Fire Investigation Report, Dance Hall Fire, Gothenburg, Sweden*, National Fire Protection Association, Quincy, MA, 1998.

[19] Lostetter, S.M.O., and Reijman, P.B., "Reconstruction of the Fire in 'de Hemel' in Volendam, New Years Eve 2000/2001," Interflam 2004.

[20] Johnson, Mark, *Chicago Club had been told to Close*, Milwaukee Journal Sentinel, 18 Feb. 2003.

[21] "Making Rhode Island the Safest State," Report to the Rhode Island General Assembly, June 5 2003.

[22] Comprehensive Fire Safety Act of 2003, Chapter 23-28, Amendment to the General Laws, Health and Safety, SECTION 2. Title 23.

[23] Associated Press, March 28, 2005.

[24] http://www.safecomprogram.gov/SAFECOM/