Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

The fire fighter was located in this area after the collapse.

Executive Summary

On May 8, 2013, a 29-year-old male career probationary fire fighter died after running out of air and being trapped by a roof collapse in a commercial strip mall fire. The fire fighter was one of three fire fighters who had stretched a 1½-inch hoseline from Side A into a commercial strip mall fire. The hose team had stretched deep into the structure under high heat and heavy smoke conditions and was unsuccessful in locating the seat of the fire. The hose team decided to exit the structure. During the exit, the fire fighter became separated from the other two crew members. The incident commander saw the two members of the hose team exit on Side A and called over the radio for the fire fighter. The fire fighter acknowledged the incident commander and gave his location in the rear of the structure. The fire fighter later gave a radio transmission that he was out of air. A rapid intervention team was activated but was unable to locate him before a flashover occurred and the roof collapsed. He was later recovered and pronounced dead on the scene.

Contributing Factors

- *Risk assessment*
- *Communications*
- *Crew integrity*
- *Fire fighter ran out of air in an IDLH atmosphere*
- *Staffing and deployment*
- *Arson fire in a commercial structure*
- *Lack of automatic fire sprinklers*

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

Key Recommendations

- *Fire departments should ensure that an initial risk assessment is performed and continuous risk assessment is performed throughout the incident and the strategy and tactics match the conditions encountered.*
- *Fire departments should ensure that fire fighters are trained to understand the influence of building design and construction on structural collapse.*
- *Fire fighters and officers should ensure critical benchmarks, such as progress or lack of progress, are communicated to the incident commander and that positive communication discipline are used.*
- *Emergency fireground conditions should be communicated and acknowledged on the fireground and radio discipline maintained.*
- *Fire departments should ensure that crew integrity is maintained during fire suppression operations.*
- *Fire departments should ensure adequate staffing and deployment of resources based on the community's risk assessment.*
- *Fire departments should ensure that fire fighters and officers are properly trained in air management.*
- *Fire departments should ensure that fire fighters are properly trained in out-of-air SCBA emergencies and SCBA repetitive skills training.*
- *Fire departments should ensure fire fighters are properly trained in Mayday procedures and survival techniques.*
- *Fire departments should ensure that fire fighters are trained in situational awareness, personal safety, and accountability.*
- *Code-setting organizations and municipalities should consider requiring the use of sprinkler systems in commercial structures.*

For further information, visit the program Web site at www.cdc.gov/niosh/fire or call toll free 1-800-CDC-INFO (1-800-232-4636).

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

Introduction

On May 8, 2013, a 29-year-old male career probationary fire fighter died after running out of air and being trapped by a roof collapse in a commercial strip mall fire. On May 8, 2013, the U.S. Fire Administration notified the National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research, Fire Fighter Fatality Investigation and Prevention Program of the incident. On May 20–25, 2013, two NIOSH investigators traveled to Michigan to conduct an investigation. Two engineers from the NIOSH National Personal Protective Technology Laboratory (NPPTL) also traveled to the site to assist in the examination of the self-contained breathing apparatus (SCBA) and personal protective equipment (PPE). The NIOSH investigators met with the assistant fire chief and senior staff of the fire department, fire marshal's office, the International Association of Fire Fighters local union, and the fire communication center. The investigators reviewed fire department standard operating procedures, training records from the department, radio channel printouts plus audio radio transmissions. During the investigation, witness statements were reviewed and interviews were conducted with the fire fighters and fire officers involved in the incident. The NIOSH investigators inspected and photographed the SCBA and personal protective clothing (turnout gear) of the fire fighter, which was under control of the local police department. NIOSH investigators recommended that the SCBA be sent to the NIOSH lab in Bruceton, Pennsylvania for further evaluation. The turnout gear was sent to the NIOSH lab in Morgantown, West Virginia, for further evaluation.

Fire Department

The fire department involved in this incident has 5 fire stations with 85 members, who serve a population of approximately 100,000 within an area of about 25 square miles. The department operates 5 engines, 1 ladder truck, and 5 advanced life support ambulances and has 1 battalion chief.

The department also provides emergency medical services (EMS) and advance life support and responds to approximately 14,000 fire and EMS incidents annually.

The department has automatic and mutual aid agreements with surrounding fire departments for additional resource needs, three of which responded to this incident.

Training and Experience

The department requires all fire fighters to complete NFPA Fire Fighter 1 and 2 training, driver training, hazardous materials awareness and operations training, and emergency medical training.

The fire fighter in this incident had approximately 10 months of experience as a professional fire fighter with this department. He had completed the department's required training and had additional training noted below:

- Fire Fighter 1 and 2
- Hazmat First Responder-Awareness
- Hazmat First Responder-Operations
- FEMA ICS-100
- FEMA ICS-200 for Health Care/Hospitals
- FEMA NIMS IS-00700.a

Additionally, the fire fighter had a number of hours of station-level training in his records, which included training on engine operations, fire fighter survival, hand tools, hose and ladder operations, power tools, pump operations, SCBA, and ventilation. He also had a number of hours of station level EMS training, directives, hazmat, standard operating guidelines (SOGs), and other station-level training.

The department provides training at the station level and makes available to its fire fighters training facilities outside of the jurisdiction. The department has a training officer who manages the required monthly training schedule. The department does not have a dedicated live-burn facility (burn building or smoke house) to conduct annual practical live fire training. The department does have access to a mobile flashover trainer and has conducted live fire training using the flashover trainer.

Equipment and Personnel

The initial dispatch (by radio) assignment included Engine 1 with two fire fighters (E-1 is a 55-foot Quint), Ladder 1 with two fire fighters (L-1 is a 134-foot articulating bucket), Rescue 1 with two fire fighters (R-1 is a medical unit), Engine 2 with two fire fighters (E-2), and the acting BC 1 with two fire fighters. The acting BC rode in E-1 while his aide took the battalion vehicle to the scene. Engine 3 was assigned to Side C (75-foot Quint) and Rescue 3 was assigned to Side C.

The following automatic mutual aid units responded for the 1st alarm assignment:

- Rescue 6, assigned to RIT on Side A
- Engine 1021, assigned to Side C

Timeline

This timeline is provided to set out, to the extent possible, the sequence of events according to recorded radio transmissions. Times are approximate and were obtained from review of the dispatch records, witness interviews, SCBA personal alert safety system (PASS) data loggers and other available information. Some of the times have been rounded to the nearest minute. This timeline is not intended, nor should it be used, as a formal record of events.

Incident and Fireground Communications	Time	Response & Fireground Operations
	0730-0745	Probationary fire fighter and another fire fighter report to work and are riding ambulance R-1.
R-1 runs a medical assist call.	0745	
Dispatched to a commercial structure fire, R-1 responds while on the road.	0817	
	0820	R-1 arrives on scene.
	0821	The fire fighter's SCBA PASS data is logger activated; the other 2 fire fighters SCBA PASS devices are activated at 0822.
	0822	E-1 on scene.
	0823	IC on scene.
	0823-0829	E-2 arrived and officer and 2 fire fighters from R-1 were sent in with a 200 feet of 1½-inch hoseline off of E-1. Another crew of 3 fire fighters makes entry into exposure B (restaurant) with a 1½-inch hoseline. IC assigned E-3 and R-3 to Side C. The IC does a face-to-face with the captain on Side C and then returns to Side A.
IC asks interior crews for progress report.	0829	No response
	0832	The fire fighter's PASS alarm goes into pre-alert and is reset.
	0839-0840	Command sees the crew exit Side A without the fire fighter and tries twice to contact him; no reply.

Incident and Fireground Communications	Time	Response & Fireground Operations
	0840-0843	A store front window self-vents and other store front windows are vented.
Command calls the missing fire fighter on the radio.	0842:29	
Radio transmission believed to be the missing fire fighter answering.	0842:38	
Command asks, "What's your location?"	0842:40	
Fire fighter responds that he is "hoseline, back of the building, near the fire, near the kitchen."	0842:57	
Command asks the fire fighter "What crew are you with?"	0842:57	
Fireground transmission occurred referencing Ladder 1 crew and the IC believed it was the missing fire fighter saying he is with the Engine 1 crew. Engine 1 was inside the rear of the restaurant occupancy and not the pool hall separated by the roll-down fire doors. The IC did not know that these doors were down.	0843:11	Large store front window self-vents on Side A and other windows are vented by fire fighters.
Engine 3, from their ladder, reports air conditioner is ready to come through the roof and they need to get everybody out of there.	0844:42	
Command calls for a progress report.	0845:17	
The fire fighter radios out of air. This transmission is hard to understand and very quick and no one hears the transmission.	0845:32	
Radio transmission to Command: "Need to get everyone out; 2 units ready to come through the roof."	0845:39	

Incident and Fireground Communications	Time	Response & Fireground Operations
Dispatcher asks Command, "Do you want me to have building evacuated?"	0845:56	
Command replies affirmative.	0846:02	
Dispatcher radios for all units on scene to evacuate the building.	0846:05	
	0846	Fire fighter's PASS data logger indicates pre-alarm.
Engine 3 on Side C radios Command that they have personal accountability report (PAR) for their unit and another mutual aid unit in the rear.	0846:22	
	0846	Fire fighter's PASS data logger indicates full alarm. (Note: The PASS data logger indicated full alarm from approximately 0846 until 0900:34 when it indicated a powered off followed by powered on and then powered off again at 0900:37. The collapse was first reported at 0900:58 and this impact to the PASS may have been responsible for the power down).
Command acknowledges Engine 3.	0846:30	
From unknown: "Command, we need a PAR count, fire fighter (name) is unaccounted for."	0847:52	
Commands calls fire fighter's name on radio.	0848:05	
Dispatcher calls fire fighter's name on radio.	0848:23	
Engine 3 radio's Command that the fire fighter is not at the back of the building (Side C).	0848:45	

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Incident and Fireground Communications	Time	Response & Fireground Operations
Dispatcher calls fire fighter's name on radio.	0849:20	
Dispatcher asks Command if the fire fighter is accounted for.	0849:39	
Command answers, "Negative at this time."	0849:45	
Dispatcher calls fire fighter's name on radio.	0849:48	
	0850	Command assigns mutual aid company (2 fire fighters) to enter Side A and try to locate the fire fighter. This crew made entry and attempted to follow the fire fighter's hoseline and were unable to locate the fire fighter. They exited 45–60 seconds later and said they only made it about 60 feet inside. They did not report hearing a PASS alarm inside.
Dispatcher asks Command, "Do you want a Mayday call?"	0850:16	
Command acknowledges, "Affirmative."	0850:21	
Dispatch sets off tones for a Mayday.	0850:40	
	0851	Flashover occurs. Command phones dispatcher and asks for a 10-minute timer to be set.
Deputy chief radios for all units to report to the front of the building.	0851:39	
Dispatch calls the fire fighter's name on radio.	0853:28	
	0900:34	Fire fighter's SCBA PASS data logger indicates power off.

Incident and Fireground Communications	Time	Response & Fireground Operations
	0900:36	Fire fighter's SCBA PASS data logger indicates power on.
	0900:37	Fire fighter's SCBA PASS data logger indicates power off.
Engine 3 radios Command that a collapse has occurred North side of building.	0900:58	
Dispatch radios that there is a collapse, North side of building.	0901:02	
Engine 3 radios, "Building down."	0901:03	
Command acknowledges.	0901:06	
Deputy chief radios, "Take a PAR count back there."	0901:11	
Engine 3 crew radios that they have just had a collapse on the C/D corner and all personnel are accounted for except for the missing fire fighter.	0901:32	Defensive operation begins.
	1030	The fire is reported out.
	1115	The fire fighter is located. (PASS alarm is not sounding.)

Building Construction and History

Shopping Center Layout and Configuration

Note: The following description of the shopping center is based on material provided by Chief Christopher J. Naum, SFPE (NY). His full report of the performance and predictive risk for collapse of the structure is included in Appendix 1.

The shopping center property consisted of two primary commercial retail buildings configured in an L-shaped layout that were not physically connected. The shorter building was approximately 260 feet x 125 feet [32,500 square feet (SF)] with the longer building approximately 100 feet x 625 feet (59,000 SF). The buildings housed commercial retail and business tenant spaces with two standalone buildings located on the property as well. Individual tenant spaces varied in commercial/retail use and size. (See Diagram.)

The individual tenant spaces opened directly to an exterior pedestrian sidewalk area and then to the parking lot, reflecting the common strip shopping center configuration of the 1970's time period. A perimeter access road surrounded the buildings for service and deliveries, with a primary parking lot located along the store fronts and adjacent to two primary highways and an intersection. The property was located in a mixed-use area that consisted of business, retail, and residential occupancies and urban density levels. A perimeter barrier fence bounded the site on two sides. Five access points led in and out of the property. (See Photo 1.)

The adjacent end unit tenant space housing a pool hall subsequently caught fire, culminating in a catastrophic roof collapse of that area. Progressive fire extension and structural collapse occurred in the adjacent tenant space occupied by a restaurant within the main building shopping complex. The fire and collapse originated in the farthest north end of the larger retail building and subsequently spread to two other adjoining tenant spaces.

The shopping center was built in 1979 [Naum 2014b] under the adopted building and construction codes in effect at that time, which was the Building Officials Conference of America Basic Building Code, 1975 edition, and various Michigan amendments (adopted November 13, 1976) [BOCC 1976]. The shopping center structures were of Type II, noncombustible construction consisting of steel frame and supports and a masonry perimeter wall in accordance with NFPA 220 Standard [NFPA 2012].

Proximal property exposures included a low rise multiple occupancy housing (west), single family residential homes (west and south) and a multiple occupancy apartment complex (north).

A detailed description of the construction features of the shopping center occupancies is included in Appendix 1.

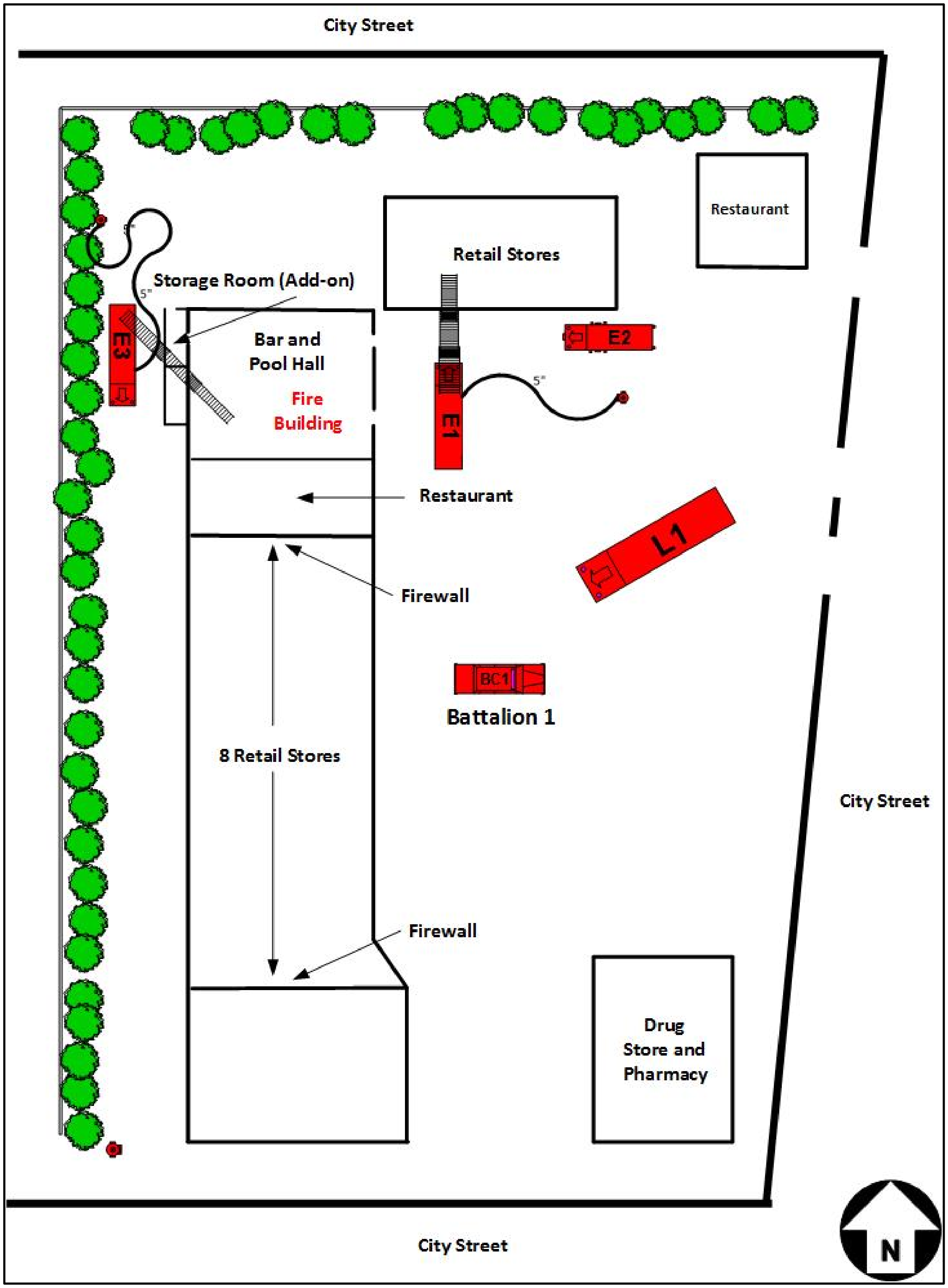

Diagram. Initial apparatus placement of first arriving units.

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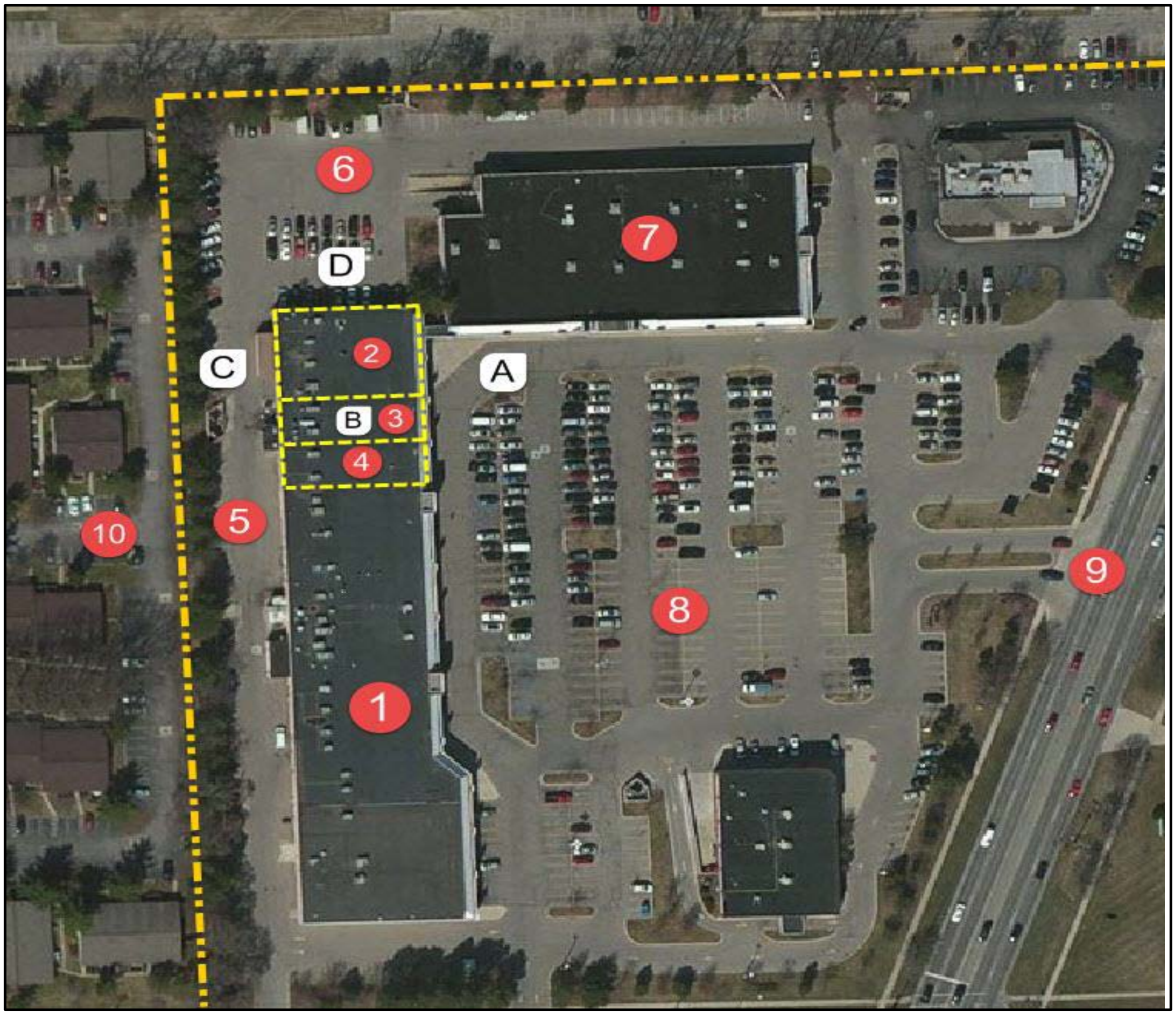

Photo 1. Aerial view of shopping center complex and buildings.
(Bing.com Maps/analysis diagram courtesy of Buildingsonfire.com.)

1. Larger Multiple Tenant Building; 59,000 SF; 14 tenant spaces
2. Pool Hall; location of bulk of fire and fire fighter fatality; 8,000 SF
3. Restaurant; Expose B; 4,000 SF
4. Tenant Space; Exposure B1 SF (fire wall separation located at south interior partition); 4,000 SF; 7 tenant spaces
5. Service-Delivery Road; Charlie (C) Division
6. Parking Lot (North) Delta (D) Division
7. Smaller Multiple Tenant Space Building; 32,500 SF (not attached)
8. Primary Open Public Parking Lot
9. Main Center Entrance off Major Highway
10. Single family residential Exposures (beyond perimeter fence line)

Fire Structure Construction and Occupancy, Pool Hall and Restaurant

The restaurant and pool hall complex, constructed circa 1979, was of NPFA 220 Type II [NFPA 2012], unprotected steel and masonry construction. The pool hall consisted of an open floor plan with a large expanse of seating, tables, and entertainment equipment. A food preparation and service area was located along the west side. A suspended acoustic tile ceiling approximately 12 feet high, concealed a ceiling void space of approximately 30,000 cubic feet. (See Photo 2 pre-fire and Photo 3 post fire.)

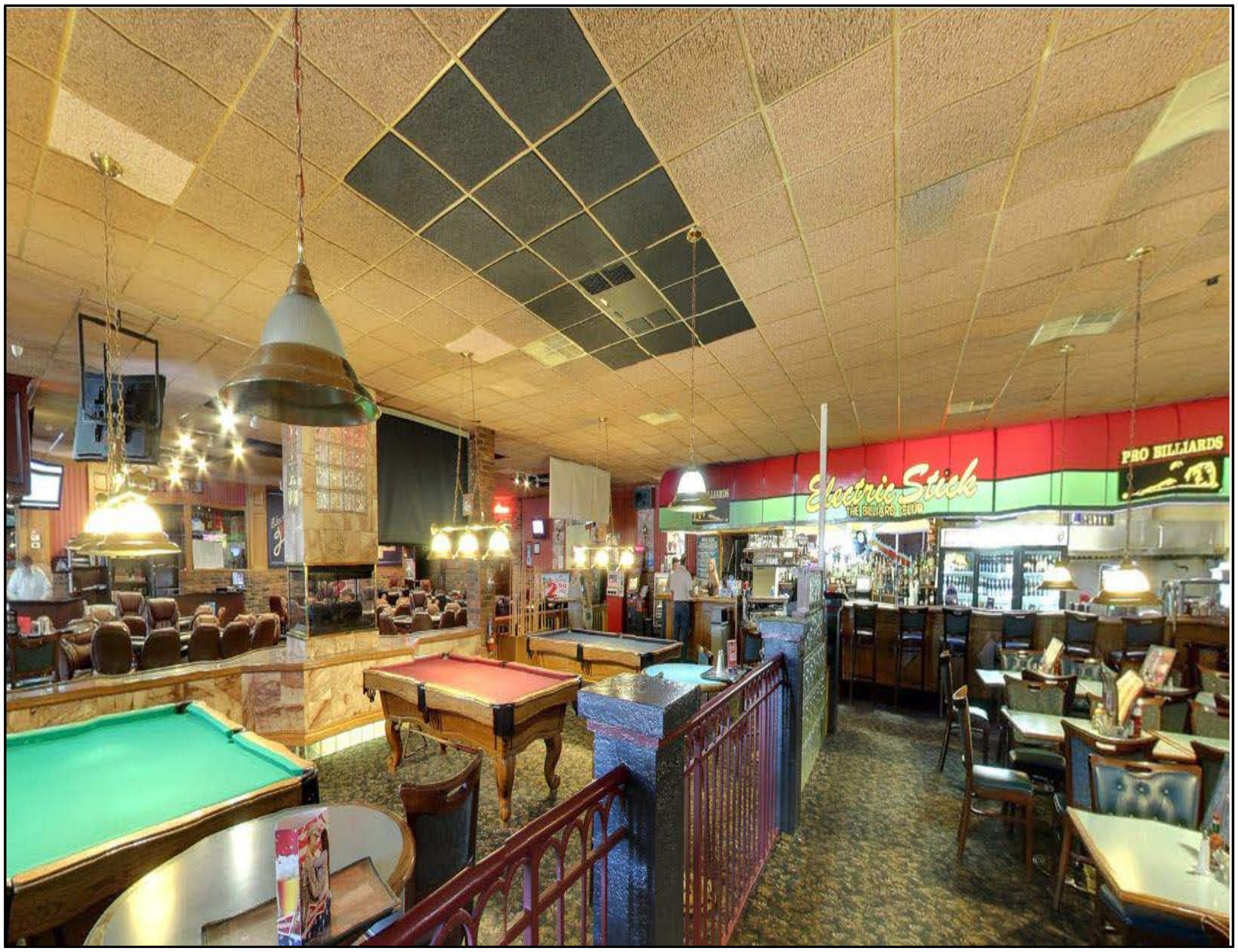

Photo 2. Pre-fire interior view of pool hall building occupancy. Interior view looking toward the west, pre-fire.
(*Luna Tech 3D (2012)/analysis diagram courtesy of Buildingsonfire.com*)

Photo 3. Post fire collapse interior view of pool hall building occupancy. Interior view looking toward the west, post-fire.
(*NIOSH Photo*)

The restaurant had a limited open floor plan with a raised entertainment stage, large expansive bar, and stool seating. A dining area with table seating and semi-enclosed booth seating with observation windows was adjacent to the pool hall. These windows along the occupancy separation partition were protected by three fire-rated roiling coil steel curtains, which provided fire separation between the tenant occupancies. A fully enclosed, commercial food kitchen was located to the interior west. Interior tenant space wall separation consisted of 2x4 dimensioned wood framing and gypsum wall board construction. A suspended acoustic tile ceiling, approximately 12 feet high, concealed a ceiling void space of approximately 9,000 cubic feet. Vinyl and ceramic tile and carpeting floor coverings were used throughout occupancies. (See Photo 4 pre-fire and Photo 5 post fire.)

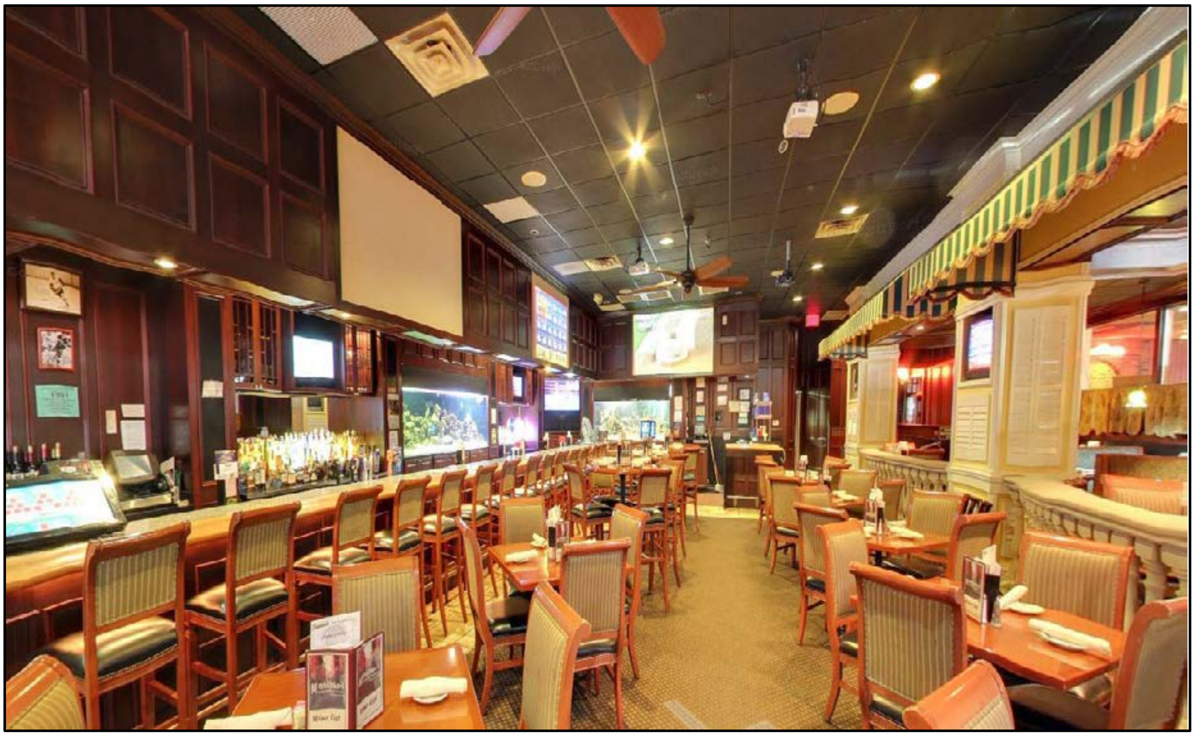

Photo 4. Pre-fire interior view of restaurants occupancy.
(Courtesy of Buildingsonfire.com.)

Photo 5. Post fire interior view of collapsed restaurant occupancy.
(NIOSH Photo)

The perimeter walls were concrete masonry units with integrated outer face treatments. A bearing wall along the north exterior perimeter was for the pocketed bearing of steel bar joists in the pool hall occupancy. Limited controlled access delivery doors were located along the service road on Side C. (See Photo 6.)

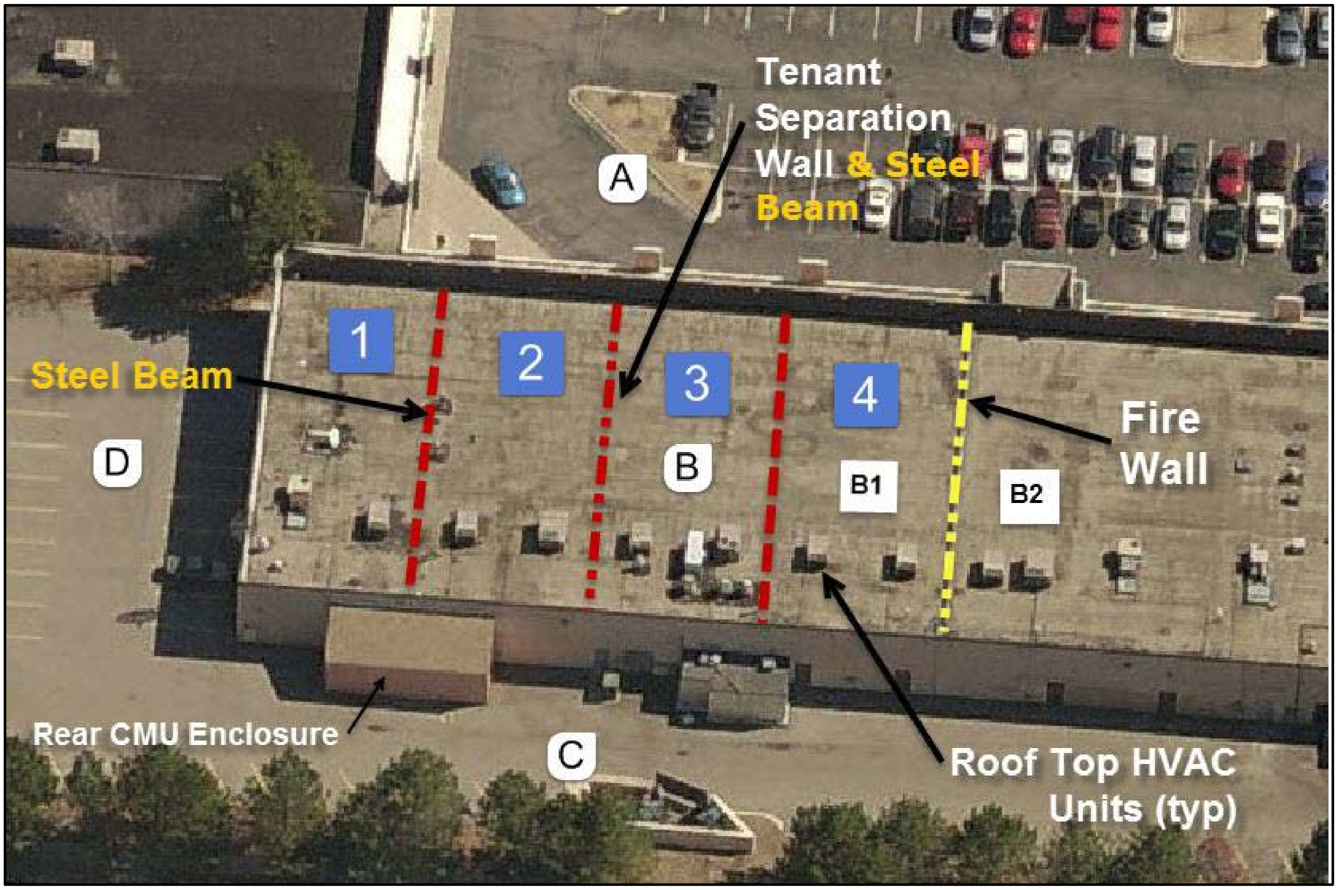

Photo 6. Pre-fire Division Charlie aerial view of fire building complex. (*Courtesy of Buildingsonfire.com.*)

Exemplifying features of the building complex noted in Photo 6.

1. Pool Hall; congruent space; see #2
2. Pool Hall: total area 8,000 SF
3. Restaurant; Exposure B; 4,000 SF
4. Tenant Space; Exposure B1 SF (4,000 SF); Exposure B2 (4,000 SF) (fire wall separation located at south interior partition) 4,000 SF

Steel Beam. Unprotected steel I-beams spanning approximately 100 feet east-west provided structural support for the steel joists that spanned approximately 40 feet north-south (typical bay configuration) and rear concrete masonry unit enclosure.

Roof Top Heating, Ventilation, and Air Conditioning Unit (HVAC). Numerous-sized air handling units, also referred to as HVACs were present along a line running primarily north-side proximal to the Charlie (C) exterior perimeter wall and framed into roof deck and joist openings. Included in the roof opening were fan ventilators from the kitchen areas.

Fire Wall. A designated fire wall provided fire area zone separation from the upper tenant spaces from the next designed fire area zone within this building foot print.

Exemplifying Features of the building complex noted in Photo 6 (continued).

A- Alpha Division (East)
B- Bravo Division (South)
B1- Exposure (South)
B2- Exposure (South)
C- Charlie Division (West)
D- Delta Division (North)

The store fronts on Side A were set back from the road and parking lot by a 10-foot-wide concrete sidewalk and larger framed façade and overhang. The façade included large decorative panel treatments, metal roof perimeter screen walls for aesthetic treatment, and wood soffits. The concealed area of the façade and overhang included unprotected steel beams with bolted connections. The store fronts varied with either full-height glass doors and metal-framed panel windows or a combination of partial brick walls and metal-framed panel windows (See Photo 7.)

Photo 7. Pre-fire street level view of fire building entrance; pool hall Alpha Division.
(Courtesy of Buildingsonfire.com.)

The flat roof was constructed of 18-inch-deep open web steel bar joists with a standard gage metal deck with mechanically fastened rigid insulation board and roof covering membrane. Heating ventilating and air conditioning units of various sizes were located in a line running primarily north-side along the Side C exterior perimeter wall. These were framed into roof deck and joist openings.

The roof framing included various-sized, unprotected structural steel I-beams running east and west spanning the width of the building (100 feet). The unprotected steel beams were bolt-connected along the beam web, together in three spans over the pool hall, restaurant, and exposure occupancies. The beam spans were supported by interior tube steel columns bolted to the bottom flange of the beam.

These columns were encased in brick in the pool hall from the floor to just above the suspended acoustic tile ceiling system. They were imbedded in wall construction in the restaurant occupancy.

Fixed sprinkler protection was not present within the occupancies or within the concealed spaces.

Weather

At approximately 0753 hours, the weather in the immediate area was reported to be 63 degrees Fahrenheit with a dew point of 43 degrees Fahrenheit, and the relative humidity was 48%. Wind conditions were up to 5 miles per hour from the north-northeast with maximum wind speed of 15 mph and maximum wind gusts of 31 mph. The sky was mostly cloudy and there was no precipitation [Weather Underground 2013].

Investigation

On May 8, 2013, a 29-year-old male career fire fighter died after running out of air in a commercial strip mall fire. The fire fighter was one of three fire fighters who had stretched a 1½-inch hoseline from Side A into a commercial strip mall fire. The hose team had stretched deep into the structure under high heat and heavy smoke conditions and was unsuccessful in locating the seat of the fire. The hose team decided to exit the structure and the fire fighter became separated from the other two crew members.

The fire fighter responded to the report of a structure fire on an ambulance (R-1). R-1 arrived first on the scene followed by Engine 1 (E-1). E-1 had a sergeant acting as a captain. The battalion chief (BC) was a captain acting as a BC and had an aide who drove the BC vehicle to the fire. The acting BC rode the jump-seat of E-1 to the scene. Engine 2 (E-2) responded and arrived after E-1. E-2 also had a sergeant acting as a captain.

The acting BC arrived at 0822 and observed light smoke conditions from the exterior, but the smoke was banked down on the interior and he thought it was possibly a kitchen fire. He walked around back (via Side D to Side C) and then back to Side A. The acting BC had the officer from E-2 and the 2 fire fighters from R-1 stretch a 1½-inch pre-connect inside through the doorway on side A and then went to the BC vehicle to set up command. Command assigned Engine 3 (E-3) and Rescue 3 to Side C. He then assigned a crew of 3 fire fighters to exposure B with a 1½-inch pre-connected hoseline. A mutual aid company arrived on the scene and Command assigned them as a RIT crew on Side A.

The fire fighter was one of three fire fighters (second position on the hoseline) stretching the charged 1½-inch pre-connect into the pool hall. The nozzleman (also from R-1) reported during interviews that they first tried to make entry into the restaurant and then went to the pool hall entrance. He observed heavy smoke with zero visibility and could feel heat overhead. They stretched the 1½-inch approximately 30 feet in and then couldn't pull any more hose so they sent the third fire fighter back to pull more hose. He opened the nozzle and penciled (short burst of water) into "lots of heat" and then moved further and stopped at a wall behind a bar. He then gave the nozzle to the fire fighter and ran into a number of bar stools. He spoke with the fire fighter three or 4 four times and told the fire fighter that he only had one light left on his heads-up display (HUD) air indicator and was concerned about air level. The captain on the hoseline reported that when they stretched the 1½-inch in from Side A they experienced heavy smoke and heat. The hose team then decided to back out by following the hoseline and the nozzleman said he had communicated with the fire fighter and he was right behind him. However, when they got out, the fire fighter wasn't with them.

At approximately 0839, the Incident Commander saw a crew exiting Side A and noticed that only two fire fighters came out. The IC stated during interviews that he tried calling twice for the missing fire fighter at that point but got no reply. At 0842:40 the IC called on the radio for the fire fighter asking his location and the fire fighter answered he was "hoseline, back of the building, near the fire, near the kitchen." Command asked the fire fighter "What crew are you with?" A fireground transmission occurred referencing Ladder 1 crew and the IC believed it was the fire fighter saying he was with Ladder 1 crew who was in the rear of the building. At approximately 0843, a large store front window self-vented on Side A and FF's vented other widows on Side A.

At 0844:42, personnel from Engine 3 (on the ladder) radioed that the air conditioner was ready to come through the roof and they needed to get everyone out of there. At 0845:17, the IC asked for progress reports by radio. Shortly after (0845:32) there was a very brief and hard to understand radio transmission from the fire fighter stating that he was out of air; however, this transmission was not heard by anyone on the fireground.

The IC noticed the smoke conditions changing and decided to switch to a defensive fire operation. He ordered an evacuation at 0846 hours. Shortly after, Engine 3 radioed command and reported they had a personal accountability report (PAR) for their unit and another mutual aid company in the rear. The IC acknowledged and then a radio transmission occurred (unknown source) that stated, "Command, we need a PAR count, fire fighter [name] is unaccounted for." Command and dispatch then tried repeated times to contact the fire fighter on the radio.

At 0850, Command assigned a mutual aid company (2 FFs) to enter Side A and search for the fire fighter. This crew made entry and followed the hoseline to try and locate the fire fighter. They reported that they were only able to make it about 60 feet inside the structure and after 45–60 seconds could not locate the fire fighter and had to back out due to the increasing fire conditions. At 0850:16, the dispatcher asked command if he wanted a Mayday called and he replied affirmative. A Mayday was transmitted by the dispatcher at 0850:40 and at approximately 0851 a flashover occurred.

At approximately 0851, the department's deputy chief arrived and after consulting with command ordered all units to report to the front of the building. The deputy chief assumed command and continued with setting up for a defensive fire-fighting operation.

At 0900, Engine 3 radioed that a collapse had occurred on the north side of the building (C/D corner). The deputy chief then radioed for a PAR to be taken at Side C. Shortly after (0901), Engine 3 radioed that all personnel on Side C were accounted for except for the missing fire fighter. The defensive operations included stretching lines into the exposures and a 2½-inch blitz line from Side A.

Master streams and ladder pipes were set up and operated. The fire-fighting operations continued in a defensive strategy until approximately 1030 hours when the fire was reported out and fire units began a recovery search for the fire fighter. The excavation and search operations continued until approximately 1115 when the fire fighter was located and later removed from the building. The fire fighter was transported to the medical examiner's office who later reported the cause of death as smoke and soot inhalation.

Fire Behavior and Extension

The local fire marshal reported to NIOSH investigators that the origin and cause ruling on this fire is an "incendiary" type fire and is still under investigation by the Michigan State Police at the time of this report. We do not have the information on the point(s) of origin or original fire development and, therefore, we cannot at this point describe the original fire development. It is surmised that a large fire developed in the concealed 30,000 cubic foot space above the acoustic tile ceiling (ACT) in the pool hall (see Figure 1).

There were no fixed sprinkler protection systems present within the occupancies or within the concealed spaces to slow or stop the progress of the fire that eventually spread throughout the complex. The lack of a fixed fire protection system in the occupied tenant spaces and the concealed ceiling plenum creates significant risks to firefighter personnel and makes the building highly susceptible to structural compromise and collapse due to fire.

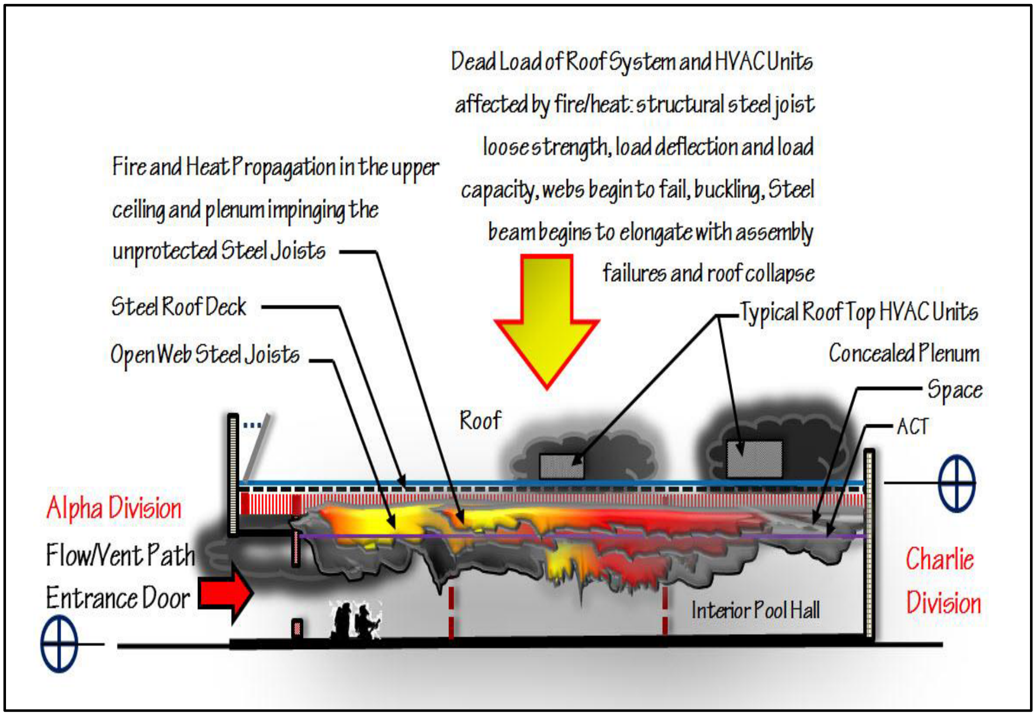

Figure 1. Cross section of pool hall occupancy Side A to Side C.
(Courtesy of Buildingsonfire.com).

The risk assessment of a building during fire-fighting operations should be continuous with building intelligence and reconnaissance communicated on degrading conditions, fire extension and compromise, building integrity considerations, the effects of fire spread and suppression on the interior compartment(s), and the structural system and building envelope. The "Fire Risk Matrix" listed below can be used to conduct the continuous risk assessment during fire-fighting operations in which the potential for structural collapse exists (see Figure 2).

The inherent building materials in the form of the light-frame structural steel system, the presence of a contiguous metal gage roof diaphragm, unrestrained steel beams and a moderate to high interior fuel load package (common to retail shopping occupancies) that would contribute toward fire growth in both intensity and magnitude support the premise of a higher probability of expected fire development in a compartment, rapid fire extension in the event of a fire incident and building component and assembly compromise, deterioration, failure, and collapse. The Pool Hall occupancy's severity of risk would be considered marginal-critical with the operational probability of an adverse event to be High (H) to Extreme (E), resulting in a likely event to occur during operational times. The large open span floor area, concealed plenum, and structural support system increase that occupancy risk [Naum 2014a].

Buildings on Fire Risk Assessment Matrix

Levels	**Severity of Risk**
Catastrophic	**May result in personnel death, grave personnel injury, large-scale destruction, and perilous conditions.**
Critical	**May cause severe personnel injury, possible death; major property loss; or significant degraded conditions.**
Marginal	**May cause or result in personnel injury, prominent property loss, or degraded and compromised conditions.**
Normal	**Hazards and conditions are consistent with generally accepted Fire Service work practices and operational parameters for adequately resourced and trained companies. Operations may cause or result in some personnel injury, corresponding property loss, or damage conditions consistent with fire-fighting principle and practices.**
Negligible	**Conditions have minimal threat to the safety and well-being of companies operating under generally accepted Fire Service work practices and parameters.**

Figure 2. Buildings on Fire Risk Assessment Matrix.
(*Courtesy of Buildingsonfire.com and the Command Institute. Additional information can be accessed at http://buildingsonfire.com/buildings-on-fire-risk-assessment-matrix.*)

Based on potential severity and urgency factors given a fire of any great magnitude or other initiating event, this would require judicious and thoughtful pre-fire planning to not only identify postulated incident events and occurrences, but to also assess the potential demands for escalating incidents, resource needs, and suggested incident management scenarios, situations, and consequences.

The Identified Severity of Risk Level for postulated incident conditions for the tenant spaces involved and the overall shopping building complex suggests a defined level of:

Marginal; May cause or result in personnel injury, prominent property loss or degraded and compromised conditions.

The Severity of Risk Level for postulated incident conditions for the Pool Hall and Restaurant tenant spaces in the building section suggests a defined level of:

Critical; May cause severe personnel injury, possible death; major property loss or significant degraded conditions.

This is based on two primary factors; the presence of the unprotected steel truss assembly and roof system and a large open span compartment in the Pool Hall occupancy and the unprotected tenant spaces and associated fire load package (assumed) present.

The probability for an escalating multiple alarm fire occurring in this shopping center building complex creating limiting conditions of operations, high resource demands, operational severity, urgency and escalating incident growth issues were highly probable and could be expected based on fire location within a given tenant location, the occupancy use of that tenant space, the time of day of the incident, and the operational readiness and availability of the fire department to respond, deploy, and intervene [Naum 2014a].

Contributing Factors

Occupational injuries and fatalities are often the result of one or more contributing factors or key events in a larger sequence of events that ultimately result in the injury or fatality. NIOSH investigators identified the following items as key contributing factors in this incident that ultimately led to the fatalities:

- *Risk assessment*
- *Communications*
- *Crew Integrity*
- *Fire fighter ran out of air in an IDLH atmosphere*
- *Staffing and deployment*
- *Arson fire in an commercial structure*

- *Lack of automatic fire sprinklers*

Cause of Death

According to the office of the medical examiner, the fire fighter died from smoke and soot inhalation.

Recommendations

Recommendation #1: Fire departments should ensure that an initial risk assessment is performed and continuous risk assessment is performed throughout the incident and the strategy and tactics match the conditions encountered.

Discussion: A risk management plan ensures that the risks are evaluated and matched with the actions and conditions. At any incident, life safety is always the first priority, followed by incident stabilization (second priority) and then property conservation (third priority). The ability to ensure for the safety of fire fighters is a continuous process throughout the incident.

The following risk management principles should be utilized by the incident commander:

- Activities that present a significant risk to the safety of fire fighters should be limited to situations that have the potential to save endangered lives.

- Activities that are routinely employed to protect property should be recognized as inherent risks to the safety of fire fighters, and the actions should be taken to reduce or avoid these risks.

- No risk to the safety of fire fighters should be acceptable where there is no possibility to save lives or property [Brunacini 2002].

The strategy and tactics of an incident are dictated by the size-up, initial risk assessment, and initial report by the first arriving officer.

It is a priority that a 360 degree size up is included in the risk assessment. Life hazard, fire extent and location, building conditions are factors that need to be a part of the size up and help to match the strategy and tactics with the conditions encountered and this information must be continual. If a 360 degree walk around cannot be completed, then a size up of the areas can be accomplished through divisions starting with a priority of Division C or the rear of the building.

The incident commander is responsible for evaluating conditions at a structure fire and determining the strategy and tactics for fighting the fire. In many cases the first arriving officer is the initial incident commander and sets in motion the strategy and tactics. Command is later passed to a higher-level officer and a formal command is established. The incident commander needs to ensure that the strategy and tactics are appropriate with all of the size-up factors. To accomplish this, the incident commander should use a standardized strategic decision-making model.

First, the incident commander should size up the critical fireground factors [PFD 2009]. Before ordering an offensive attack, the incident commander must make a determination that offensive (interior) operations may be conducted without exceeding a reasonable degree of risk to fire fighters and must be prepared to discontinue the offensive attack if the risk evaluation changes during the fire-fighting operation. A full range of factors must be considered in making the risk evaluation, including the following:

- Presence of occupants in the building
- A realistic evaluation of occupant survivability and rescue potential
- Size, construction, and use of the building
- Age and condition of the building
- Nature and value of building contents
- Location and extent of the fire within the building
- Adjacent exposures (structures)
- Fire involvement or compromise of the building's structural components
- **Residential or commercial structure**
- Delayed discovery/reporting and its effect on burn time and structural stability
- Considerations of fire loading and fire behavior
- A realistic evaluation of the ability to execute a successful offensive fire attack with the resources that are available [PFD 2009; NIOSH 2010b].

These fireground factors should be weighed against the risk management plan. Fire fighters are routinely exposed to certain known and predictable risks while conducting operations that are directed toward saving property. The incident commander is responsible for recognizing and evaluating those risks and determining whether the level of risk is acceptable or unacceptable. However, risks taken to save property should always be less than those to save lives [Grorud 2009; NIOSH 2010b]. Risks to fire fighters versus gains in saving lives and property should always be considered when deciding whether to use an offensive or defensive attack.

The incident commander should continually match the actions against the conditions based upon continuous reports from all operating companies. This gives the incident commander the ability to control the situation by forecasting and staying ahead, rather than the fire dictating the actions taken. The incident commander should routinely evaluate and re-evaluate conditions and radio progress reports in reaching objectives to dispatch and on-scene fire fighters. This process allows the incident commander to determine whether to continue or revise the strategy and attack plans. Failure to revise an inappropriate or outdated attack strategy is likely to result in an elevated risk of death or injury to fire fighters [NFPA 2013b; PFD 2009].

The risk assessment of a building during fire-fighting operations should be continuous with building intelligence and reconnaissance communicated on degrading conditions, fire extension and compromise, building integrity considerations, the effects of fire spread and suppression on the interior compartment(s), and the structural system and building envelope.

It is important that fire officers and fire fighters understand risk management and applying that knowledge to modern fire conditions, especially in commercial structures.

Chief Christopher Naum, SFPE (Command Institute) notes:

Firefighting in commercial buildings and occupancies demands alternate tactical engagement and management that differentiate from residential deployment and operations. Building features and systems and complexities create very distinct and defined incident action parameters that required commanders, officers and firefighters to implement discrete strategies, tactics and awareness that are commonly resource driven, complex, concurrent and high risk.

Commercial building fires and incidents require specific training, skill sets, and experience and risk management protocols. Today's fireground demands, challenges and risks are less forgiving than in the past, leave little to no margin for error and when those errors and omissions manifest themselves-may be very unforgiving in their resulting severity and magnitude. This then requires significant adaptability in the identification, selection of strategic, tactical and task level actions that demand critical thinking skills, based on fluid incident and building assessment and evaluation for conditions.

The importance of implementing Tactical Discipline, Tactical Patience and Adaptive Fireground Management [Clark 2008] is formative on today's fireground and built upon an established platform of building knowledge, an understanding of the predictability of the building's performance under fire conditions and the integration of critical thinking skills that aligns with the unique given conditions of an incident scene and structural fire in a building.

Firefighting continues to be driven by long established practices and protocols that have a basis on expected building or fire performance and behaviors. These long held beliefs and methodologies have had new perspectives applied based on on-going research, development and emerging practices that suggest adaptive and alternatives methods, practices and protocols that are changing the rules of engagement.

First-due company operations are influenced by a number of parameters and factors; some deliberate and dictated, others prescribed and prearranged and yet others subjective, biased, predisposed or at times accidental, casual and emotional. The connotations and implications are significant and can be characteristic of successful or detrimental operations.

Buildings and occupancies when involved in a structure fire will continue to require the suppression and rescue engagement and intervention of fire department resources and staffing; evolving into an art and science of firefighting that demands greater command and company officer skill sets and understanding of building parameters and fire dynamics."[Naum 2014a]

In this incident, the arriving crews initiated an offensive strategy and the tactics were to stretch a 1½-inch hoseline into the pool hall and locate the seat of the fire. The attack crew stretched a 1½-inch hoseline into a large commercial property and heavy fire was likely concealed in the concealed space overhead, deep inside the structure.

An offensive strategy may have been able to control a limited kitchen fire if the hoseline had been larger and the stretch had a more direct approach to the seat of the fire. In this case, the small hoseline and the length of the stretch from Side A almost to Side C, coupled with not being able to locate the likely seat of the fire in the large overhead concealed space, was a challenging operation.

The incident commander repeatedly asked for progress reports. However, there was little communication to command from interior crews, and there was little to no progress on fire control. Command then had the added pressure of an unaccounted for fire fighter to deal with and a rapidly growing fire event. The fire fighter became lost and ran out of air and his out-of-air radio transmission was very hard to understand.

Recommendation #2: Fire departments should ensure that fire fighters are trained to understand the influence of building design and construction on structural collapse.

Discussion: Fire fighters are at significant risk for injury or death due to structural collapse during fire-fighting operations. The United States Fire Administration and the National Fire Protection Association (NFPA) report that 984 fire fighters died between 2000 and 2010. Structural collapse caused 134 (13.7%) of these fire fighter line-of-duty deaths. Structural collapse often results in multiple fire fighter injuries and fatalities. While structural collapse is a significant cause of injury and death to fire fighters, the potential for a structural collapse is one of the most difficult circumstances to predict.

During initial size-up and ongoing fire-fighting operations, the incident commander must consider numerous variables to determine the integrity of a burning structure. Understanding the influence of building design and construction on structural collapse has a direct correlation to safe fire-fighting operations and fire fighter survivability. In virtually every case, structural collapse results from damage to the structural system of the building caused by the fire or by fire-fighting operations. **The longer a fire burns in a building, the more likely that the building will collapse** [NIOSH 2013]. The walls of buildings—especially curtain walls, false fronts, marquees, parapet walls, and heavy signs—can all come crashing down. Chief Christopher Naum, SFPE (Command Institute) notes, *"The potential for structural collapse in a building on fire can be predicated by a building's inherent susceptibility to a variety of factors that include fire dynamics and behavior, fire exposure and extension, environmental impact, fire suppression activities and age, deterioration and occupancy use factors. The predictability of a building's performance and risk to structural collapse, compromise or failure must be foremost in the development and execution of incident action plans (IAP) with collapse precursors or indicators identified, monitored and managed by incident commanders, supervisors and operating companies."*[Naum 2014a]

Based upon continuous risk assessments being conducted, coupled with pre-incident planning information, a collapse zone should be established when factors indicate the potential for a building collapse. Fire departments should not rely solely on the amount of time a fire has been burning as a collapse indicator. An external load—such as a parapet wall, steeple, overhanging porch roof, awning, sign, or large electrical service connections—may cause a structural collapse. Other factors to consider include:

- fuel loads
- fire behavior and building ventilation characteristics
- fire duration, size and location
- pre-existing structural damage/deterioration
- renovation/modifications to structure
- presence of wall anchor plates or stars
- height and age of the building
- types of doors and windows
- engineered load systems/lightweight truss construction
- roof design and covering
- fire protection features such as sprinkler systems, standpipe systems, automatic fire alarm system [NIOSH 2014]

Construction features, combined with fire factors, indicate the most probable type of structural failure [Klaene and Sanders 2007]. Given the fact that the incident commander is always working with incomplete and imperfect information, it is impossible to accurately predict the type of collapse and resultant collapse zone. A safe collapse zone is one that is equal to the height of the building plus an allowance for scattering debris. A good rule of thumb for setting a collapse zone for most buildings is to establish an area 1½ times the height of the fire building. This sometimes presents a dilemma—for example, when the safe zone is beyond the street width and therefore the effective defensive positions are within the collapse zone. A risk-versus-benefit analysis is essential. The crucial question that any incident commander must ask is, "What could I potentially save in relation to the risk being taken?" Obviously, no building is worth a fire fighter's life; therefore, imminent risk to a fire fighter's life to save a building is unacceptable. When a defensive operation represents a reasonable risk, positions at the corners of the buildings are normally safer than those on the flat side of a wall. Consideration should also be given to using unstaffed ground monitors to reduce the risk of placing personnel in exposed positions. When total collapse is imminent, collapse zones represent exclusion zones that no one is permitted to enter regardless of the level of protective clothing [Klaene and Sanders 2007].

Recommendation #3: Fire fighters and officers should ensure critical benchmarks, such as progress or lack of progress, are communicated to the incident commander and that positive communication discipline are used.

Discussion: The size-up of interior conditions is just as important as exterior size-up. The incident commander monitors exterior conditions while the interior conditions are monitored and communicated to the incident commander as soon as possible from company officers. Knowing the location and the size of the fire inside the building lays the foundation for all subsequent operations. Interior conditions could change the incident commander's initial strategy [Smith 2002]. Fire fighters and officers need to communicate their progress, and **especially lack of progress, while searching for victims, locating the fire, or experiencing deteriorating conditions**. Also, when operating inside the structure, company officers should communicate to the incident commander or division supervisor when making initial entry, when searching and clearing areas, during fire attack, and when exiting the structure.

Proper size-up and risk versus gain analysis requires that the incident commander gather a number of key pieces of information and be kept informed of the constantly changing conditions on the fireground. The incident commander should develop and utilize a system that captures pertinent incident information to allow continuous situational evaluation, effective decision making, and development of an incident management structure. Decisions can be no better than the information on which they are based. The incident commander should use an evaluation system that considers and accounts for changing fireground conditions in order to stay ahead of the fire. If this is not done, the Incident Action Plan will be out of sequence with the phase of the fire and the incident commander will be constantly surprised by changing conditions [Brunacini 2002; NIOSH 2010b; Smith 2002].

Interior size-up is just as important as exterior size-up. Since the incident commander is located at the command post (outside), the interior conditions should be communicated by interior crews as soon as possible to the incident commander. Interior conditions could change the incident commander's strategy. Interior crews can aid the incident commander in this process by providing reports of the interior conditions as soon as they enter the fire building and by providing regular updates, especially when benchmarks are met (e.g., "primary search complete is all clear" and "water on the fire"). It is equally important to communicate when those benchmarks cannot be accomplished, such as not finding fire or difficulty in making a hoseline stretch due to deteriorating conditions. The incident commander relies on regular updates from interior crews and, combined with other information, adjust his/her Incident Action Plan accordingly.

Retired Fire Chief Alan Brunacini states that critical fireground factors, including interior and exterior conditions, are among the many items that the incident commander must consider when evaluating tactical situations. These items provide a checklist of the major issues involved in size-up, decision making, initiating operations, and review and revision. The incident commander deals with these critical factors through a systematic management process that creates a rapid, overall evaluation; sorts out the critical factors in priority order; and then seeks out more information about each factor. The incident commander should train and prepare (through practice) to engage in conscious information management. Incident factors and their possible consequences offer the basis for a standard incident management approach. A standard information approach is the launching pad for effective incident decision making and successful operational performance. The incident commander should develop the habit of using the critical factors in their order of importance as the basis for assigning the specific assignments that make up the Incident Action Plan. The incident commander should create a standard information system and use effective techniques to keep informed at the incident. **The incident commander can never assume the action-oriented responder engaged in operational activities will stop what they are doing so they can feed the incident commander with a continuous supply of objective information. It is the incident commander's responsibility to do whatever is required to stay effectively informed** [Brunacini 2002]**.**

Fire officers and fire fighters need to understand that communicating benchmarks is critical and radio communications are often difficult to hear and/or understand. Effective communication involves a thorough understanding of the message. The sender transmits a clear message and the receiver must acknowledge the transmission so the sender knows that the transmission was understood.

When using radio communication the sender and receiver are only using one of the human senses (hearing) to communicate. Effective communication is always better when you can use more of the human senses to communicate. This is not always practical or possible on the fire ground and it is why positive communication discipline is required to close the communication loop. It is not a complicated process, but frequently overlooked (positive feedback from the receiver). If the sender communicates a message and the receiver doesn’t provide a disciplined feedback response, the sender may assume his/her message was understood.

Recommendation #4: Emergency fireground conditions should be communicated and acknowledged on the fireground and radio discipline maintained.

Discussion: Examples of emergency fireground conditions can include interior as well as exterior conditions. Examples of interior emergency conditions include being lost, running low on air, out of water and unable to escape. Examples of exterior emergency conditions include significant fire events such as flash over, partial or total collapse, an unplanned change in the strategic mode of operation, missing or injured fire fighters and deteriorating or extremely hazardous structural conditions. All of these situations require prompt and coordinated action to avert an operational adversity. Effective communications is the key to assuring that appropriate action occur or are implemented quickly. NFPA 1561, *Standard on Emergency Services Incident Management System*, states in Paragraph 6.3.4, “Emergency traffic shall be declared by the Incident Commander, a division/group supervisor, or any member who is in trouble, subjected to an emergency condition, or aware of such a condition” [NFPA 2008c]. An exemplar command worksheet for Mayday is included in Appendix 3

The emergency notification system should provide a means to rapidly notify or warn all persons who might be in danger if an imminent hazard is identified or if a change in strategy is made. An emergency message format with a distinctive alert tone and definitive instruction should be used to make such notifications [NFPA 2008c].

All responders operating at an incident should maintain radio discipline and transmit clear concise information and the receiver should acknowledge the message. When a sender transmits a message and doesn’t receive feedback or an acknowledgment, he/she needs to re-send the message and require a response. When an emergency fireground condition exists, radio discipline is extremely important for the proper communications to be transmitted and acknowledged. Any unsafe or changing condition should be communicated to the Incident Commander, as well as the division/group supervisor, and any members working or operating in the affected area.

In this incident, the IC observed the crew exit without the fire fighter and he radioed the fire fighter to find out where he was. The fire fighter radioed back that he was "hoseline, back of building, near the fire, near the kitchen." Command asked him what crew he was with and at that moment another transmission came across referencing Ladder 1. There wasn't anything in the radio message that indicated the fire fighter was in distress and the IC believed the transmission was from the fire fighter stating he was with Ladder 1. The fire conditions were changing significantly at that moment, but there were no emergency transmissions from the fire fighter. Shortly thereafter the fire fighter made a very brief and hard to understand transmission that he was out of air. No one heard that transmission on the fireground. *Note: The fire dispatcher in this incident was able to recognize the need for a Mayday notification and prompt the Incident Commander for a building evacuation order and a Mayday notification. NIOSH investigators noted the outstanding performance of this communications officer while reviewing radio transmissions and during interviews.*

Recommendation #5: Fire departments should ensure that crew integrity is maintained during fire suppression operations.

Discussion: Fire fighters should always work and remain in teams whenever they are operating in a hazardous environment [IFSTA 2008]. Team continuity means team members knowing who is on their team and who is the team leader; team members staying within visual contact at all times (if visibility is low, teams must stay within touch or voice distance of each other); team members communicating needs and observations to the team leader; and team members rotating together to rehabilitation, staging as a team, and watching out for each other (practicing a strong buddy system). Following these basic rules helps prevent serious injury or even death by providing personnel with the added safety net of fellow team members. Teams that enter a hazardous environment together should leave together to ensure that team continuity is maintained [Dunn 1992; NFPA 2008c]. Working alone increases the risk for individuals and possibly to others during search and rescue efforts. Thermal imaging cameras, portable radios, and crew-to-crew communication can also be used to ensure crew integrity is maintained. It is especially important when crews are "made up" and not used to working with each other due to covering assignments, transfers, overtime, and fill-ins. Task-level, positive communication should occur, and the members should not take for granted that a task-level communication (such as, "we are going to exit") is understood without positive feedback from the receiver.

Fire departments should also ensure that all members are comfortable using their portable radio. They should ensure that they are trained on radio discipline, which not only keeps unnecessary radio communication to a minimum but also emphasizes the importance of "its ok to radio a message when you think you may be in trouble." It is especially important for new members who may think they are going to be in trouble by radioing a message such as, "I can't find my team," "I'm alone," or "I'm running low on air." These radio messages are so important at the beginning of an uncontrolled event that the department and officers need to ensure that everyone understands that it is ok to radio for help.

Federal regulations [29 CFR 1910.134 (g)(4)(i)] states, "…at least two employees enter the immediately-dangerous-to-life-or-health (IDLH) atmosphere and remain in visual or voice contact with one another at all times" [OSHA 1998] NFPA 1500 *Standard for a Fire Department Occupational*

Safety and Health Program, Chapter 8, Section 8.5.4, states that members operating in hazardous areas at emergency incidents shall operate in crews of two or more [NFPA 2013].

In this incident, the fire fighter became separated from his crew and lost. He was a probationary fire fighter and by himself for a period of time. He did not have a great deal of experience in working fires (much less, commercial building fires) and was likely struggling to find his way out. Experienced fire fighters and officers may take for granted the repetitive skills from years of experience, such as knowing how much air you have, where you may be in relation to the hoseline, and how to follow the hoseline out. Using the radio to call for help when conditions are deteriorating and you have become separated from your crew should be every fire fighter's first action. If fire fighters are not experienced and comfortable with calling for help, then they may not take that action until the conditions deteriorate even more and anxiety or panic can set in.

Fire fighters should never hesitate to use the radio and call for help when they become separated or lost. When command called the missing fire fighter on the radio, he indicated that he was "hoseline, back of building, near the fire, near the kitchen." When Command asked what crew he was with, another transmission occurred at the same time referencing Ladder 1, and Command thought that the missing fire fighter was with Ladder 1. During this communication, the missing fire fighter's voice and comments did not suggest that he was in any kind of trouble or distress. His later communication of "out of air" was very hard to understand and was not heard on the fireground.

Recommendation #6: Fire departments should ensure adequate staffing and deployment of resources based on the community's risk assessment.

Discussion: 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* contains recommended guidelines for minimum staffing of career fire departments [NFPA 2010a].

NFPA 1710 states the following: "On-duty fire suppression personnel shall be comprised of the numbers necessary for fire-fighting performance relative to the expected fire-fighting conditions. These numbers shall be determined through task analyses that take the following factors into consideration:

1. Life hazard to the populace protected.
2. Provisions of safe and effective fire-fighting performance conditions for the fire fighters.
3. Potential property loss.
4. Nature, configuration, hazards, and internal protection of the properties involved.
5. Types of fireground tactics and evolutions employed as standard procedure, type of apparatus used, and results expected to be obtained at the fire scene" [NFPA 2010a].

NFPA 1710 states that both engine companies and truck companies shall be staffed with a minimum of four on-duty personnel. The standard also states that companies shall be staffed with a minimum of five or six on-duty members in jurisdictions with tactical hazards, high-hazard occupancies, high-incident frequencies, geographical restrictions, or other pertinent factors identified by the authority having jurisdiction.

Staffing studies have concluded that four-person crews were more effective versus three-person crews once a water supply from an external source is established [NFPA 2010a; PFD 1991]. Such additional tasks that may be accomplished by a four-person crew include:

- Two person interior search and rescue with no hand-held back-up line
- Two person interior structural fire fighting with no rescue component and no hand-held back-up line
- Limited roof-level ventilation operations
- Laddering operations
- Salvage operations

Four-person crews, depending on the circumstances, may also be capable of completing the following:

- Use of 2½-inch handline
- Establishment of a water supply from a static source
- Establishment of a second point of entry and approach to the fire location in the structure
- Preparing for a second area of search and rescue for person(s) in need of rescue [PFD 1991]

NFPA 1710 sets a standard for delivering a full first-alarm assignment to lower-risk occupancies (e.g., single-family dwelling). This requires a minimum of 15 fire fighters to be on the scene of a structure fire within 8 minutes. Using the specified minimum staffing level of four members per engine company and ladder company, this would require four companies (e.g., three engine companies, and one truck company) plus a battalion chief and staff assistant/incident command technician.

The requirements for moderate risk occupancies (typically multifamily residential and small commercial buildings) are based on performing the same basic functions that are listed for low-risk occupancies, however the scale of the required operation demands additional resources. NFPA 1710 does not specify minimum requirements, leaving it up to the individual fire department to make this determination. Staffing studies have determined that a minimum of 20 fire fighters should be included in the first alarm assignment for moderate-risk occupancies. This combined force would require a total of five companies plus a battalion chief, staff assistant, and a safety officer [NIST 2013].

The requirements for higher-risk occupancies are also based on performing the same basic functions on a larger scale. These occupancies would be classified as apartment buildings, hotels, and similar structures over two stories in height; schools; hospitals; nursing homes; and larger commercial buildings. Staffing studies have determined that a minimum of 29 fire fighters should be deployed on the first alarm assignment for a high-risk occupancy. This combined force would require a total of six companies plus two battalion chiefs with staff assistants and an incident safety officer [NIST 2013].

Many communities are struggling with ensuring adequate staffing. However, deployment studies have determined that certain occupancies require more personnel to effectively fight a fire and stop the spread of fire.

Commercial building fires not only require more staffing than a residential fire, they also require a greater degree of risk assessment and size-up considerations. Once an incident expands in size or complexity, a properly staffed and equipped rapid intervention crew (RIC) or team (RIT) should be immediately available to respond to rescue incidents. This formal RIC is beyond the initial RIC considerations of 2 in 2 out. It is a much more capable and equipped crew or team. For operations at large commercial structures, including high rise, factories, shopping malls, and on ships, consideration should be made for a much greater RIT capability. This could include multiple companies, specialty companies and alternate deployment strategies such as designated RIT or rescue groups staged in the most advantageous locations.

The officers and fire fighters in this incident were tactically deployed into task level and command level positions after they arrived on the scene. Staffing (resources) and deployment (assignments) potential should be considered in the initial risk assessment and size up for a large commercial structure. If the available staffing and deployment are insufficient for the situation encountered, the risk assessment should steer the initial strategy towards a defensive posture until additional resources arrive. During this time, the fire will continue to grow and have negative impacts on the structural integrity of the building, making an offensive attack much less desirable and certainly more dangerous. If the initial fire fighting forces and deployment ability don't match the hazard or fire, the incident commander should consider a defensive strategy.

Recommendation #7: Fire departments should ensure that fire fighters and officers are properly trained in air management.

Discussion: Chief Bobby Halton, retired chief and Editor in Chief of Fire Engineering, notes: *"If you run out of air in a working fire today, you are in mortal danger. There is no good air at the floor anymore, no effective filtering methods, no matter what others may say to the contrary"* [Gagliano et al. 2008]. The only protection for fire fighters in the toxic smoke environments in today's fires is the air that they carry on their backs. Like SCUBA divers, fire fighters must manage their air effectively and leave enough reserve air in case of unforeseen occurrences while inside a structure fire. Fire fighters must manage their air so that they leave the IDLH atmosphere before the low air alarm activates. This leaves an adequate emergency reserve [air] and removes the noise of the low air alarm from the fireground [Gagliano et al. 2008].

Air management is a program that the fire service can use to ensure that fire fighters have enough breathing air to complete their primary mission and allow enough reserve air for the fire fighter to escape an unforeseen emergency. Fire departments and fire fighters need to recognize that the smoke in modern construction is an IDLH atmosphere and manage their air along with their work periods so the fire fighters exit the IDLH with their reserve air intact. NFPA 1404 Standard for fire service respiratory protection training states that fire fighters should exit from an IDLH atmosphere before the consumption of reserve air supply begins, and a low air alarm is notification that the individual is consuming the reserve air supply and that the activation of the reserve air alarm is an immediate action item for the individual and the [firefighting] team [NFPA 2006].

Fire fighters and command officers need to recognize and communicate their air status and use air management on the fireground. Air management happens at the individual fire fighter level, the crew level, and the command level. Fire fighters need to ensure their air supply is adequate (full cylinder) at the start of the shift and need to recognize and monitor their air usage during an event: for example, recognizing the 50% HUD light flash and then communicating that information to his/her crew members. Fire fighters need to understand principals of air management such as the need to exit the IDLH before they go into their emergency reserve air and their end of service time indicator (EOSTI) sounds. If they are not out of the IDLH and go into their emergency reserve air, they need to immediately communicate with their crew and command and this can now be considered an emergency. Fire fighters should not wait until they are in their EOSTI or out of air to communicate.

Fire-fighting crews need to understand and communicate their air supply status among the crews so they can plan accordingly to notify command of the need to exit and still have their EOSTI in place. One method is to have the first person on a crew who reaches their 50% (flashing yellow light on HUD) notify the crew leader and he/she can then estimate the amount of work period left so they can leave the structure (or IDLH) before the person with the least amount of air goes into their emergency reserve air.

Command needs to understand air management at the command level. This means that someone at the command post is monitoring not only accountability of the crews, but how long they have been working (estimating air supply usage) and checking on air status through PAR checks and then rotating crews with enough time to ensure that crews exit the IDLH with their emergency reserve air intact.

Too often fire fighters may not be paying attention to their air usage and remaining air until they get into their emergency reserve air (formally called low air alarm) and their End of Service Time Indicator (EOSTI) sounds or vibrates. This can be due to a number of reasons, including lack of familiarity with a new SCBA (with Heads Up Display or HUD) or a different model, or a lack of training. Another reason may be the old culture of waiting to take an action based on the old “low air alarm.” Fire fighters in the past didn’t have HUD and relied on the “low air alarm” to warn them of their low air status. It was very difficult if not impossible in some fire-fighting incidents to be able to read the over-the-shoulder gauge. With the addition of HUD or heads up display, fire fighters now have the ability to know their approximate air supply status by reading the lights in their face piece. The four lights in the face piece start in the illuminated and green position and then turn off as the air supply decreases. Once the SCBA air supply reaches approximately 50%, the light begins to flash (some change color to yellow below 50% then change to red in the EOSTI mode). That is designed to alert the fire fighter that they should be taking an action that would ensure they have enough escape time to exit the building with their reserve air intact. Once the air supply reaches the EOSTI, the SCBA will provide another signal (bell, whistle and/or vibration signal) that alerts the user that they are nearing the end of the usable air in the cylinder. On pre-2013 edition SCBA, this level was approximately 25% (+/- 2), but on the 2013 edition and newer SCBA this EOSTI level was increased to 33%.

In this incident, the fire fighter's crew left the position due to low air concerns of one of the members. While exiting the fire fighter was separated from his crew, became lost, and ran out of air deep in the structure and was unable to escape.

NIOSH investigators have seen a lack of air management as a contributing factor on many LODD investigations. Fire departments need to ensure that training on air management occurs at both the fire-fighter and all levels of the fireground command structure (command level, crew level, and individual fire-fighter level) [NIOSH 2011a, 2012].

Recommendation #8: Fire departments should ensure that fire fighters are properly trained in out-of-air SCBA emergencies and SCBA repetitive skills training.

Discussion: Repetitive skills training with SCBA is vital for fire fighters working inside an IDLH atmosphere. SCBA skills training is an ongoing process that should be performed regularly to ensure that fire fighters "know their SCBA." The benefits of repetitive skill training with SCBA are an increased comfort and competency level, decreased anxiety, lower air consumption, increased awareness of the user's air level (noticing and using the heads-up display (HUD), and an automatic muscle memory response of the vital function controls, such as the don/doff buttons, main air valve, emergency bypass operating valve, and auxiliary air connections (i.e., rapid intervention crew/universal air connection (RIC/UAC) and the buddy breather connection). Repetitive skills training can also provide the user with an increased ability to operate these functions and controls in a high-anxiety moment or an emergency. Many times, these skills will be necessary with gloved hands, limited vision, and reduced ability to hear commands from others. Performed in conditions that are non-IDLH, repetitive skills training helps build the fire fighters' muscle memory skills so their hands will be able to activate the controls with gloves on and the operation will be a conditioned or second-nature response. Fire fighters have died in IDLH conditions because they did not react properly to an out-of-air emergency [NIOSH 2011a, 2012].

The first step in overcoming an SCBA out-of-air emergency is over familiarization with your specific SCBA and your breathing air requirements and usage. Fire fighters need to recognize that many SCBA out-of-air emergencies are caused by fire fighters not recognizing the remaining air supply relative to the mission and then another event such as becoming separated from their crew or hoseline and they become lost. Other events that can challenge a fire fighter's ability to overcome an out-of-air emergency are face piece becoming dislodged, hose entanglement, vomiting in a face piece, and mechanical issues with the SCBA. A fire fighter's ability to overcome these events is directly related to their repetitive, muscle memory skills, which are only achieved through training and experience with their current SCBA.

One helpful hint for fire fighters to understand is that they need to have sufficient "cockpit time" with their particular model SCBA so they can operate in fire environments without undue concentration on their SCBA. If a fire fighter has limited experience in a particular SCBA (whether it is because they are a new fire fighter or an experienced fire fighter in a new SCBA model or manufacturer), they may be concentrating so much on their SCBA that they miss fire environment signs such as fire growth, smoke behavior, orientation of the room or other crew members actions, and other conditions that require attention. This undue concentration on the SCBA may even be subtle and when faced with a condition that needs a trained muscle memory response, such as activating the bypass or checking the cylinder wheel, they don't have the automatic response to overcome the initial event. In addition, possibly having anxiety will further complicate steps to overcome the situation. Many uncontrolled SCBA out-of-air emergencies can be overcome by repetitive skill muscle memory training.

NIOSH investigators have seen uncontrolled SCBA out-of-air emergencies as a significant contributing factor in a large number of fire fighter line-of-duty death investigations [NIOSH 2011a, 2012]. Repetitive skill, muscle memory training on the specific SCBA that the fire department is using is a critical training need that should be supported and resourced. Fire departments need to ensure that SCBA repetitive skills training occurs at both the fire fighter and all levels of the fireground command structure (command level, crew level, and individual fire-fighter level).

Recommendation #9: Fire departments should ensure that fire fighters are properly trained in Mayday procedures and survival techniques.

Discussion: It is essential to train fire fighters to recognize when they are in trouble and know how to call for help. Fire fighters must recognize when they are in trouble, know how to call for help, and understand how incident commanders and others must react to a responder in trouble [Jakubowski and Morton 2001].

One of the most difficult situations a fire fighter can face is when they realize they need to declare a Mayday. The most important element that fire fighters need to know is recognition that they need to declare a Mayday. Recognizing that they are (or about to be) in a life-threatening situation is the first step in improving the fire fighter's chances to survive a Mayday event. Many fire departments don't have a simple procedure for what to say when a fire fighter gets into trouble (a critical situation where communications must be clear) [Jakubowski and Morton 2001]. A Mayday declaration is such an infrequent event in any fire fighter's career that they need to frequently train to recognize the need and then to declare the Mayday and what steps to take to improve their survival chances.

Fire fighters should understand that when they are faced with a life-threatening emergency, there is a very narrow window of survivability, and any delay in egress and/or transmission of a Mayday message reduces the chance for a successful rescue. Knowledge and skill training on preventing a Mayday situation or how to call a Mayday should be mastered before a fire fighter engages in fireground activities or other immediately dangerous to life and health (IDLH) environments [IAFF 2010; Sendelbach 2004]. Fire fighter training programs should include training on such topics as air management; familiarity with SCBA, a radio, and PPE; crew integrity; reading smoke, fire dynamics, and fire behavior; entanglement hazards; and building construction and signs of pending structural collapse. If fire fighters find themselves in a questionable position (dangerous or not), they must be able to recognize this and be trained on procedures for when and how a Mayday should be called. A fire fighter's knowledge, skill, and ability to declare a Mayday must be at the mastery level of performance. This performance level should be maintained throughout their career through training offered more frequently then annually [IAFF 2010; Sendelbach 2004]. Fire fighters need to also understand that their personal protective equipment (PPE) and self-contained breathing apparatus (SCBA) do not provide unlimited protection. Fire fighters should be trained to stay low when advancing into a fire as extreme temperature differences may occur between the ceiling and floor. When confronted with an emergency situation, the best action to take may be immediate egress from the building or to a place of safe refuge (e.g., behind a closed door in an uninvolved compartment, in a staging area on a lower floor) and manually activate the PASS device. A charged hoseline should always be available for a tactical withdrawal while continuing water application or as a lifeline to be followed to egress the building. Conditions can become untenable in a matter of seconds.

The ability of a fire fighter to call a Mayday is a complicated behavior that includes the affective, cognitive, and psychomotor domains of learning and performance [Clark 2005; Grossman and Christensen 2008]. Any delay in calling a Mayday reduces the chance of survival and increases the risk to other fire fighters trying to rescue the downed fire fighter.

Firefighters should be 100% confident in their competency to declare a Mayday for themselves. Fire departments should ensure that any personnel who may enter an IDLH environment meet the Authority Having Jurisdiction standards for Mayday competency throughout their active duty service. Presently there are no national Mayday standards for firefighters to be trained to and most states do not have Mayday standards. A rapid intervention team (RIT) will typically not be activated until a Mayday is declared. Any delay in calling the Mayday reduces the window of survivability and also increases the risk to the RIT [Clark 2005, 2008; IAFF 2010; USFA 2006].

There are no rules on when a fire fighter must call a Mayday, and Mayday training is not included in the job performance requirements in NFPA Fire Fighter 1 or 2 standards [NFPA 2013]. It is up to each authority having jurisdiction to develop rules and performance standards for a fire fighter to call a Mayday. The National Fire Academy Mayday courses present specific Mayday parameters or rules for when a fire fighter must call a Mayday. The courses may help fire departments in developing and teaching Mayday procedures for fire fighters.

The National Fire Academy has two courses addressing the fire fighter Mayday Doctrine. Q133 Firefighter Safety, Calling the Mayday, is a 2-hour program covering the cognitive and affective learning domain of the fire fighter Mayday Doctrine. H134 Calling the Mayday, Hands-on Training, is an 8-hour course that covers the psychomotor learning domain of the fire fighter Mayday Doctrine. These courses are based on the military methodology used to develop and teach fighter pilots ejection doctrine. A training CD is available to fire departments free of charge from the U.S. Fire Administration Publications office [Clark 2005; USFA 2006].

Also, the International Association of Fire Fighters (IAFF) Fireground Survival program is another resource fire departments can use and was developed to ensure that training for Mayday prevention and Mayday operations are consistent between all fire fighters, company officers, and chief officers [IAFF 2010].

Any Mayday communication must contain the location of the firefighter in as much detail as possible and, at a minimum, should include the division (floor) and quadrant. It is imperative that firefighters know their location when in IDLH environments at all times to effectively be able to give their location in the event of a Mayday. Once in distress, firefighters must immediately declare a Mayday. The following example uses LUNAR (Location, Unit, Name, Assignment/Air, Resources needed) as a prompt: "Mayday, Mayday, Mayday, Division 1 Quadrant C, Engine 71, Smith, search/out of air/vomited, can't find exit." When in trouble, a firefighter's first action must be to declare the Mayday as accurately as possible. Once the IC and RIT know the fire fighter's location, the firefighter can then try to fix the problem, such as clearing the nose cup, while the RIT is en-route for rescue [USFA 2005].

A fire fighter who is breathing carbon monoxide (CO) quickly loses cognitive ability to communicate correctly and can unknowingly move away from an exit, other fire fighters, or safety before becoming unconscious. Without the accurate location of a downed fire fighter, the speed at which the RIT can find them is diminished, and the window of survivability closes quickly because of lack of oxygen and high CO concentrations in an IDLH environment [Clark 2005, 2008].

Fire fighters also need to understand the psychological and physiological effects of the extreme level of stress encountered when they become lost, disoriented, injured, run low on air, or become trapped during rapid fire progression. Most fire training curricula do not include discussion of the psychological and physiological effects of extreme stress, such as encountered in an imminently life-threatening situation, nor do they address key survival skills necessary for effective response. Understanding the psychology and physiology involved is an essential step in developing appropriate responses to life-threatening situations. Reaction to the extreme stress of a life-threatening situation, such as being trapped, can result in sensory distortions and decreased cognitive processing capability [Grossman and Christensen 2008].

Fire fighters should never hesitate to declare a Mayday. There is a very narrow window of survivability in a burning, highly toxic building. Any delay declaring a Mayday reduces the chance for a successful rescue [Clark 2005]. In the book *Stress and Performance in Diving*, the author notes that while all training is important, "**We know that under conditions of stress, particularly when rapid problem-solving is crucial, over-learning responses is essential. The properly trained individual should have learned coping behavior so well that responses become virtually automatic requiring less stop and think performance**" [Bachrach and Egstrom 1987].

The word Mayday is easily recognizable and is an action word that can start the process of a rescue. The use of other words to declare an emergency situation should be discouraged because it is not as recognizable as an immediate action word that will start a rescue process. During this incident, the fireground radio traffic was busy and many different communications were taking place. A Mayday message transmitted over the radio may have gotten the attention of command officers and other fire fighters much earlier in the event when a rescue attempt might have had a better chance of locating the fire fighter.

Recommendation #10: Fire departments should ensure that fire fighters are trained in situational awareness, personal safety, and accountability.

Discussion: All fire fighters operating at an incident should maintain situational awareness and conduct a continuous risk assessment throughout the incident, reporting unsafe or changing conditions to the incident commander. Fire fighters need to understand the importance of situational awareness and personal safety on the fireground. The fireground dangers and hazards can and do change as the incident becomes larger and the event duration increases.

The book *Essentials of Fire Fighting and Fire Department Operations* [IFSTA 2008] defines situational awareness as an awareness of the immediate surroundings. On the fireground, every fire fighter should be constantly alert for changing and unsafe conditions. Even though a safety officer may be designated for an incident, it is the obligation of all personnel to remain alert to their immediate surroundings. They should maintain their situational awareness and be alert for unsafe conditions. This applies not only to the conditions found within a burning structure, but to the exterior fireground as well [Clark 2008]. **In virtually every case, structural collapse results from damage to the structural system of the building caused by the fire or by fire-fighting operations. The longer a fire burns in a building, the more likely that the building will collapse** [IFSTA 2008].

One of the most critical aspects of coordination between crews is maintaining situational awareness. The opposite of situational awareness is tunnel vision where the fire fighters become so focused on fire fighting or other operational assignments that they fail to sense changes in their environment. Fire fighters can maintain their situational awareness by looking up, down, and around as well as listening for new or unusual sounds and feeling vibrations or movement. Fire fighters and officers should communicate any changes in their environment to other members as well as to the incident commander.

The International Association of Fire Chiefs (IAFC), Safety, Health and Survival section developed the "Rules of Engagement for Structural Fire Fighting." The rules of engagement have been developed to assist both the fire fighter and the incident commander as well as command team officers in risk assessment and "Go" or "No-Go" decisions. The fireground creates a significant risk to fire fighters and it is the responsibility of the incident commander and command organization officers to minimize fire fighter exposure to unsafe conditions and stop unsafe practices [IAFF 2010].

The rules of engagement can assist the incident commander, company officers, and fire fighters who are at the highest level of risk in assessing their situational awareness. One principle applied in the rules of engagement is that fire fighters and the company officers are the members most exposed to the risk for injury or death and will be the first to identify unsafe conditions and practices. The rules integrate the fire fighter into the risk assessment/decision making process. These members should be the ultimate decision makers as to whether it's safe to proceed with assigned objectives. Where it is not safe to proceed the rules allow a process for that decision to be made while still maintaining command unity and discipline.

Rules of Engagement for Fire Fighter Survival:

- *Size-up your tactical area of operation*. This causes the company officer and fire fighters to pause for a moment, look over their area of operation, and evaluate their individual risk exposure to determine a safe approach for completing their tactical objectives.
- *Determine the occupant survival profile*. Occupant survival should be considered as part of the individual fire fighter's risk assessment and action plan development.
- *Do not risk your life for lives or property that cannot be saved*. This includes fire-fighting operations that may harm fire fighters when fire conditions prevent occupant survival and significant or total destruction of the building is inevitable.
- *Extend limited risk to protect savable property*. Risk exposure should be limited to a reasonable, cautious, and conservative level when trying to save a building.
- *Extend vigilant and measured risk to protect and rescue savable lives*. Search and rescue operations should be managed in a calculated, controlled, and safe manner while remaining alert to changing conditions during high-risk primary search and rescue operations where lives can be saved.
- *Go in together, stay together, and come out together*. Two or more fire fighters should operate as a team.
- *Maintain continuous awareness of your air supply, situation, location in the building, and fire conditions*. Situational awareness is knowing where they are in the building and what is happening around them and elsewhere that can affect their risk and safety.
- *Constantly monitor fireground communications for critical radio reports*.
- *You are required to report unsafe conditions or practices that can harm you. Stop, evaluate, decide.* This prevents fire fighter exposure to unsafe conditions or practices that can harm them, allows any member to raise an alert about a safety concern without penalty, and mandates the supervisor address the question to ensure safe operations.
- *You are required to abandon your position and retreat before deteriorating conditions can harm you*. Fire fighters must remain aware and exit early to a safe area when they are exposed to deteriorating conditions, unacceptable risk, and a life-threatening situation.
- *Declare a Mayday as soon as you think you are in danger*. This ensures the fire fighter is comfortable with declaring a Mayday as soon as they think they are in trouble [IAFF 2010].

The Incident Commander's Rules of Engagement for Fire fighter Safety:

- *Rapidly conduct or obtain a 360-degree situational size-up of the incident*. Determine the safest approach to tactical operations as part of the risk assessment plan and action development plan before fire fighters are placed at substantial risk.
- *Determine the occupant survival profile*. Consider fire conditions in relation to the potential for occupant survival of a rescue event before committing to a high-risk search-and-rescue operation.

- *Conduct an initial risk assessment and implement a safe action plan*. This rule causes an incident commander to develop a safe action plan by conducting a size-up, assessing the survival profile, and completing a risk assessment before fire fighters are placed in high-risk positions on the fireground.
- *If you do not have the resources to safely support and protect fire fighters, seriously consider a defensive strategy*. This rule prevents the commitment of fire fighters to high-risk tactical objectives that cannot be accomplished safely due to inadequate resources on the scene.
- *Do not risk fire fighter lives for lives or property that cannot be saved. Seriously consider a defensive strategy*. This rule prevents the commitment of fire fighters to high-risk fire-fighting operations that may harm them when fire conditions prevent occupant survival and significant or total destruction of the building is inevitable.
- *Extend limited risk to protect savable property*. The incident commander should limit risk exposure to a reasonable, cautious, and conservative level when trying to save a building that is believed, following a thorough size-up, to be savable.
- *Extend vigilant and measured risk to protect and rescue savable lives*. The incident commander should manage search and rescue and supporting fire-fighting operations in a highly calculated, controlled, and cautious manner while remaining alert to changing conditions during high-risk search-and-rescue operations where lives can be saved.
- *Maintain frequent two-way communications and keep interior crews informed of changing conditions*. The incident commander should obtain frequent progress reports, keeping all interior crews informed of changing fire conditions observed from the exterior that may affect crew safety.
- *Obtain frequent progress reports and revise the action plan*. Frequent progress reports enable the incident commander to continually assess fire conditions and any risk to fire fighters and to regularly adjust and revise the action plan to maintain safe operations.
- *Ensure accountability of every fire fighter's location and status.* The incident commander and command organizational officers must maintain a constant and accurate accountability of the locations and status of all fire fighters within a small geographic area of accuracy within the hazard zone and an awareness of who is presently in or out of the building.
- *If after completion of the primary search, little or no progress towards fire control has been achieved, seriously consider a defensive strategy*.
- *Always have a rapid intervention team in place at all working fires*.
- *Always have fire fighter rehab services in place at all working fires*. This allows fire fighters who endured strenuous physical activities at a working fire to be rehabilitated and medically evaluated for continued duty and before being released from the scene [IAFF 2010].

In this incident, the attack crew stretched a 1½-inch hoseline into a large commercial property. Heavy fire was likely concealed in the concealed space overhead deep inside the structure. The offensive strategy may have been able to control a limited kitchen fire if the hoseline had been larger and the stretch had a more direct approach to the seat of the fire. In this case, the small hoseline and the length of the stretch from Side A almost to Side C, coupled with not being able to locate the likely seat of the fire in the large overhead concealed space, was a challenging operation.

Recommendation #11: Fire departments should ensure that a trained incident safety officer is appointed at each structure fire.

Discussion: *"Considering the dynamics involved in today's fireground environment, it is easy to understand how it can become overwhelming and even compromised. Challenges such as limited experience or staffing, violent fire conditions and building construction practices all contribute to the importance of having someone dedicated to looking out for our safety on the fireground"* [Pindelski 2013].

Fire departments need to ensure that a trained incident safety officer (ISO) is appointed at each structure fire. An incident safety officer can monitor the incident action plan, conditions, activities, and operations to determine whether they fall within the criteria as defined by the fire department's risk management plan. The role of the incident safety officer needs to be filled by a knowledgeable and qualified supervisory level officer who is dedicated to incident safety officer responsibilities.

NFPA 1561 *Standard on Emergency Services Incident Management System and Command Safety* states in Paragraph 5.3.1 that "The Incident Commander shall have overall authority for management of the incident" [NFPA 2008c]. NFPA 1561 Paragraph 5.3.2 states, "The Incident Commander shall ensure that adequate safety measures are in place" [NFPA 2008c]. With the advent of the Incident Command System, the goal is to ensure that the incident commander is responsible for the safety and welfare of all members and other first responders that were on-scene at an incident.

Based upon the size and complexity of an incident, the incident commander should delegate responsibilities that include safety. The Incident Command System can be expanded to include functions necessary to effectively command and control an incident. Though the incident commander is still responsible for the safety and welfare of all members and first responders on-scene, this responsibility is delegated to the incident safety officer [NIOSH 2010b]. The pre-designated incident safety officer, independent of the incident commander, responds automatically to incidents as defined by the fire department. Upon arrival at the incident, the safety officer should meet with the incident commander to confirm the incident safety officer assignment and be integrated into the personnel accountability system. Upon confirmation, the incident safety officer should obtain the following information:

- Overall situation status and resource status
- The strategy and Incident Action Plan
- Known hazards and concerns plus the establishment of control zones
- Status or rapid intervention crews
- Establishment of the Rehabilitation Group
- Confirmation of established radio communication channels (Command Channel, Tactical Channels)

Once the information is obtained, the incident safety officer should don the personal protective equipment appropriate for the potential hazards that he/she will be exposed to. Also, the incident safety officer should be identified by a vest or helmet. The incident safety officer should perform a reconnaissance of the incident and began initiating functions of this position.

Based upon the size and complexity of the incident, the incident safety officer may request the appointment of assistant incident safety officers.

Types of incidents that might require expansion of the safety officer role include the following:

- Incidents covering a large geographical area that include numerous branches, divisions, or groups.
- Incidents where significant acute or chronic health concerns of responders require coordination and input to the planning section (responsible for accounting for the organizational structure, availability of resources, deployment of resources, and the situation status reports).
- Incidents requiring interface with local, state, federal, or other health and safety representatives.
- Multi-agency incidents where Unified Command is established.
- Incidents where Area Command is established [NFPA 2008b].

Assistant incident safety officers assigned to branches, divisions, or groups can be addressed according to their area of responsibility. For example, an assistant incident safety officer assigned to "Division C" can be addressed as "Division C assistant incident safety officer." The assistant incident safety officers assigned to branches, divisions, or groups report to and follow direction from the incident safety officer in the command staff, but the assistant incident safety officer works with the supervisory person in the assigned branch, division, or group to assure safety conditions are being met [Dunn 2000; NIOSH 2012; USFA 2010].

NFPA 1521 *Standard for Fire Department Safety Officer Professional Qualifications* defines the role of the incident safety officer (ISO) at an incident scene and identifies duties such as recon of the fireground and reporting pertinent information back to the incident commander; ensuring the department's accountability system is in place and operational; monitoring radio transmissions and identifying barriers to effective communications; and ensuring established safety zones, collapse zones, hot zones, and other designated hazard areas are communicated to all members on scene [NFPA 2008b].

Larger fire departments should consider one or more full-time dedicated ISOs who are on duty and can routinely respond to working fires (an example would be full time shift safety officers). In smaller departments, every officer should be prepared to function as the ISO when assigned by the incident commander. The presence of an ISO does not diminish the responsibility of individual fire fighters and fire officers for their own safety and the safety of others. The dedicated ISO adds a higher level of training, attention, and expertise to help the incident commander and division commanders, as well as the fire fighters and fire officers. The ISO should have particular expertise in analyzing safety hazards and should know the particular uses and limitations of protective equipment [Dodson 2007; NIOSH 2010a].

One of the important functions of an ISO is to offer judgment about the collapse potential of buildings during incidents. To do this, ISOs should front-load their building construction knowledge so that they can “read” the building and predict collapse potential. This ability comes from a long-term commitment to reading and studying building construction information. Knowledge of building construction starts with an understanding of the loads, forces, and materials found in the structural makeup of buildings. The ISO should also understand the effects of fires on materials and construction types [Dunn 2000]. The ISO can provide a fire department with a higher level of expertise to perform the necessary incident scene functions and assist the incident commander with fireground safety.

Some incident commanders believe that any fire officer should be able to fill the fire department ISO function at any time under any circumstance. Therefore an agency really does not need a pre-designated ISO. Just as incident commanders have various levels of knowledge and expertise, so do other fire officers. The requirements necessary to be a fire officer may change from department to department, a problem if mutual aid situations arise. Additionally, the emphasis placed on safety may vary from one incident commander to another [Dodson 1999].

Deputy Chief John Sullivan of Worcester Fire Department, Worcester, Massachusetts, states: “The incident safety officer’s (ISO) role is challenging and dynamic. We often task our incident safety officer with more responsibilities than any other human could possibly accomplish on the fireground. The ISO should focus primarily on perimeter scene safety and is instrumental in assisting the IC with establishing collapse zone parameters and making certain that any personnel and equipment are properly positioned.” The ISO serves as a key figure in fireground operations (not tactics), gathers a broad overall perspective of the fireground, and acts as the eyes and ears for the incident commander. The incident commander can be over-tasked with strategic objectives and may not be able to give full attention to every safety detail, and the ISO can assist the incident commander as well as other command level officers [Sullivan 2012].

In this incident an initial incident safety officer was not designated at the scene.

Recommendation #12: Fire departments should ensure that all fire fighters and officers receive regularly scheduled, hands-on (practical) fundamental skills training and specialized training on building construction and modern fire behavior.

Discussion: Structure fires have decreased by 53% over the past 30 years, which in turn has limited the opportunities for today’s fire service to gain necessary experience to understand the increasingly complex fires they are now up against [NFPA 2010c]. Many fire departments across the country are faced with challenges associated with the lack of fire fighter and officer experience in structural fire-fighting in both residential and (to a greater extent) commercial applications. With an increase demand for EMS and other service calls and the rapid retirement of experienced fire fighters and officers hired in the 60s, 70s, and 80s, fire departments can find themselves challenged to maintain experienced fire fighters and officers on the front lines. One way that fire departments can balance the lack of experience is to increase the frequency of hands-on, practical fire-fighting training. The military recognizes that practical battlefield or operational training is very important and provides consistent repetitive training such as war games for officers and fighting forces. Practical repetitive skills training on fire scenarios can help build a conditioned memory response (a slide tray of past events to draw from) for fire fighters as well as officers (much the same as the military). This type of practical training can help to overcome a natural response of underestimating an event and using a conditioned response. This can occur when fire fighters may respond to a large number of incidents but not have any experience in another area. When sizing up an incident, the natural inclination of a fire fighter or officer is to search in their memory bank and apply a strategy or tactic used before. If there is nothing in their memory bank (from experience and training) for a specific incident, a fire fighter or officer may apply a strategy or tactic that may closely match the scenario based on their experience but that solution may be insufficient or underestimate the event. One area that fire departments need to recognize is the danger of a fire fighter or officer using a residential response (strategy and tactics) in a commercial setting. This can be overcome by training fire fighters and officers to recognize that, if they don't have anything in their "slide tray" for a large or complex incident event, they may want to reconsider their strategy and tactics.

Along with the challenges of experience faced by today's fire service, a lack of staffing is also a factor in many departments. Fire-fighting crews often have difficulty identifying hazards on the fireground simply because they are understaffed [Jakubowski and Morton 2001]. They may be busy performing multiple demanding tasks and overlook ongoing size-up. The fire fighter's natural desire to attack the immediate problem and finish the job quickly can result in critical errors such as checking voids in the ceilings, opening doors, and taking windows (creating flow paths) without charged hoselines readily available. With minimal personnel and multiple assignments, fire fighters may neglect ventilation, thus allowing built-up heat and smoke to intensify [Jakubowski and Morton 2001; NIOSH 2009a].

Identifying and predicting fire behavior can be a challenge for experienced fire fighters and officers and **even more difficult for a novice fire fighter**. Commercial structure fires may not be encountered frequently enough for fire fighters to build a "slide tray" of past events to draw from. While fire departments may have enough residential structure fire "slide tray" experience, the same tactics employed on a commercial structure fire may not yield the same results. A large issue here is when fire fighters draw on their residential experience of a quick attack with small lines in a large commercial structure fire. There are many more factors to consider with large commercial structure fires. Different styles of construction with significantly larger floor space and very high ceilings with large void areas (that conceal fire and products of combustion) make it harder to check overhead and the fire may get behind the crews stretching in. Chief Christopher Naum, SFPE (Command Institute) notes: "In most situations involving a structure fire, the probability of and anticipation for structural collapse or compromise are inevitably minimized, overlooked or at times disregarded until the catastrophic conditions present themselves with little to no time to react accordingly. The loss of situational awareness coupled with distracted attention to subtle or obvious pre-collapse building indicators and gaps in building and construction system knowledge combine to elevate operational risks to personnel on the fireground at structure fires."

As the number of fire calls is dropping nationwide, fire fighters are becoming less experienced in their main responsibility—fighting fires [Jakubowski and Morton 2001]. The number of calls for other types of service are increasing. Many departments have seen increases in emergency medical service (EMS) calls and automatic fire alarms. Fire departments that provide EMS typically answer two or three EMS calls for every fire call they run. In many cases, even career fire fighters who work every two or three days may go months or years before they work on a structure fire [Jakubowski and Morton 2001], and even longer before they respond on a large commercial structure fire. It is important for fire departments to understand how to overcome the experience gap by providing regularly scheduled, hands-on (practical) fundamental skills training for fire fighters and officers.

Fire departments should ensure that all fire fighters and officers receive fundamental and annual refresher training according to NFPA 1001 [NFPA 2013a] and NFPA 1021 [NFPA 2008a]. Initial and continual training provides an opportunity to ensure that all fire fighters and line officers are proficient in their knowledge and skills in recognizing and mitigating hazards. This annual training ensures that knowledge and skill retention are demonstrated and the training can be continually refocused to address needs. Training on structural fire-fighting should include departmental standard operating procedures, fire fighter safety, building construction, and fireground tactics. NFPA 1500, Chapter 5 [NFPA 2013], requires that the fire department provide an annual skills check to verify minimum professional qualifications of its members [NFPA 2013].

Fire departments should ensure that all fire fighters and officers receive additional annual training in building construction and fire behavior. For example, there have been many advancements in training curriculum available for building construction (predictability and performance of buildings on fire) and fire behavior. Underwriters Laboratories (UL) and the National Institute for Standards and Technology (NIST) have jointly conducted research that suggests a more innovative fire attack can make the fireground safer for fire fighters and occupants [UL 2013]. A large focus of the research is on ventilation and how ventilation effects the fire growth. Two types of ventilation most commonly used in the fire service are horizontal and vertical ventilation, and they can be either forced (positive-pressure ventilation) or natural (cutting a hole in the roof or cross ventilation by openings such as doors and windows). Improper or uncoordinated ventilation can have significant effects on fire behavior in structure fires. Horizontal ventilation allows for heat, smoke, and gases to escape by means of a doorway or window but is highly influenced by the location and extent of the fire, and special caution should be taken if the fire is in the attic or above the ceiling (as in this incident) [IFSTA 2008]. Ensuring that fire fighters and officers are trained in understanding the effects of ventilation on fire behavior is critical to fire fighter safety. The effects of ventilation may not be widely understood in the fire service and the new research by UL and NIST has provided scientific foundations for better understanding.

NFPA 1001 *Standard for Fire Fighter Professional Qualifications* was established to facilitate the development of nationally applicable performance standards for uniformed fire service personnel [NIOSH 2009a]. NFPA 1021 *Standard for Fire Officer Professional Qualifications* was developed in the same way to determine that an individual possesses the skills and knowledge to perform as a fire officer [NFPA 2008a]. The intent of both of these standards is to develop clear and concise job performance requirements (JPRs) that can be used to determine that an individual, when measured to the standard, possesses the skills and knowledge to perform as a fire fighter or a fire officer. These JPRs can be used by any fire department in the country. Training is an ongoing process. Whether held daily, weekly, or monthly, it allows members to maintain proficiency at their present levels, meet certification requirements, learn new procedures, and keep up with emerging technology [NFPA 2008a]. Many departments may find themselves with difficult mandatory training such as EMS and other special needs training that may impact the ability of the department to provide annual in-service training on fire-fighting skills. Although the decrease in fires and fire deaths is a testament to the progress that the fire service has made, fire departments still need hands-on, practical skills training to learn and maintain proper fire-fighting procedures. Officers and fire fighters can identify areas that need more training emphasis by providing annual in-service training on fire-fighting skills as well as command and tactical-level skill building. Muscle memory, repetitive skill building is a very useful training tool, not only for task-level skills (SCBA, hose and ladder work), but also for incident command and tactical-level skills. Most importantly, fire fighter safety and survival can be continually reinforced through annual in-service training.

Fire departments should develop and implement a written training program that ensures members are trained and competencies are maintained in order to effectively, efficiently, and safely execute all responsibilities [NFPA 2000]. This is consistent with the organizational statement for the fire department, which establishes the existence of the fire department, the services the fire department is authorized and expected to perform, and the organizational structure.

The primary goal of all training, education, and professional development programs is the reduction of occupational injuries, illnesses, and fatalities. As members progress through various job duties and responsibilities, the department should ensure the introduction of necessary knowledge, skills, and abilities to members who are new in their job titles as well as ongoing development of existing skills [NFPA 2013]. These programs should include the following:

- Community risk reduction (fire prevention, public education, investigations, etc.)
- Health and safety
- Fire suppression
- Emergency medical services
- Human resources (leadership, supervision, inter-personal dynamics, equal employment opportunity, etc.)
- Incident management system
- Hazardous materials
- Technical rescue
- Information systems and computer technology
- Position-specific development (fire fighter, company officer, chief officer, tele-communicator, investigator, inspector, driver/operator, etc.) [NFPA 2013]

Hands-on training for fireground operations and emergency incidents should be conducted annually. This training should include SCBA use, search and rescue, hoseline operations, ground and aerial ladders, ventilation, fire attack, fire fighter safety, building construction, fire behavior, incident management, proper use of PPE, personnel accountability, incident scene rehabilitation, and fireground strategy and tactics. It is essential that all members, especially those engaged in emergency operations, receive this hands-on training on an annual basis. Although hands-on training requires more preparation and costs, it is the preferred method over didactic training for many fireground activities for knowledge and skill retention. In-service training is an excellent method for evaluating the proficiency of members to ensure they have the necessary knowledge, skills, and abilities to perform the tasks assigned during fireground operations.

NFPA 1500 *Standard on Fire Department Occupational Safety and Health Program,* Chapter 5, "Training, Education and Professional Development," states in paragraph 5.1.9, "As a duty function, members shall be responsible to maintain proficiency in their skills and knowledge and to avail themselves of the professional development provided to members through department training and education programs" [NFPA 2013]. Additionally, training programs for all members engaged in emergency operations should include procedures for the safe exit and accountability of members during rapid evacuation, equipment failure, or other dangerous situations and events. In-service training should extend to incident management and the personnel accountability system used by the fire department.

In this incident, the department provides training at the station level and makes available to its fire fighters training facilities outside of the jurisdiction. The department has a training officer who manages the required monthly training schedule. The department does not have a dedicated live burn facility (burn building or smoke house) to conduct annual live (practical) fire training. The department does have access to a mobile flashover trainer and has conducted live fire training using the flashover trainer.

Recommendation #13: Ensure an effective personnel accountability system is used to account for all fire fighters and first responders assigned to any incident.

Discussion: Personnel accountability on a fireground means identifying and tracking all personnel working at the incident. A fire department should develop its own system and standardize it for all incidents. Accountability on the fireground can be maintained by several methods: a passport system, a system using individual tags assigned to each fire fighter, a riding list provided by the company officer, a SCBA tag system, or an incident command board [IFSTA 2008; NFPA 2008c, 2013; NIOSH 2011b]. Some personal alert safety system (PASS) devices incorporated into SCBA have the ability to communicate automatically with a command/control module at the incident command post, establishing an automatic accountability system. NFPA 1500 Chapter 8, Section 8.4, and NFPA 1561, Chapter 4, Section 4.5, contain guidelines for the development of an accountability system for fireground and other emergency operations [NFPA 2008c, 2013].

As the incident escalates, additional staffing and resources will be needed, adding to the burden of tracking personnel accountability. A tactical worksheet should be established at this point with an assigned accountability officer or chief's aide. In large incidents, this can also be used at the division level, with resources assigned to that division being assigned and tracked at the division level.

An important aspect of a personnel accountability system is the personnel accountability report (PAR). A PAR is an organized on-scene roll call in which each supervisor reports the status of their crew when requested by the incident commander [NFPA 2013]. The use of a personnel accountability system is recommended by NFPA 1500 *Standard on Fire Department Occupational Safety and Health* Program [NFPA 2013] and NFPA 1561 *Standard on Emergency Services Incident Management System and Command Safety* [NFPA 2008c]. A functional personnel accountability system requires the following:

- Development of a departmental SOP
- Training all personnel
- Strict enforcement during emergency incidents

The control of the personnel accountability system should be assigned to an individual responsible for maintaining the location and status of all assigned resources (resource status) at an incident. This is a separate role from the duties of the incident commander. The incident commander is responsible for overall command and control of the incident. Due to the importance of responder safety, this function would be assigned to a personnel accountability officer or resource status officer. This function can be staffed by the chief's aide, staff assistant, field incident technician, chief officer, or other responder familiar with the department's accountability system [NFPA 2008c].

There are many different methods and tools for accounting of resources. Some examples are:

- Command boards
- Tactical worksheets
- Apparatus riding lists
- Electronic bar-coding systems
- Accountability tags or keys (e.g. PASSPORT System) [NFPA 2008c]

Different methods and tools for resource tracking and accountability can be used in conjunction with one another to facilitate the tracking of responders by both location and function. The components of the personnel accountability system should be modular and expand with the size and complexity of the incident [NFPA 2008c].

As a fire escalates and additional fire companies respond, a chief's aide or accountability officer assists the incident commander with accounting for all firefighting companies at the fire, at the staging area, and at the rehabilitation area. With an accountability system in place, the incident commander may readily identify the location and time of all fire fighters on the fireground. A properly initiated and enforced personnel accountability system that is consistently integrated into fireground command and control enhances fire fighter safety and survival by helping to ensure a more timely and successful identification.

There has been much technological advancement in accountability systems. **There are currently available PASS systems that have the capacity to act as a standard PASS device but also transmit a signal to the command console when the fire fighter has gone into alarm. Additionally, the**

incident commander can signal any and all fire fighters through their PASS device when there is a need to evacuate a structure.

Recommendation #14: Fire departments should use thermal imaging cameras (TICs) during fire-fighting operations.

Discussion: Thermal imaging cameras (TICs) provide a technology with potential to enhance fire fighter safety and improve the ability to perform tasks such as size-up, search and rescue, fire attack, and ventilation. TICs should be used in a timely manner. Fire fighters should be properly trained in the use of a thermal imaging camera and be aware of their limitations [IAFF 2010; SAFE-IR 2012].

The application of thermal imaging on the fireground may help fire departments accomplish their primary mission, which is saving lives. This mission can be accomplished in many ways. First and foremost, in near zero visibility conditions, primary searches may be completed quickly and with an added degree of safety. The use of thermal imaging technology may also be invaluable when a fire department is confronted with larger floor areas or unusual floor plans [SAFE-IR 2012]. Searching for trapped civilians is part of a fire department's primary mission. At times, the search may be for a member who has become separated from the company or crew. TICs may also provide a method for fire fighters to track and locate other fire fighters in very limited visibility conditions. The TIC may provide invaluable **assistance** in locating a missing member of the company or crew. This process can enhance fire fighter accountability before an issue arises [NISH 2009b].

At a structure fire, the TIC may help identify the location of the fire or the extent of fire involvement prior to fire fighters being deployed into a structure. Knowing the location of the fire may help fire fighters determine the best approach to the fire. The TIC may provide additional information for a crew making the fire attack that they would not previously have due to poor visibility and building construction. Using this information, fire fighters may be able to locate the fire more quickly and may also ensure that the water application is effective. One of the most important aspects of the TIC is that when used properly it may provide the potential to detect a fire that is isolated or hidden within parts of a structure [Corbin 2000]. While the use of a TIC is important, research by Underwriters Laboratories has shown that there are significant limitations in the ability of these devices to detect temperature differences behind structural materials, such as the exterior finish of a building or outside compartment linings (i.e., walls, ceilings, and floors) [UL 2009].

Of all the operations in which the TIC can improve a fire fighter's efforts, this technology has the most dramatic impact on search and rescue. Fire fighters using thermal imagers can see the room, which enables them to quickly navigate and identify victims. Without a TIC, fire fighters search burning buildings by crawling through smoke to try and locate possible victims.

From a ventilation perspective, fire fighters can use the TIC to identify areas of heat accumulation, possible ventilation points, and significant building construction features. This helps ensure proper and effective ventilation that successfully removes smoke and heat from a building.

Technology is rapidly changing with TICs. When fire departments are considering the purchase of a TIC, they should refer to the most current edition of NFPA 1801 *Standard on Thermal Imagers for the Fire Service* [NFPA 2010b].

In this incident, the initial hose crew did not have a TIC with them. A TIC may have been able to help them account for all the fire fighters during their exit or may have allowed the fire fighter to find the hoseline and escape. A TIC may have also be able to help locate the seat of the fire or even the fire and/or excessive heat above them in the ceiling void space.

Recommendation #14: Research organizations and manufacturers should consider new technologies for enhanced accountability and fire fighter tracking.

Discussion: Manufacturers, equipment designers, and researchers should conduct research into refining existing and developing new technology to track the movement of fire fighters inside structures. Fire fighter fatalities often are the result of fire fighters becoming lost or disoriented on the fireground. The use of systems for locating lost or disoriented fire fighters could be instrumental in reducing the number of fire fighter deaths on the fireground. The National Institute for Standards and Technology (NIST) has been evaluating the feasibility of real-time fire fighter tracking and locator systems [NIST 2006, 2012]. Research into refining existing systems and developing new technologies for tracking the movement of fire fighters on the fireground should continue [NIOSH 2009a].

There are currently available electronic accountability systems that can assist the incident commander by acknowledging the fire fighters on a particular scene. The system can also let the incident commander (or accountability officer) know if the fire fighter’s PASS device has gone into pre-alarm or full alarm. The same system can be used to electronically order an evacuation of one fire fighter or a group of fire fighters. Future systems should consider the ability of accountability officers to monitor the air supply of fire fighters and keep division officers advised of crews going through milestone markers such as the SCBA 50% and whenever users have entered into their SCBA end of service time indicator.

Many emergency response agencies use mobile data terminals in fire apparatus and command vehicles. With the advancements in technology information that is stored in an agency’s computer-aided dispatch (CAD) system, information on pre-incident planning and target hazard occupancy can be provided to responding units for a defined occupancy. This information can be a valuable tool for the first responders, especially when the jurisdiction has many target hazard occupancies. Also, this information assists the incident commander in developing a strategy and Incident Action Plan for an occupancy that has been pre-planned and/or is a target hazard. Another important resource that the CAD system can provide to fire fighters and other first responders is the ability to view the address of the incident to view the structure. This can be done using a mapping program (e.g., Google Earth) that gives the fire officer a current view including a street view of the building.

Recommendation #15: Code-setting organizations and municipalities should consider requiring the use of sprinkler systems in commercial structures, especially ones having high fuel loads and other unique life-safety hazards, and establish retroactive requirements for the installation of fire sprinkler systems when additions or renovations to commercial buildings increase the fire and life safety hazards.

Discussion: This recommendation focuses on fire prevention and minimizing the impact of a fire if one does start. The *NFPA Fire Protection Handbook* states: "Throughout history there have been building regulations for preventing fire and restricting its spread. Over the years these regulations have evolved into the codes and standards developed by committees concerned with fire protection. The requirements contained in building codes are generally based upon the known properties of materials, the hazards presented by various occupancies, and the lessons learned from previous experiences, such as fire and natural disasters" [NFPA 1997]. Although municipalities have adopted specific codes and standards for the design and construction of buildings, structures erected prior to the enactment of these building laws may not be compliant. Such new and improved codes can improve the safety of existing structures [Naum 2014b]. Sprinkler systems are one example of a safety feature that can be retrofitted into older structures. Sprinkler systems can reduce civilian and fire fighter fatalities since such systems can contain and may even extinguish fires prior to the arrival of the fire department.

In this incident, this structure was a commercial strip mall building. The original structure was built in the 1970s and was not required to be retrofitted with sprinklers.

Recommendation #16: SCBA and PASS manufacturers, standards-making organizations, and research organizations should consider a certification impact test to prevent power supply interruption to PASS devices that are in full alarm.

Discussion: The electronics component in SCBA and PASS devices should be capable of operating in extreme environments that fire fighters encounter. Current testing and certification of electronics included with SCBA and PASS are tested to NFPA 1981 *Standard on Open-Circuit Self-Contained Breathing Apparatus for Emergency Services* [NFPA 2013c] and NFPA 1982 *Standard on Personal Alert Safety System* [NFPA 2007]. There are a number of certification tests that simulate extreme environments such as heat, cold, moisture, and impact. The current impact testing includes a 6-inch drop test (for the entire SCBA and PASS ensemble) and a specific tumble test for the PASS device. During the tumble test, the PASS device is not powered on during the long test but is powered on and checked for proper operation after the test. SCBA and PASS manufacturers, standard-making organizations, and research organizations should consider developing a certification impact test while the device is powered on (in full alarm) to ensure the device does not power off inadvertently.

In this incident, the fire fighter's PASS device data logger recorded his PASS activities during the incident. The data logger recorded his initial air on (PASS activated) at approximately 08:21. A low battery signal recorded on the data logger at 08:27:44, then a pre-alarm (motion) at 08:32:53 was reset by the fire fighter. A radio transmission from the fire fighter giving his location in the structure was noted at 08:42:49, and then another transmission stating he was out of air was noted at approximately 08:45. The next notation on the PASS data logger indicated pre-alarm (motion) at approximately

08:46:15 then full alarm (motion) at 08:46: 27. The PASS stayed in full alarm for approximately 14 minutes until the data logger recorded a power off event at 0900:34, followed by a power on at 0900:36, then power off again at 09:00:37. At approximately 09:00, Engine 3 radioed Command that the north side of the building had collapsed. The fire event coinciding at approximately the same time was a rapid fire increase and building collapse. The fire fighter's PASS device was not heard by anyone at the fire scene during or after the fire. The fire fighter was located approximately 2 hours later under debris, but his PASS device was not going off although there was still battery life in the power pack. *Note: All times noted are approximate and have been gathered from radio logs, SCBA/PASS data logger information (adjusted for day light savings time), and information provided by the department.*

During the NIOSH investigation, the SCBA and PASS device were examined. The PASS device functioned during a field check (by NIOSH investigators) at the department's SCBA maintenance room and later at the NIOSH lab. The batteries were replaced by NIOSH investigators and the PASS device did function and alarm properly during the evaluation in the lab. It is not known why the PASS device powered off during the fire, but this occurred close to the same time the roof collapse was reported on the radio. It is unlikely that the fire fighter powered off his PASS due to the extremely short period between the recorded power off, power on, and power off events. This data logger event occurred approximately 14–15 minutes after his "out of air" radio transmission and 14 minutes after his lack of motion data logger event.

During the examination of the SCBA and PASS device, NIOSH investigators and certification personnel requested and received technical assistance from the manufacturer in obtaining the data logger information. The SCBA involved in this incident exhibited signs of severe damage likely sustained during the roof collapse. The PASS device was not severely damaged, but the power supply for the electronics, which was located in the SCBA back frame assembly, was damaged.

The NIOSH SCBA examination report is included in Appendix 2.

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Investigator Information

This incident was investigated by Stephen Miles and Jay Tarley of the NIOSH Fire Fighter Fatality Investigation and Prevention Program, Surveillance and Field Investigations Branch, Division of Safety Research, located in Morgantown, West Virginia. The report was authored by Stephen Miles. An expert technical review was provided by Chief Christopher J. Naum, SFPE (NY). Chief Naum also provided information on building construction, performance, and predictive risk and insights on structural collapse and compromise. His full report is included in Appendix 1. A technical review was also provided by the National Fire Protection Association, Public Fire Protection Division. Some text provided by expert reviewers was incorporated into the final report.

Additional Information

IAFC Rules of Engagement for Firefighter Survival

The International Association of Fire Chiefs (IAFC) is committed to reducing fire fighter fatalities and injuries. As part of that effort, the nearly 1,000-member Safety, Health and Survival Section of the IAFC has drafted *Rules of Engagement for Structural Firefighting* to provide guidance to individual fire fighters and incident commanders, regarding risk and safety issues when operating on the fireground. The intent is to provide a set of model procedures for structural fire fighting to be made available by the IAFC to fire departments as a guide for developing their own standard operating procedure (http://www.iafcsafety.org/downloads/Rules_of_Engagement).

IAFF Fireground Survival Program

The purpose of the International Association of Fire Fighters (IAFF) Fireground Survival Program is to ensure that training for Mayday prevention and Mayday operations are consistent between all fire fighters, company officers, and chief officers. Fire fighters must be trained to perform potentially life-saving actions if they become lost, disoriented, injured, low on air, or trapped. Funded by the IAFF and assisted by a grant from the U.S. Department of Homeland Security through the Assistance to Firefighters (FIRE Act) grant program, this comprehensive fireground survival training program applies the lessons learned from fire fighter fatality investigations conducted by the National Institute for Occupational Safety and Health (NIOSH) and has been developed by a committee of subject matter experts from the IAFF, the International Association of Fire Chiefs (IAFC), and NIOSH (http://www.iaff.org/HS/FGS/FGSIndex.htm).

CommandSafety.com

Predictability of occupancy performance during suppression operations
http://commandsafety.com/2010/02/predictability-of-occupancy-performance-during-suppression-operations/

Building Knowledge = Firefighter Safety, Know Your District and its Risk
http://commandsafety.com/2009/06/fireems-safety-health-and-survival-week-day-two-building-knowledge-firefighter-safety-know-your-district-and-its-risk/

National Institute for Occupational Safety and Health
Paid-on-call Fire Fighter Killed by Exterior Wall Collapse During Defensive Operations at a Commercial Structure Fire—Illinois. Fatality Assessment and Control Evaluation (FACE) Report F2011-15

Career Fire Fighter Dies Following Structure Collapse at a Triple-decker Residential Fire—Massachusetts. Fatality Assessment and Control Evaluation (FACE) Report F2011-30

NIOSH Alert: Preventing Injuries and Deaths of Fire Fighters Due to Structural Collapse, DHHS (NIOSH) Publication No. 99-146

National Institute of Standards and Technology
The Building and Fire Research Laboratory of the National Institute of Standards and Technology (http://www.fire.nist.gov/) maintains a website with links to publications on a number of fire safety topics:

Early Warning Capabilities for Firefighters: Testing of Collapse Prediction Technologies
http://www.fire.nist.gov/bfrlpubs/fire03/art072.html

Early Warning Capabilities for Firefighters: Testing of Collapse Prediction Technologies
http://www.fire.nist.gov/bfrlpubs/fire02/art144.html

Trends in Fire Fighter Fatalities Due to Structural Collapse, 1979–2002
http://www.fire.nist.gov/bfrlpubs/fire03/art024.html

Structural Collapse Research at NIST. By DW Stroup and NP Bryner. Presented at Interflam '07, International Interflam Conference, September 3-5, 2007
http://www.fire.nist.gov/bfrlpubs/fire07/art084.html

Disclaimer

Appendix 1

NIOSH F2013-14
(MI) FD Fire Fighter LODD
Commercial Fire & Collapse
May 8, 2013

BUILDING CONSTRUCTION ANALYSIS AND INSIGHTS REPORT
Prepared for;
Stephen T. Miles
NIOSH Fire Fighter Fatality Investigation Team

Submitted November 8, 2014
FINAL Version

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I. Building Construction
   a. Shopping Center Layout and Configuration

II. Building Construction and Occupancy
   a. Tenant Spaces: Construction and Materials
   b. Pool Hall and Restaurant Roofing System

III. Fire-fighter Risk Profile and Insights
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IV. Operational Factors and Considerations
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I. Building Construction

Shopping Center layout and Configuration
The shopping center property consisted of two (2) primary commercial retail buildings configured in an L-shaped layout that were not physically connected. The shorter building was approximately 260 ft. x 125 ft. (32,500 SF) with the longer building approx. 100 ft. x 625 ft. (59,000 SF). The buildings housed commercial retail and business tenant spaces with two (2) standalone buildings located on the property as well. Individual tenant spaces varied in commercial/retail use and size (SF).

The individual tenant spaces opened directly to an exterior pedestrian sidewalk area and then to the parking lot, which reflects the common strip shopping center configuration of the 1970's time period. A perimeter access road surrounds the buildings for service and deliveries, with a primary parking lot located along the store fronts and adjacent to the two primary highways and intersection. The property was located in a mixed use area that consisted of business, retail and residential occupancies and density levels in an urban setting. A perimeter barrier fence bound the site on two sides. There were five (5) access points leading in and out of the property. (Refer to Photos 1 & 2)

The attached end unit tenant space subsequently caught fire, culminating in a catastrophic roof collapse of that area, which resulted in the firefighter fatality. Progressive fire extension and structural collapse occurred in an adjacent tenant space occupied by a restaurant within the main building shopping complex. The fire and collapse originated in the farthest north end of the larger retail building in the end tenant space and subsequently communicated to two other adjoining tenant spaces.

The shopping center was built in 1979 1 under the adopted building and construction codes in effect at that time, which was the BOCA Basic Building Code, 1975 edition and various Michigan amendments (adopted November 13, 1976)[3] . The shopping center structures were of Type II-non-combustible construction consisting of steel frame and supports and a masonry perimeter wall construction in accordance with NFPA 220 Standard.[2]

Proximal property exposures included a low rise multiple occupancy housing (west), single family residential homes (west and south) and a multiple occupancy apartment complex (north).

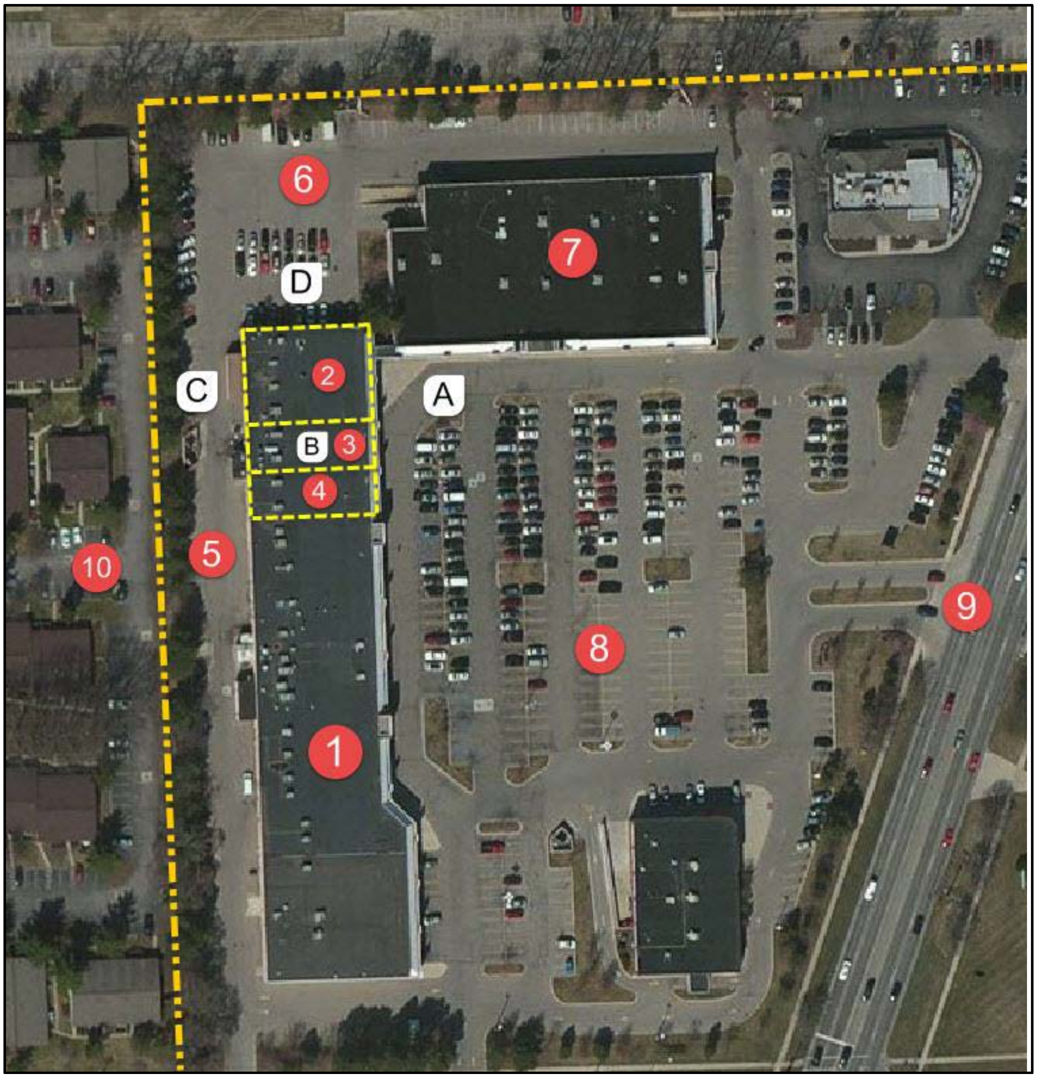

Photo 1. Aerial View of Shopping Center Complex and Buildings.
(Bing.com Maps/ Analysis Diagram Courtesy of Buildingsonfire.com.)

1. Larger Multiple Tenant Space Building; 59,000 SF – ~Fourteen (14) tenant spaces
2. Pool Hall; Location of Bulk of fire and Firefighter fatality; 8,000 SF
3. Restaurant; Expose Bravo (B) 4,000 SF
4. Tenant Space: Exposure B1 SF (fire wall separation located at south interior partition) 4,000 SF – ~Seven (7) tenant spaces
5. Service-Delivery Road: Charlie (C) Division
6. Parking Lot (North) Delta (D) Division
7. Smaller Multiple Tenant Space Building; 32,500 SF (not attached)
8. Primary Open Public Parking Lot
9. Main Center Entrance off Major Highway

10. Single family residential Exposures (beyond perimeter fence line)

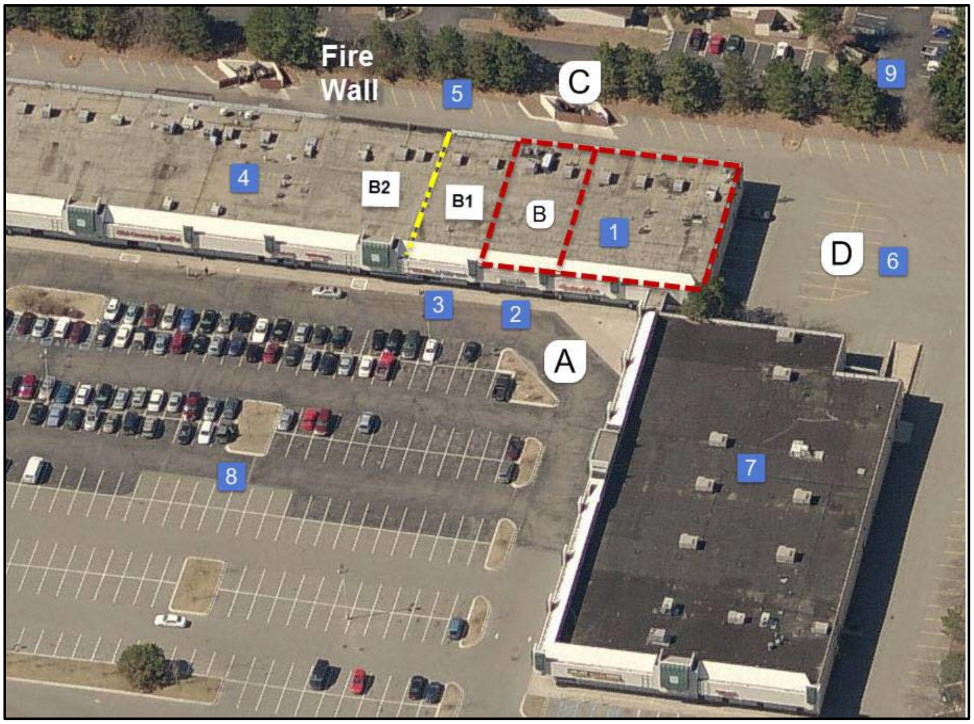

Photo 2 Aerial View of Fire Building Location and Exposures.
(Bing.com Maps/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Geographic north end of the primary retail building; Primary access from public parking lot with direct access to individual tenant spaces. Note number of roof top air handling units (RTU) or also referred to as Heating, Ventilation & Air Conditioning Units (HVAC)

1. Pool Hall; Originating Location of Bulk of Fire and Firefighter Fatality; 8,000 SF
2. Restaurant; Expose Bravo (B) 4,000 SF
3. Tenant Space: Exposure B1 SF 4,000 SF
   B2 Exposure-Tenant Space: 4,000 SF (fire wall separation located at south interior partition) 4,000 SF
4. Remained of Multiple Tenant Space Building; 59,500 aggregate SF
5. Service-Delivery Road: Charlie (C) Division
6. Parking Lot (North) Delta (D) Division
7. Smaller Multiple Tenant Space Building; 32,500 SF (not attached)
8. Primary Open Public Parking Lot
9. Single family residential Exposures (beyond perimeter fence line)
   A- Alpha Division (East)
   B- Bravo Division (South)
      B1- Exposure (South)
      B2- Exposure (South)
   C- Charlie Division (West)

D- Delta Division (North)

II. Building Construction and Occupancy

Tenant Spaces: Construction and Materials
Restaurant and Pool Hall Complex
Constructed: Circa 19791

- Construction Type: Non-Combustible, (Unprotected Steel and Masonry)
- NFPA 220 Type: Type II (BOCA-Type 2)
- Occupancy: Commercial-Retail
- State Class Code: BOCA Use Group M Mercantile3
- Building Area:
  - Primary Tenant Building: 100 ft. x 625 ft. (59,000 SF).
  - Secondary Tenant Building: 260 ft. x 125 ft. (32,500 SF)
  - Pool Hall: 100 ft. x 80 ft. (8,000 SF)
  - Restaurant: 100 ft. x 40 ft. (4,000 SF)
- Total Number of Proximal Tenant Spaced in Building: Approx. Twelve (12)

Construction Systems:

- Floor Area:
  - Pool Hall- Open Floor Plan (Limited columns-2x) Large expanse of seating, tables and entertainment equipment present. Service area along the west wall with food preparation and service area behind.
  - Suspended acoustic tile ceiling system (ACT) Approximate height 12 ft. Concealed ceiling void space approx. 30, 000 cubic feet.
  - Restaurant- Limited Open Plan, with Raised entertainment stage, large expansive Bar and Stool Seating and Table Seating Area and Semi-enclosed. seating booths with observation windows looking directly into the adjacent Pool Hall occupancy.
  - These windows along the occupancy separation partition were protected by fire rated roiling coil steel curtains (3X) that provide fire separation between the tenant occupancies. Fully enclosed commercial food preparation kitchen area located to the interior west. Interior tenant space wall separation consisted of 2x4 dimensioned wood framing and gypsum wall board construction.
  - Suspended acoustic tile ceiling system (ACT) Approximate height 12 ft. (varied in booth seating area) Concealed ceiling void space approx. 9,000 cubic feet.
  - Various floor treatments included vinyl or ceramic tile and carpeting.
- **Perimeter Walls:** Concrete masonry units (CMU) with integrated outer face treatment. Bearing wall along the north exterior perimeter wall (PW) for pocketed bearing of steel bar joists in the pool hall occupancy. Limited controlled access (delivery) doors located along the service road Charlie Division
- **Store Fronts:** Alpha Division consisted of set back from road and parking lot by a 10ft wide concrete sidewalk and larger framed façade and overhang.
  - The façade included large decorative panel treatments, and metal roof perimeter screen wall for aesthetic treatment, and wood soffits.

- The concealed area of the façade and overhand included unprotected steel beams with bolted connections.
- 2x4 inch dimensioned wood framing, gypsum wall board and plywood.
- Storefronts varied with full height glass doors and metal framed panel windows, or a combination of partial brick walls and metal framed panel windows. The restaurant storefront included wood framed windows and shaker wood treatment on the exterior entry face.

- **Roof:** Flat Roof System- Approx. 18 inch depth Open Web (Crimped web) Steel Bar Joists with standard gage metal deck. Mechanically fastened rigid insulation board and membrane roofing covering.
  - Roof Top Units (RTU): numerous sized air handling units (AHU) also referred to as Heating, Ventilation & Air Conditioning Units (HVAC) present along a line running primarily north-side proximal to the Charlie (C) exterior perimeter wall. Framed into roof deck and joist openings.
  - Roof Framing included various sized unprotected (no fire proofing) Structural Steel I-Beams running East-West spanning the width of the building (100 ft.) The unprotected steel beams were bolt connected along the beam web, together in three (3) spans in the Pool Hall, Restaurant and Exposure occupancies.
  - The beam spans were supported by interior tube steel columns that were bolted to the bottom flange of the beam. These columns were encased in brick in the Pool Hall occupancy from the floor to just above the suspended acoustic tile ceiling system (ACT). They were imbedded in wall construction in the Restaurant occupancy.
- **Protective Systems**: None – No Fixed Sprinkler Protection System present within the occupancies or within the concealed spaced.

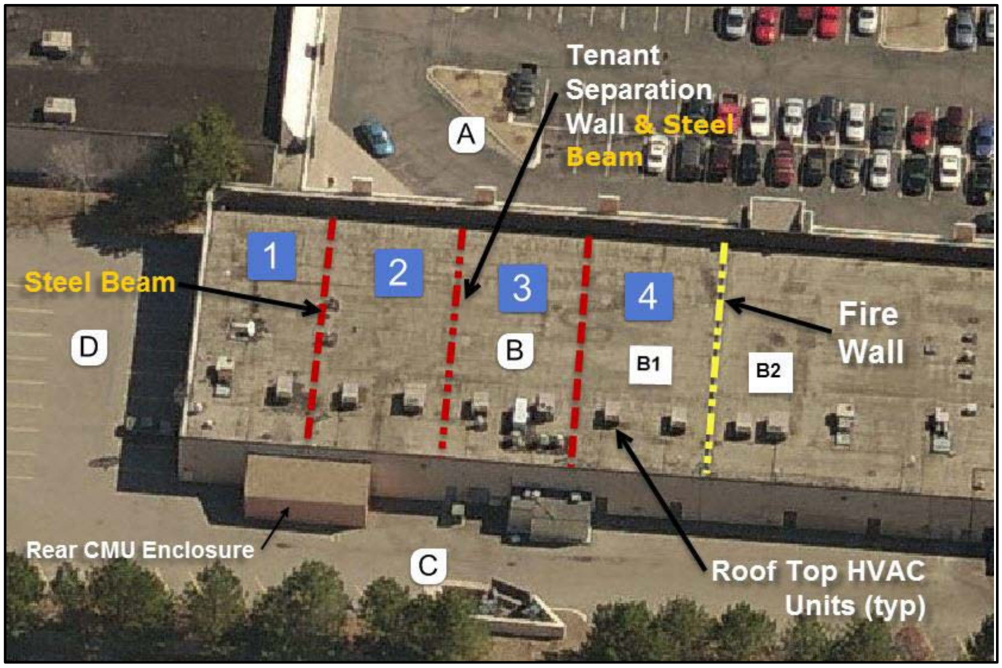

Photo 3 Pre-fire Division Charlie Aerial View of Fire Building Complex.
(Bing.com Maps/ Analysis Diagram Courtesy of Buildingsonfire.com.)

1. Pool Hall; congruent space-see #2 .
2. Pool Hall: Total area 8,000 SF.
3. Restaurant; Expose Bravo (B) 4,000 SF .
4. Tenant Space: Exposure B1 SF (4,000 SF) B2 Exposure-Tenant Space: 4,000 SF (fire wall separation located at south interior partition) 4,000 SF.
    - Unprotected Steel I-Beams spanning ~100 ft. east-west provided structural support for the steel joists that spanning ~ 40 ft. north-south (typical bay configuration).
    - Typical Roof Top Units (RTU): numerous sized air handling units (AHU) also referred to as Heating, Ventilation & Air Conditioning Units (HVAC) present along a line running primarily north-side proximal to the Charlie (C) exterior perimeter wall. Framed into roof deck and joist openings. Included in the roof opening were fan ventilators from the kitchen areas.
    - A designated fire wall provided fire area zone separation from the upper tenant spaces from the next designed fire area zone within this building foot print.

A- Alpha Division (East)
B- Bravo Division (South)
B1- Exposure (South)
B2- Exposure (South)
C- Charlie Division (West)
D- Delta Division (North)

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Photo 4. Pre-fire View of Fire Building Entrance-Pool Hall, Alpha Division.
(Photo: Luna Tech 3D (2012)/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Photo 5. Pre-fire View of Fire Building Entrance-Pool Hall Alpha Division.
(Photo: Luna Tech 3D (2012) /Analysis Diagram Courtesy of Buildingsonfire.com.)

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Photo 6. Pre-Fire Interior View of Pool Hall Building Occupancy.
(Photo: Luna Tech 3D (2012)/ Analysis Diagram Courtesy of Buildingsonfire.com
Interior view looking towards the west-Pre-fire.)

Photo 7. Post Fire Collapse Interior View of Pool Hall Building Occupancy.
(Photo: NIOSH/ Analysis Diagram Courtesy of Buildingsonfire.com
Interior view looking towards the west: Post-fire.)

Photo 8. Pre-fire Street View of Restaurant Building Entry Alpha.
(Photo: Luna Tech 3D (2012)/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Photo 9. Pre-Fire Street View of Restaurant Building Entry Alpha.
(Photo: Luna Tech 3D (2012 / Analysis Diagram Courtesy of Buildingsonfire.com.)

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Photo 10. Pre-Fire Interior View of Restaurants Occupancy.
(Photo: Luna Tech 3D (2012)/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Photo 11. Post Fire Collapse Interior View of Restaurant Occupancy.
(Photo: NIOSH / Analysis Diagram Courtesy of Buildingsonfire.com.)

Pool Hall and Restaurant and Roof Construction Systems
Flat Roof System: Approximate 18 inch deep Open Web (Crimped web) Steel Bar Joists with standard gage 36 inch wide metal decking with mechanically fastened rigid insulation board and membrane ply roofing covering.
Contiguous Roof: Pool Hall Area= ~8,000 SF / Restaurant= ~4,000SF

- ~18 inch deep Open Web Steel Bar Joist at ~ 4 ft. on center (est) Span= ~ 40 feet (est) (unprotected) [24,25,26]
- Structural Steel I-Beam, multi-span, ~ 100 ft., total span (unprotected) 24,25,26
    - Roof Top Units (RTU): numerous sized air handling units (AHU) also referred to as Heating, Ventilation & Air Conditioning Units (HVAC) present along a line running primarily north-side proximal to the Charlie (C) exterior perimeter wall. Framed into roof deck and joist openings.
    - Roof Framing included various sized unprotected (no fire proofing) Structural Steel I-Beams running East-West spanning the width of the building (100 ft.)
    - The unprotected steel beams were bolt connected along the beam web, together in three (3) spans in the Pool Hall, Restaurant and Exposure occupancies.
    - The beam spans were supported by interior tube steel columns that were bolted to the bottom flange of the beam. These columns were encased in brick in the Pool Hall occupancy from the floor to just above the suspended acoustic tile ceiling system (ACT). They were imbedded in wall construction in the Restaurant occupancy.
    - Suspended acoustic tile ceiling system (ACT) Approximate height 12 ft. Varies in Restaurant occupancy. Concealed ceiling void space approx. 30, 000 cubic feet (est). In Pool Hall and 9,000 cubic feet (est) in the Restaurant occupancy.

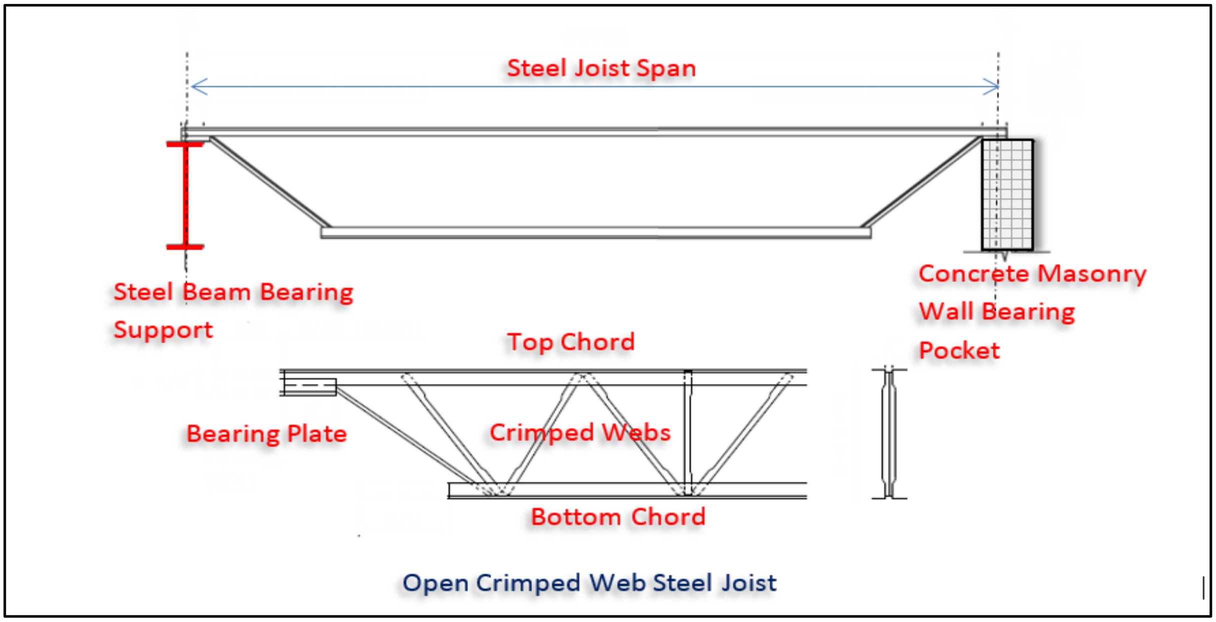

Figure 1. Plan Details of Roof Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

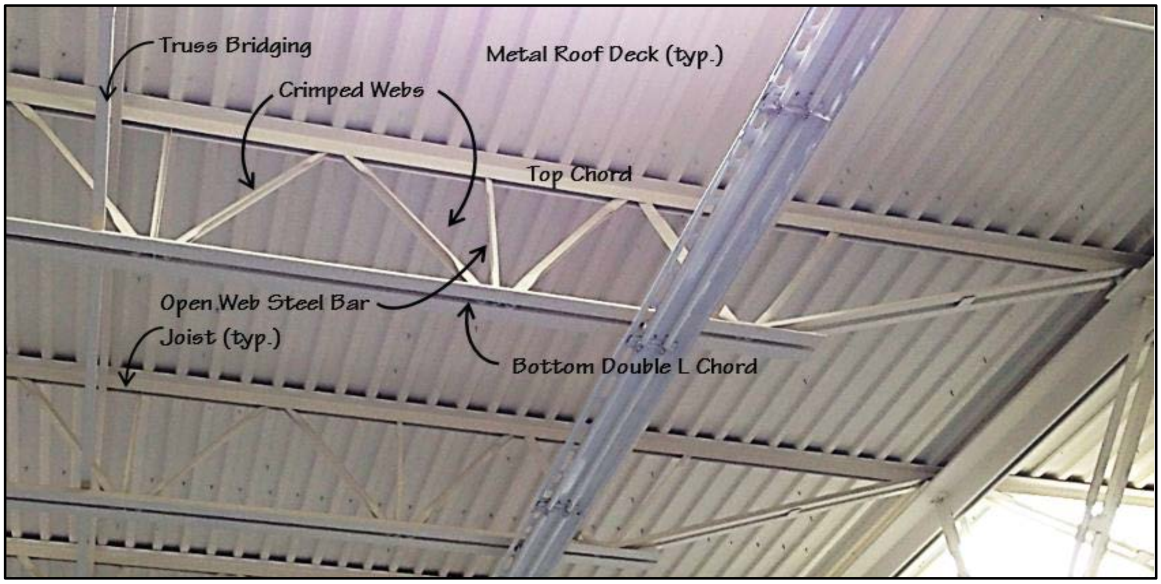

Photo 12. Pre-Fire View of Restaurant Roof Structure.
Photo and Analysis Diagram Courtesy of Buildingsonfire.com (this is a representative photo-not actual incident condition.)

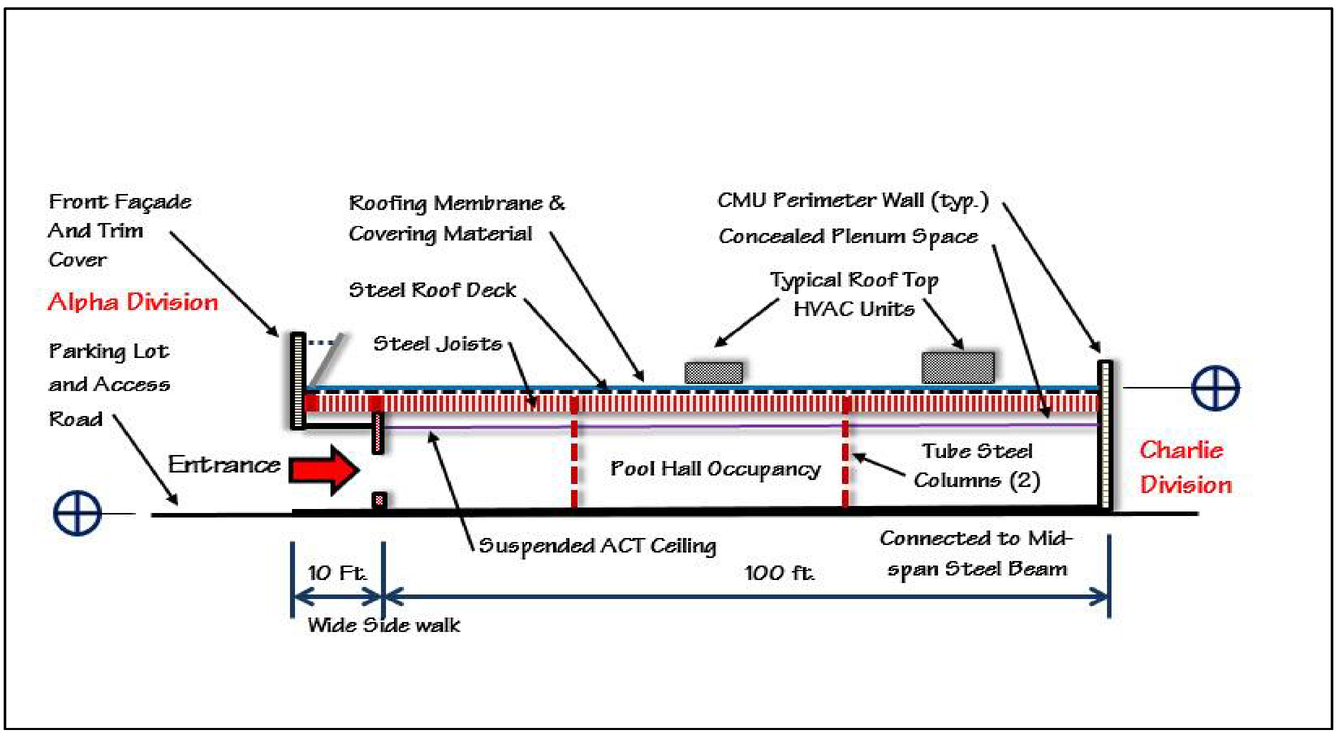

Figure 2. Plan Details of Roof Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

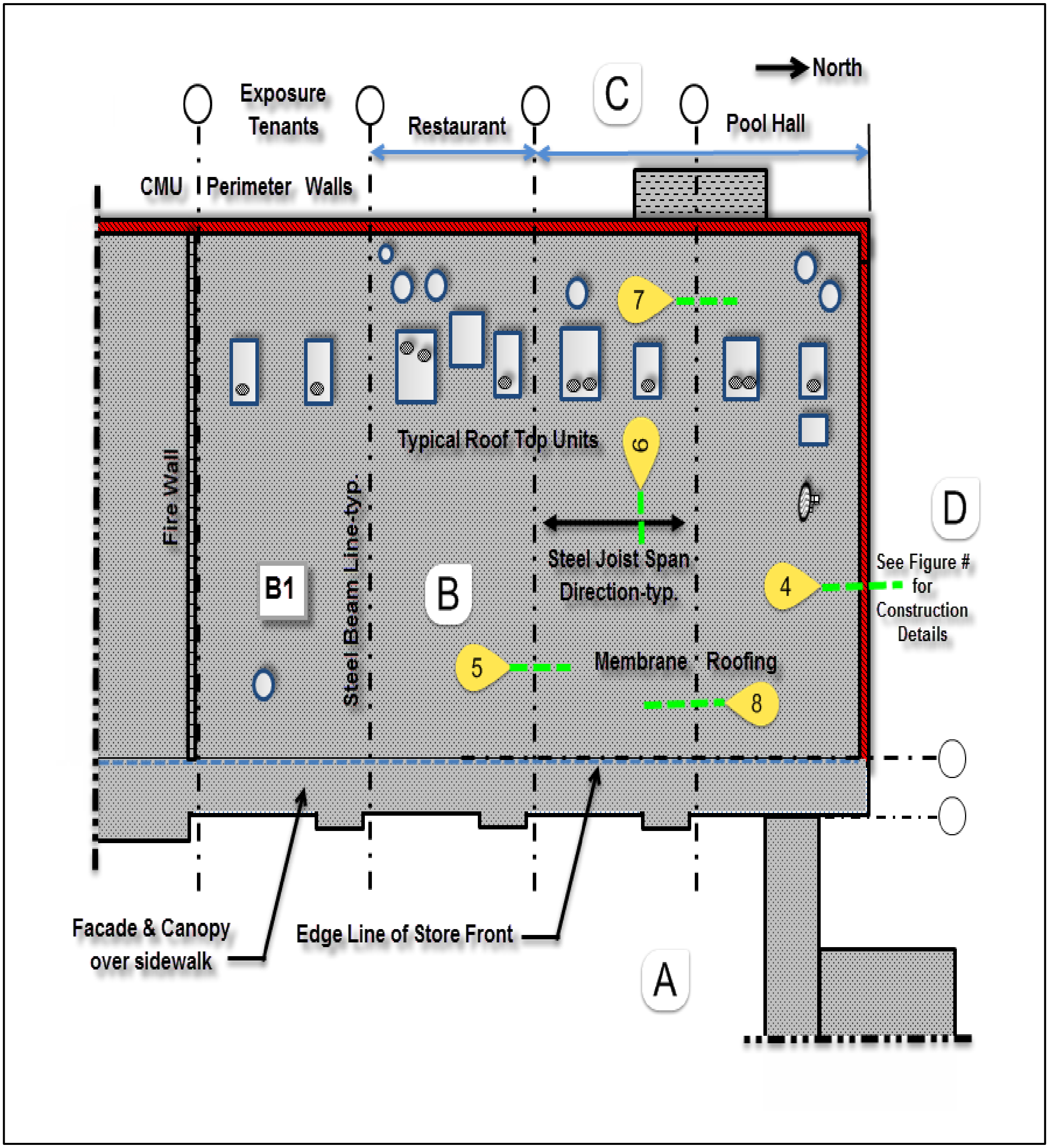

Figure 3. Roof Plan and RTU Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

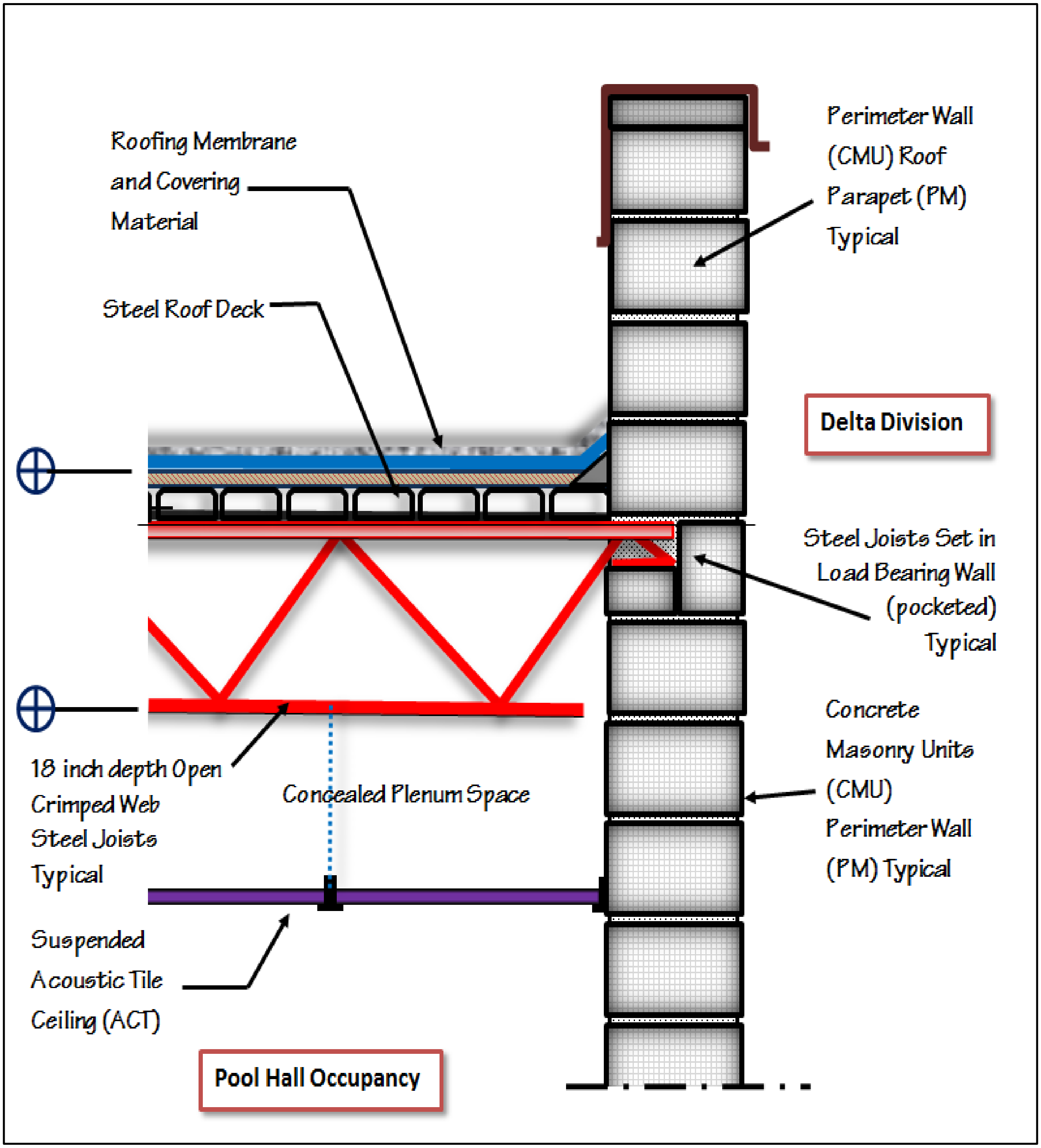

Figure 4. Section Detail of Roof Joist Configuration at Delta Wall.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

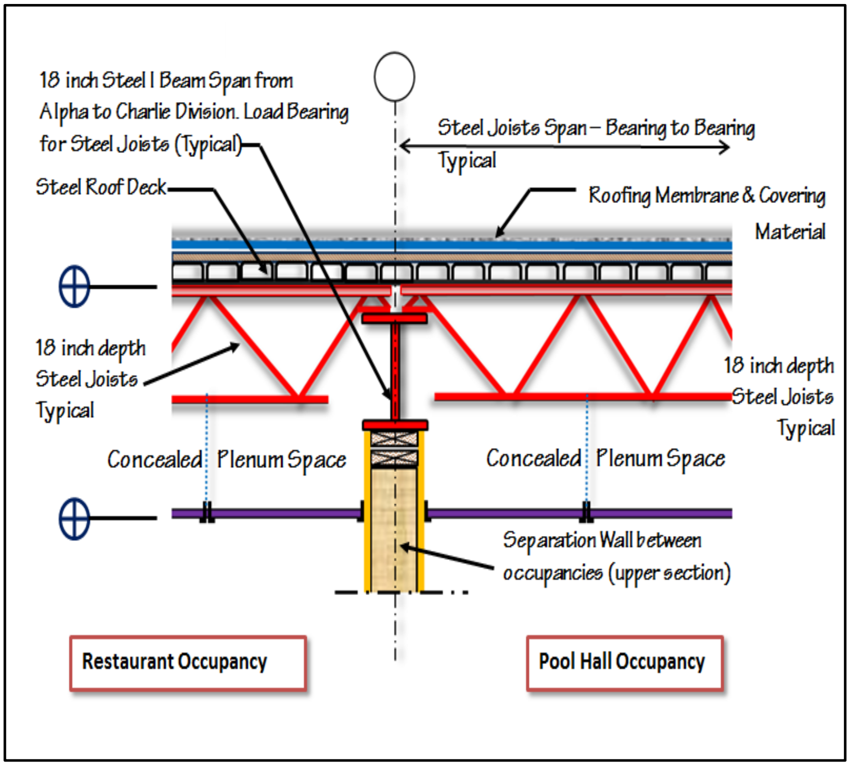

Figure 5. Plan Details of Roof Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

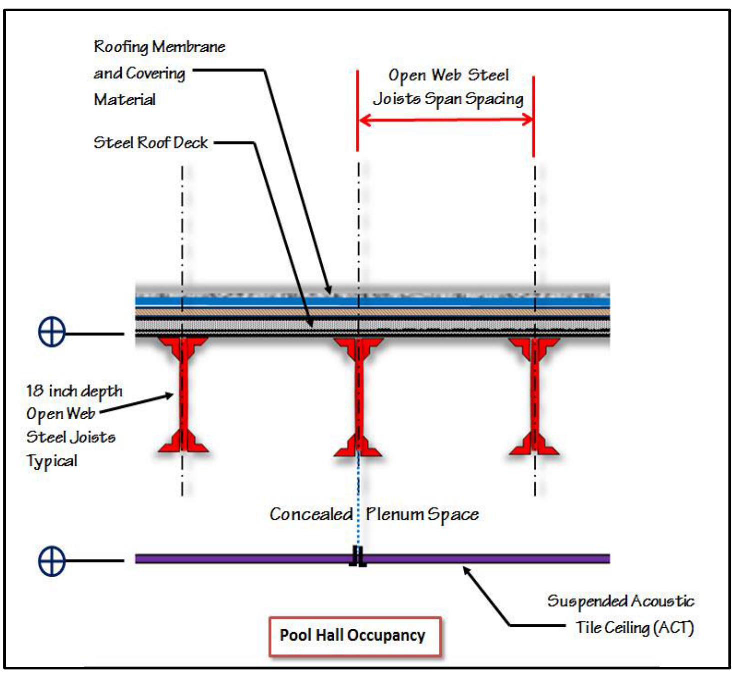

Figure 6. Plan Details of Roof Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

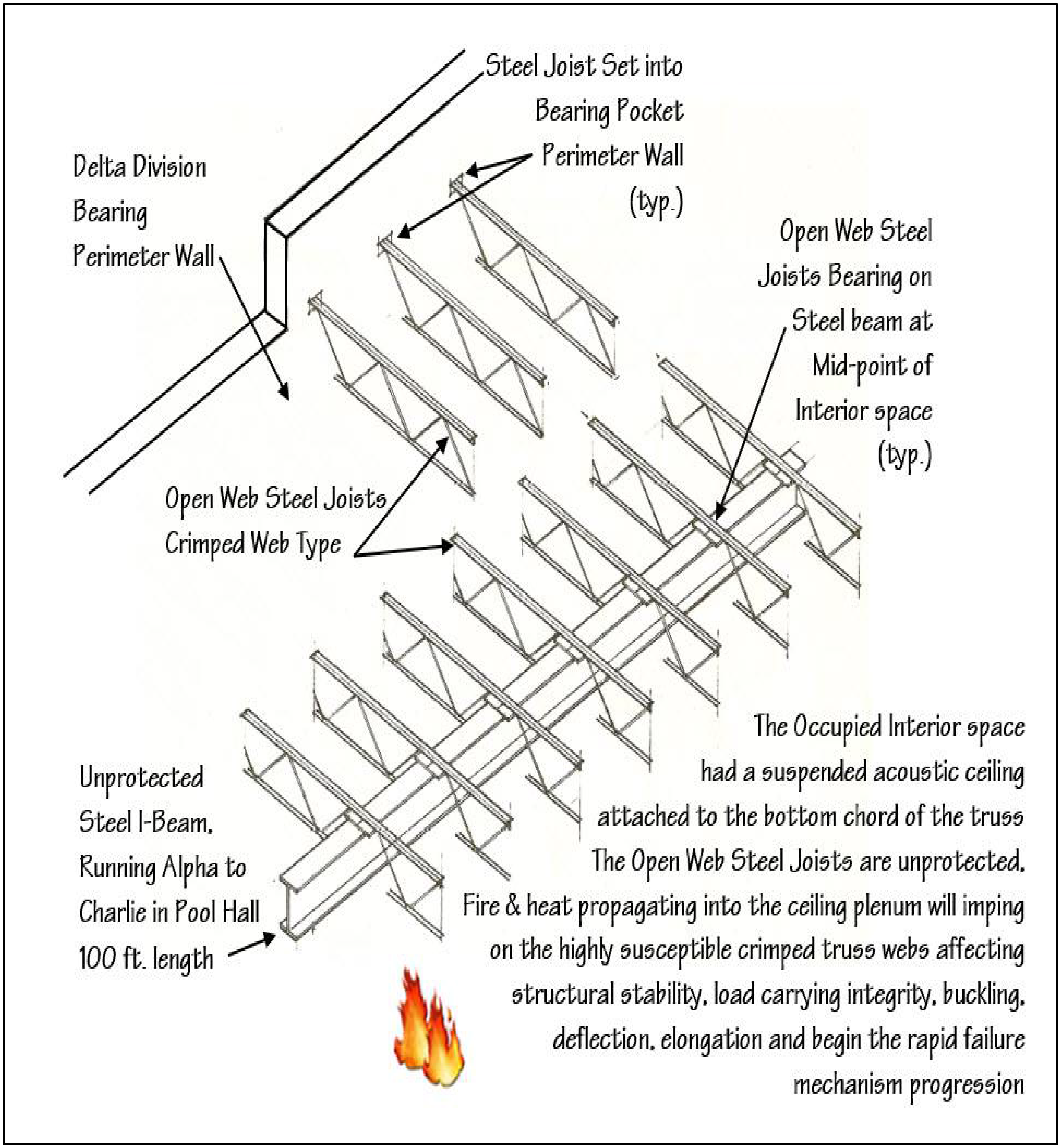

Figure 7. Details of Roof Structural Steel Beam/Joist Configuration.
(Analysis Diagram Courtesy of Buildingsonfire.com,
Refer to Figures 4 & 8 and Photos 14, 15 and 20 for additional construction details and assembly configurations.)

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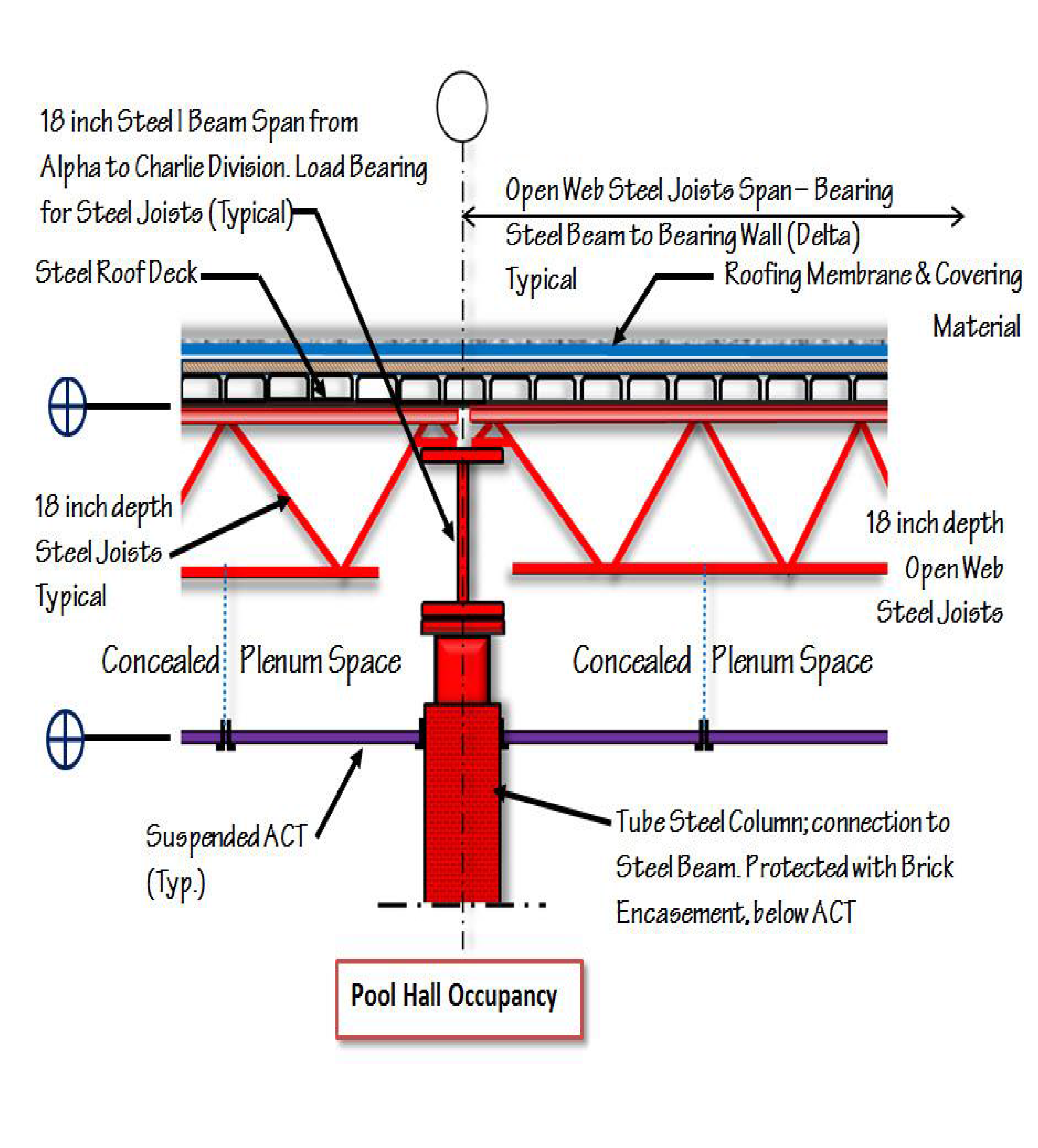

Figure 8. Plan Details of Roof Configurations.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

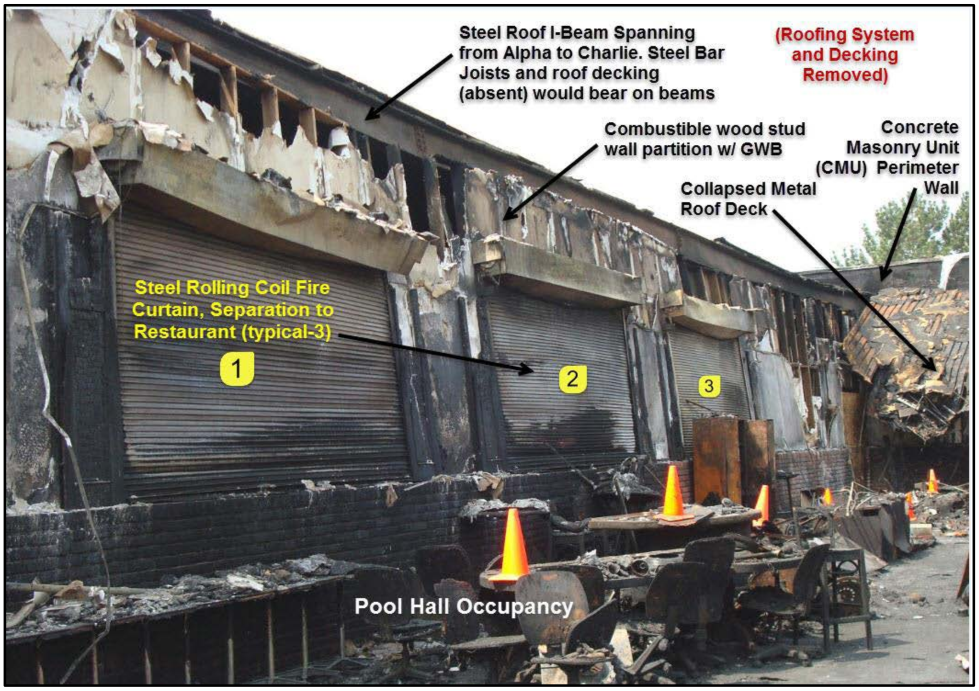

Photo 13. Rolling Coil Fire Curtain- Pool Hall Occupancy.
(Photo: NIOSH / Analysis Diagram Courtesy of Buildingsonfire.com.)

III. Fire-Fighter Risk Profile and Insights

Occupancy Risk Profile

The tenant spaces within the shopping center that comprised the building envelope and spaces had common inherent building, construction, design features and characteristics which would provide a recognizable predictability of expected building performance under fire conditions. Non-Combustible (un-protected) steel structural assemblies present in retail commercial complex have defined and expected performance, risks and hazards that define the conduct of fireground operations.

This predictability of building performance had definable degrees of risk potential that once identified and assessed against an evolving fireground scenario can be align with recognized strategic and tactical measures that must be considered and implemented in order to increase the probability of a safe and effective incident stabilization and mitigation. The time-demand identification and selection of tactical measures is borne with the arrival of the first-due company: the effectiveness and suitability of those tactical measures are validated or alter by the assuming command officer or incident commander.

Understanding the building's anatomy, its current occupancy use and the characteristic of the building's internal compartments (occupied rooms and space use) are integral to effective and efficient firefighting operations within buildings on fire and are essential for all phases of fire engagement and suppression.[4]

The challenge for today's incident commanders and operating companies on the modern fireground is to clearly recognize building performance factors and inherent characteristics fundamental to the manner in which a building's anatomy (and fire conditions) presents itself at an evolving incident and to ascertain and distinguish how it will subsequently perform during fire duress and the continuum of elapsed incident time.[4,5]

The prevailing building characteristics present, for the Pool Hall and Restaurant Occupancy and adjacent tenant spaces within the context of the strip shopping center design, the overall building anatomy, operational risk and probability of performance for operating firefighting personnel and in the management of the incident is Normal-Marginal, with a higher emphasis toward the Marginal band primarily due to the inherent unprotected steel frame and steel bar joist construction, interconnected building tenant spaces and the roofing systems structural support, structural spans and the open floor areas of the Pool Hall occupancy.

The lack of a fixed fire protection system in the occupied tenant spaces and the concealed ceiling plenum creates significant risks to firefighter personnel and makes the building highly susceptible to structural compromise and collapse due to fire.

The inherent building materials in the form of the light-frame structural steel system, the presence of a contiguous metal gage roof diaphragm, unrestrained steel beams and a moderate to high interior fuel load package (common to retail shopping occupancies) that would contribute towards fire growth in both intensity and magnitude support the premise of a higher probability of expected fire development in a compartment , rapid fire extension in the event of a fire incident and building component and assembly compromise , deterioration, failure and collapse.

The Pool Hall occupancy's severity of risk would be considered marginal-critical with the operational probability of an adverse event to be High (H) to Extreme (E) resulting in a likely event to occur during operational times. The large open span floor area, concealed plenum and structural support system increase that occupancy risk.

The Restaurant occupancy that adjoined the Pool Hall had a normal risk severity based on design, layout, occupancy use and construction systems and features. The presence of the observation window glazing in the booth seating area of the restaurant and the fire protective rolling coil steel curtains is the only non-conventional attribute found in the commonality of the occupancy.

The type of roof construction system and roof diaphragm in the form of an open web steel bar joist and steel beam system when identified on the fireground should be considered an indicator that:

- structural stability & integrity must be closely monitored or considered a higher risk factor and overall operations conducted under this area may be consider at-risk deployments that require fluid and concise risk-benefit assessment,
- investigation or presumption of actual or projected supporting methods for beams, columns or secondary roof or diagram supports must be considered since building or structural integrity could be compromised,
- the possible presence of large open span areas may be a probable (based in occupancy and tenant use, due-diligence must be exercised and considered if fire or fire-indictors are present,
- concise incident monitoring should be considered based on incident priorities, immediate or deferrable operational demands associated with life hazards and fire severity, growth or propagation.

The structural collapse potential and probability would be considered a predominate building performance consideration and predictability variable for operations, if identified by command or company officers and assimilated as such into the initial on-scene size-up and incident risk assessment process during tactical plan development.

The presence of an unprotected steel bar joist/metal deck roof and structural roof system in a commercial building, its influence on the and the impact of fire dynamics within the room or a concealed plenum, void space between a ceiling and roof underdeck or in the presence of exposed underdeck and support construction in the compartment- elevate occupancy risk considerations and directly impact firefighter safety.

The susceptibility for the lack of tenant space separation in the form of either fire rated fire walls, partition or the presence of voids, and probability of common open penetrations between tenant spaces presents commonalities that would lead to selective strategic or tactical determinations and incident management.

These factors would also dictate and influence required sustainable fire flow and deliverability rates for fire suppression tasks and the optional manner in which that deliverability would be implemented (hand lines, size and capacity, flow rate, interior, exterior, master streams, elevated streams etc.).

Predicting a potential structural collapse is one of the most challenging tasks facing an incident commander at a fire scene. Usually the lack of information on the construction of the building, fire size, fire location, fire burn time, condition of the building, fuel load, etc., makes the task nearly impossible. [7,10,31,32,33]

- Pre-incident information, pre-fire plans and building knowledge are mission critical- at a minimum for the first-due area response.
- Understanding building construction, related engineering, reading key building indictors and having the skills to take those observations, comprehend, assimilate and apply predictive modeling and projected outcomes to tactical objectives and incident action plans thus increases exponentially the safety margin to have successful incident outcomes and not unexpected events.

Building Risk and Severity Considerations[10]

- Building Construction System and Type
- Building Age, Vintage and Condition
- Building use and function
- Structural Collapse characteristics of Steel Joist/Beam Roofing Systems; structural integrity and collapse considerations
- Building Size and Volume: large open span spaces and individual occupancy compartments tenant spaces
- Inherent Structural Compromise and Collapse potential-internal due to unprotected construction systems, materials and structural assemblies
- Degree of tenant space compartmentation: connectivity of concealed spaces and compartments and high probability for unstopped concealed spaces, voids and plenum spaces under the roof deck

- Physical arrangement of tenant occupancies (pool hall-restaurant-exposures) and impacts from smoke tunneling, compartment ventilation, single or multiple flow paths routes, ventilation-limited or fuel-limited conditions, tenability and connectivity of spaces-fire dynamics
- Fire Loading and potential for significant Heat Release Rates/effects on fire suppression based on commercial-retail tenant occupancy use
- Identifiable and Measurable Safety parameters
- Adequacy of Fire Flow Rates based on postulated fire growth and selected tactics
- Probability of Rapid Fire Travel and Extension growth
- Uncertainty of Civilian Occupancy Load
- Uncertainty of Civilian Occupancy Reaction Time and Responsiveness to Emergencies
- Probability of Fire Department Life Hazard and Risk Threat
- Resource Intensive Deployment Requirements
- Identified Severity of Risk Level and Acceptability of Risk to Organization

Buildings on Fire Risk Assessment Matrix

Levels	Severity of Risk
Catastrophic	**May result in personnel death, grave personnel injury, large-scale destruction, and perilous conditions**
Critical	**May cause severe personnel injury, possible death; major property loss or significant degraded conditions**
Marginal	**May cause or result in personnel injury, prominent property loss or degraded and compromised conditions**
Normal	**Hazards and conditions are consistent with generally accepted Fire Service work practices and operational parameters for adequately resourced and trained companies. Operations may cause or result in some personnel injury, corresponding property loss or damage conditions consistent with firefighting principle & practices**
Negligible	**Conditions have minimal threat to the safety and wellbeing of companies operating under generally accepted Fire Service work practices and parameters**

Figure 9. Buildings on Fire Risk Assessment Matrix.
(Courtesy of Buildingsonfire.com and the Command Institute, additional information can be accessed at http://buildingsonfire.com/buildings-on-fire-risk-assessment-matrix.)

Based on potential severity and urgency factors given a fire of any great magnitude or other initiating event, this would require judicious and thoughtful pre-fire planning to not only identify postulated incident events and occurrences, but to also assess the potential demands for escalating incidents, resource needs and suggested incident management scenarios, situations and consequences. [7, 10]

The Identified Severity of Risk Level for postulated incident conditions for the tenant spaces involved and the overall shopping building complex suggests a defined level of:

Marginal; May cause or result in personnel injury, prominent property loss or degraded and compromised conditions.

The Severity of Risk Level for postulated incident conditions for the Pool Hall and Restaurant tenant spaces in the building section suggests a defined level of:

Critical; May cause severe personnel injury, possible death; major property loss or significant degraded conditions.

- This is based on two primary factors; the presence of the unprotected steel truss assembly and roof system and a large open span compartment in the Pool Hall occupancy and the unprotected tenant spaces and associated fire load package (assumed) present.

The probability for an escalating multiple alarm fire occurring in this shopping center building complex creating limiting conditions of operations, high resource demands, operational severity, urgency and escalating incident growth issues were highly probable and could be expected based on fire location within a given tenant location, the occupancy use of that tenant space, the time of day of the incident and the operational readiness and availability of the fire department to respond, deploy and intervene.

- Base on both the Marginal and Critical Risk: a determination of Acceptability of Risk to Organization would govern the manner in which (a) tenant space(s) or building fire would be managed, controlled and mitigated safely with minimal impact to personnel, equipment and surround business, transportation and community amenities.
- Concise pre-incident insights, building information and the alignment of building construction knowledge, principles and relation to strategic and tactical adaptability with the fire conditions encountered may have presented variable options to the Incident Command Management Team that could have been rapidly identified, assessed and considered by first arriving companies and command staff.
- Pre-incident insights and building information coupled with a greater understanding of prevalent building construction principles may have had a greater influence on selected and implemented tactical assignments and tasks.

An understanding and application of roof system anatomy, presenting fire conditions upon arrival combined with increased situational awareness and application of predictable building performance considerations based on the building's construction, may have provided additional considerations for an enhanced fire suppression operations.

Therefore, precautions and instituted pre-fire plans and identified tactical options could have been identified, formulated and implemented prior to the initiating incident that may have contributed towards increased operational and incident management efficiencies, operational effectiveness, control and amplified managed risks.

IV. Operational Factors and Considerations

Reading the Building & Predictive Indicators

Of the many variables and factors that influence the fireground during the conduct of fire suppression operations, there are three (3) integral factors that can have the greatest impact on operational integrity, effectiveness and firefighter safety: 1) The Building; 2) The Compartment, and 3) The Company. [6, 10]

Lack of building knowledge, ineffective building and fire profiling and size-up assessment, inadequate situational awareness, diminished sensitivity to time, intervention and compromise-collapse susceptibility can lead to adverse fireground conditions, operations and command compression.

The ability to accurately identify key building attributes and features or conditions- concurrent with compartment fire conditions; process that data -comprehend, synthesize and prioritize key aspects and correlate that to a fluid risk profile model that must be acted upon tactically within a compressed timeframe with company level resources is mission critical during fireground operations.

The ability to effectively and efficiently Read the Building and apply Predictive Indicators aligns with Recognition-Primed Decision making (Naturalistic Decision making) that must be tempered with past experiences and outcomes (favorable and detrimental), initiative thinking, critical thinking and rapid tactical-risked based decision making.[5,6,9,10,20,21]

- The presence of flat roof configuration with actual or presumed unprotected steel roof components is a predictive indicator for higher risk and higher probability of compromise or collapse when combined with actual or postulated fire dynamics and behavior.
- The presence of such construction requires an understanding of the presumed or known structural support system, the size and volume of the compartment fire, the intensity and propagation of flame and heat, presence of roof accessories or building system features (RTU), ventilation features (vents, louvers, soffits etc.) and the consideration of time element.
- Building features, Tenant space occupancy proximity, connectivity of these tenant spaces present influencing operational considerations that could affect incident operations in terms of access, size-up and assessment, smoke tunneling, compartment ventilation, single or multiple flow paths routes, physical compartment configurations and influence of size (SF) and volume (CF) for tenant space(s) and concealed spaces with impacts on ventilation-limited or fuel-limited conditions, structural integrity and collapse considerations, tenability for personnel within the space and connectivity of individual tenant spaces and fire dynamics.
- The probability for isolated and catastrophic building compromise and structural collapse based on fireground conditions should have been readily apparent to all operating personnel and should have been fundamentally recognized as one of the foremost operational considerations during the initial course of incident management, command and control. [6,10,11,33]

- The need for augmented and adequate fire suppression capabilities in terms of sustained water delivery, stream penetration and reach and adequacy of flow rates based on presumed heat release rates may not have been suitably considered.

Inherent building characteristics, predictability of performance under fireground conditions, occupancy risk profile and physical conditions as previously described, collectively provide crucial performance indicators that when recognized and managed suggest a need for a higher degree of operational safety and execution in terms of selected tactics and methods of initial fire attack and hoseline advancement within a commercial occupancy with the noted construction found in this building and tenant spaces.

It was documented upon the on-scene arrival of the first-due Engine Company at 08:23-08:29 hours (T+ 6 – 12 minutes) and that indications were such that a well seated fire was highly probable emanating from the Pool Hall tenant space. Tactical deployment was initiated in an offensive attack indicative of an interior operation within the compartment utilizing a 200 ft. length- 1.5 inch hoseline for initial fire suppression.

- Intuitive, tactically-driven versus risk assessed operations were rapidly deployed that may have lacked in critical thinking when confronted with a large fire in a tenant space of a commercial shooing center complex- that may have required alternate tactics
- Initial actions by the Engine Company upon arrival did not identify any such assessment profiling or size-up.
- There are no indications that a three-sixty (360 degree) assessment of the building or at the minimum a one-eighty (180 degree) assessment from the Division Alpha-Delta areas congruent to the Pool Hall tenant side was performed.
- Tactical-based risk considerations may not have been considered in determining the selected tactical assignment made for proceeding in an offensive interior strategy in the commercial tenant space based on fire, building and compartment considerations.
- There was no apparent consideration for deployment and use of large caliber hose streams or master stream appliances from the storefront side position side for operational reach, penetration and safety margin
- The use of a 1.5 inch hand line, with related fire flow rate characteristics for initial fire suppression attack was inadequate for this type of commercial occupancy, expected fire load package (consistent with recognized Heat Release Rates), fire dynamics and building construction profile. [9,12,13,18]
- Catastrophic roof system-diaphragm compromise or failure can occur without warning just as companies are commencing with initial interior operations within a building or space with truss type construction. Other historical incidents in which fire and collapse of roof truss systems that led to LODDs provide additional lessons learned. [9,27,28,29,30,31,32]

Reading the Building Considerations:

- Physical location of the Pool Hall Restaurant at the end of the building complex and presence of concrete masonry unit block wall construction for the perimeter walls. Division Charlie-Delta.
- Occupancy Risk Considerations versus Occupancy Type precursors.
- Connectively of the Pool Hall Tenant space and adjoining Restaurant Tenant space and other subsequent Bravo exposure occupied tenant spaces.
- Presence of flat roof configuration and assembly with assumed exposed steel construction.
- Probability for isolated and catastrophic building roof compromise and structural collapse based on fire conditions encountered upon Fire Department upon their arrival.
- Potential presence of load bearing wall features on (a) the concrete masonry unit block wall construction for the perimeter wall(s). This is especially import for end unit tenant spaces.
- Interpretation and relationship of observed smoke conditions, color, velocity or intensity of the smoke emanating and direction of the smoke plume.
- Vent Path and Flow Path Considerations based on building configuration at the limited entry points of the storefront(s).
- Smoke Tunneling Considerations and Coordinated Ventilation Considerations based on tenant space configuration.
- Considerations for Room Compartment volume, Fire Intensity (Heat Release Rate).
- Presence of fire within the concealed plenum compartment space and ventilation-limited conditions.
- Presence of fire within the kitchen duct system(s), plenum space above the ACT ceiling and considerations for fire extension and communication. (and effect on exposed structural steel components).
- Collapse/Compromise considerations for rooftop units (RTU/HVAC) ventilation-cooling equipment on the roof deck (and impact on structural support framing for RTU/HVAC curbs).
- Considerations for possible long span truss or structural system present and large unsupported floor space within the Pool Hall.
- Projected Fire Load Package versus Fire Flow Requirements versus Fire Flow Capabilities.
- Closed Occupancy; limited number, size and location of perimeter windows and doors: Storefront only on the Alpha division and very limited access doors on the service road side Charlie division.
- Absence of a fixed suppression system in the building and tenant spaces.
- Building size, age, condition and any subsequent alterations, renovations and modifications that may have altered expected building conditions or features.

Anatomy and Mechanism of Roof Truss Compromise and Collapse

Operational Perspective

The Pool Hall comprised an aggregate floor area of ~8,000 SF with a compartment volume of approx. 96,000 cubic feet and a concealed plenum above the suspended acoustic tile (ACT) ceiling of approx., 30,000 SF. Based on researched photographs of the interior spaces, furnishings and products and materials the fire load package (general area fire loading) represented a postulated characteristic of a "Fast" growth rate fire.[13, 17]

There are many factors that will affect the fire development, progression, intensity and manner in which fire dynamics will impact and affect a building, compartment, furnishings and finishing materials and most importantly structural components, systems and assemblies that maintain building envelopment integrity such as perimeter walls, floor systems, roof systems and compartment enclosures.

Tactically drive operations that are time driven or lacking in real-time situational awareness when addressing rapidly developing fireground conditions, and have the need for prompt intervention and engagement by suppression, support and rescue companies; at times fail to recognize the key performance building and fire dynamics indicators that fuel intuitive decision-making and fail to implement critical thinking to fully assess key building, fire and incident data (presumed or available up to that time frame) to project how the building's anatomy will be affected by the fire, within the timespan of companies moving into the structure and undertaking suppression engagement- all before the building, systems, components or assemblies become compromised or degraded to the point of failure and collapse.[9]

Operations - Key Timeline Factors

Operations - Key Timeline Factors

Report and Deployment		
T+0	**08:17:00**	Report of Structure Fire and Dispatch and Time of Dispatch
	08:22:00	Engine 1 arrives on location
	08:23:00	Commander Officer Arrives and Assumes Incident Command
Firefighting Operations		
T+ 6-12 min	**08:23:00-08:29:00**	**Initial Fire Attack commences; 200 ft. 1.5 inch hoseline**
T+ 23-26min	**08:40:00-08:43:00**	**Fire Self-ventilated thru storefront windows due to thermal insult and glazing failure- Alpha Division**
T+ 26 min	**08:43:00**	**Storefront Window- Alpha Division Self-Ventilates** **Firefighters manually ventilate other windows in the storefronts**
T+ 27min	**08:44:00**	**Engine 3 reports Fire extending thru the Roof**
	08:45:00	Incident Command Communicates Evacuation Order
	08:50:00	Mayday Communicated by Incident Command
Approx. Elapsed Interior Operational Time: **22 minutes** [Elapsed Incident Time from Dispatch= **28 minutes**		
Compromise and Collapse		
T+43min	**09:00:00**	**Catastrophic Wall and Roof Collapse- North Side Delta Division**
T+44min	09:01:00	**Wall and Roof Collapse- Charlie-Delta Division**

The NIOSH ALERT, Preventing Injuries and Deaths of Firefighters due to Truss System Failures (2005) was issued to address the adverse trend in firefighter deaths attributed to operations in buildings containing truss systems. A decade later, the report case studies are now replaced with more recent cases that follow a similar continuum of events, causal factors, lessons learned and recommendations and suggested actions.

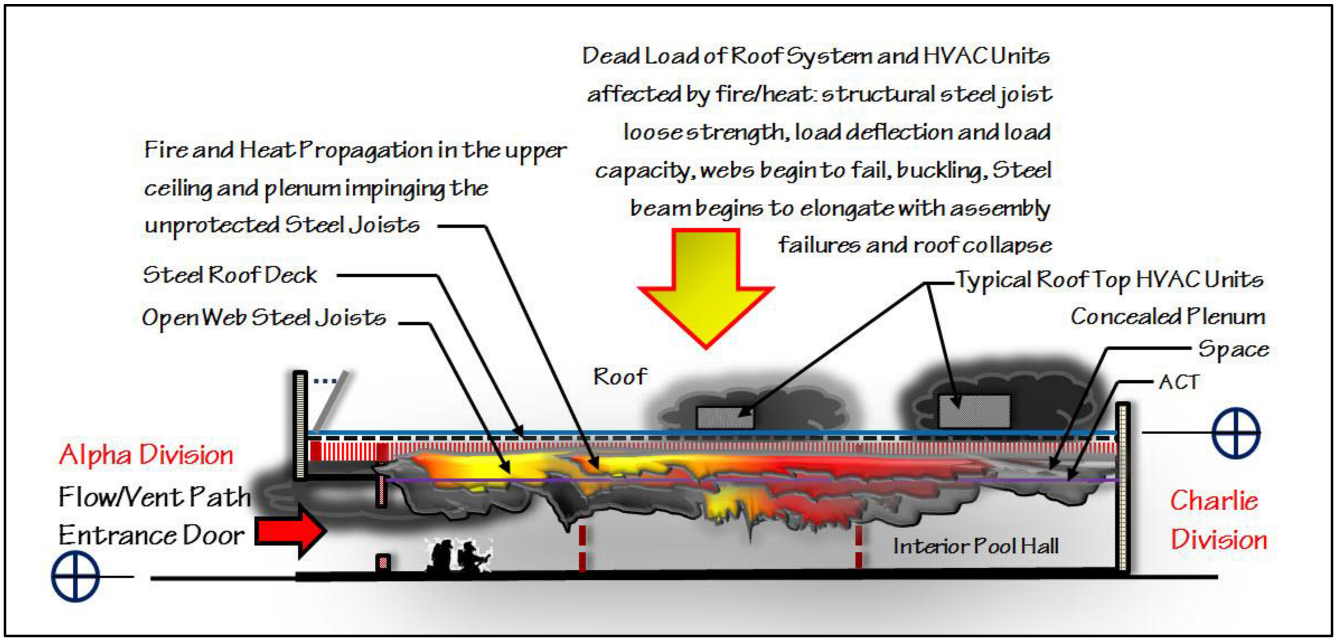

Figure 10. Cross Section of Pool Hall Occupancy Alpha to Charlie.
(Diagram Courtesy of Buildingsonfire.com.)

With specific construction systems, features and vintage, commercial buildings and occupancies have defined predictable performance factors-that when recognized, assimilated and applied to adaptive tactical models for operations, a favorable balance of risk and incident demands may be correlated by command and company officers to achieve both operational excellence and mission requirements. [6,7,10]

A balanced approach implementing conventional aggressive interior fire suppression operations in these and other risk prone buildings and occupancies requires a well-coordinated level of adequate firefighting resources, who can, upon on-scene arrival establish highly effective fire flows and delivery rates in minimal time while selecting and implementing tactical actions from risk-assessed positions that consider building system and component compromise and collapse potential.

Commercial occupancies and tenant spaces in shopping centers commonly are designed with large structural spans that will accommodate open retail and sales floor space. The presence of large spans and accompanying partition-less open floor plan designs creates compartment spaces that have very large volumes, high fireload packages, require deep penetration for personnel movement into these spaces (requiring air management protocols and tactical practices, lack direct exterior accessibility (closed structures) and place firefighting personnel in positions that are highly prone to the probability of rapidly changing fire dynamics, roof system and assembly compromise and collapse resulting from fire/heat exposure or impingement and risk from suspended or positioned roof top equipment, building features or assemblies and materials (drop-thru). Structural steel deformation, rotation & twisting, compression, elongation, restraint, movement & buckling will result in isolated or catastrophic compromise and/or collapse.

Aggressive interior operations were initiated within an approximate 3-6 minutes upon arrive on-scene by Engine 1. The three-person staffed crew deployed a 1.5 inch handline and advanced and pushed forward into the Pool Hall occupancy through the storefront entry way on the Alpha Division and proceeded into the interior along a westerly direction along the established aisle of the tenant space.

The single access entryway and enclosed vestibule was the only flow-vent path to the interior compartment and the point of egress. A rear delivery door was present opening to the service road on the Charlie Division.

- Interior firefighting operations continues for approx. twenty-two (22) minutes, which was an est. 28 minutes elapsed time from the time of dispatch.
- During this time span the fire within the Pool Hall occupancy intensified in severity and magnitude and rapidly extended with communication into the Restaurant-Bravo Exposure.
- The storefront glass failed and the fire self-vented at the 23-26 minute mark and the remainder of the windows on the Alpha were manually ventilated by personnel creating a larger vent-path opening, with suggested influenced on the interior fire dynamics, intensive and flow paths.
- At the est. 27 minute mark, Engine 3 reported that fire is visible through the roof.

Anatomy of Compromise and Collapse

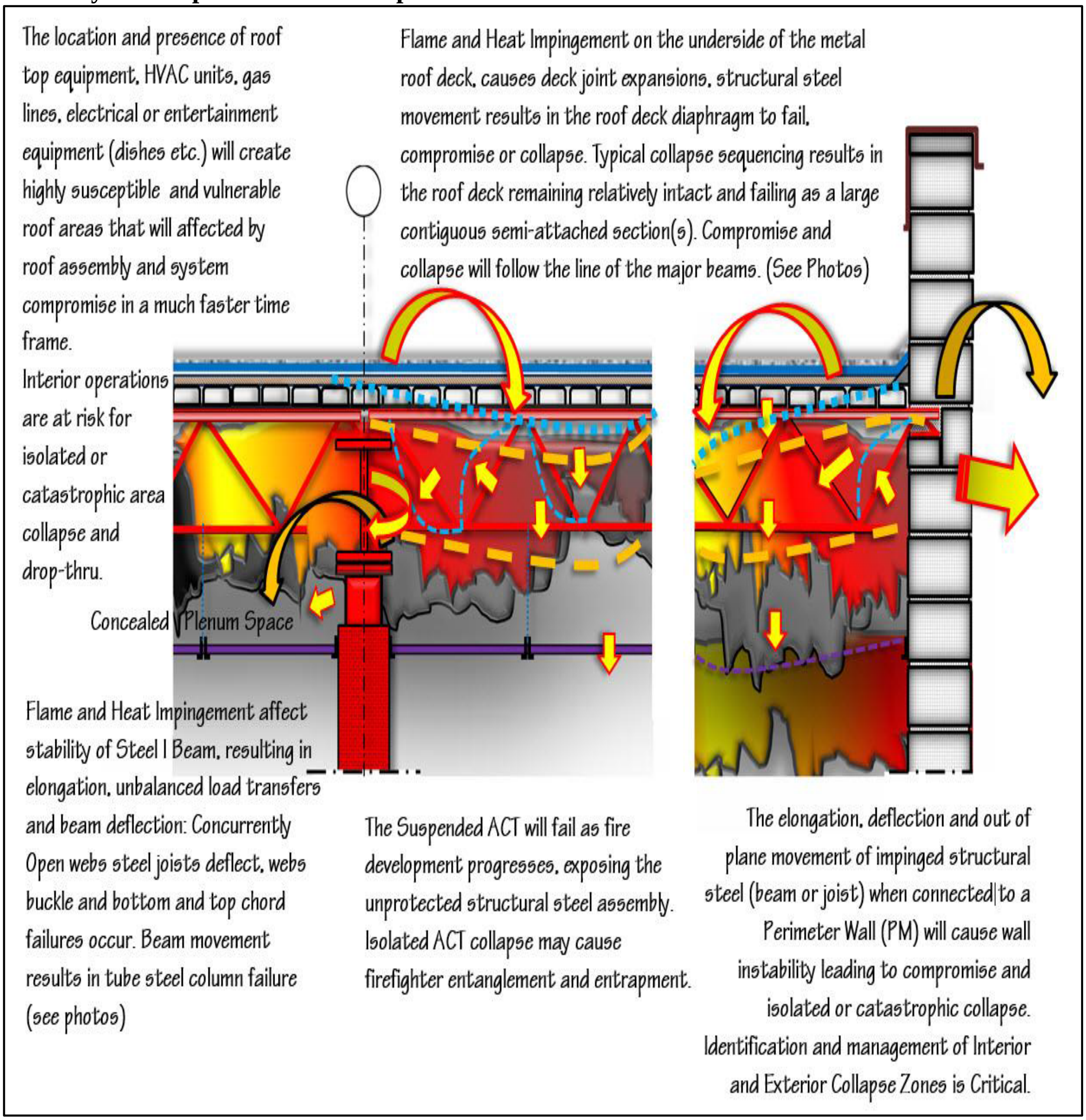

Figure 11. Anatomy of a Truss – Roof Assembly Compromise & Collapse.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

The probable sequence and causal factors that led to the roof collapse and subsequent entrapment of the firefighter were directly related to rapidly escalating fire and heat exposure and the lack of fire endurance of the open web steel joists during the time in which interior fire suppression operations were underway. RTU (loading) duress on the steel supporting assemblies was a contributor for escalating the adverse stability conditions.

There are five (5) primary structural features that have interactions and connectivity and assembly considerations that when exposed to an advancing fire and dynamics would have varying independent, interdependent, concurrent, sequential and/or progressive effects collectively.[12, 13, 16, 18]

- Structural Steel Beams
- Structural Tube Steel Columns
- Open Web Steel Joists
- Metal Roof Deck
- Concrete Masonry Unit Perimeter Walls

Each building material and component is affected differently (over time) based on their material characteristics and fire resistance or vulnerability. This includes such factors as; applied structural load intensity, member/component type, member dimensions and boundary type, incident heat flux from the fire on the member or assembly, type of construction and effects of temperature rise within the structural member on the relevant properties of the member.[12, 13, 18]

The effects of fire and heat exposure and impingement on non-protected Structural Steel I-beams, open web steel joists and their assemblies, connections and results in an assortment of variable conditions that result in structural steel deformation, rotation & twisting, web and chord compression, elongation, restraint, movement and buckling, loss of load sustainability or transfer will result in isolated or catastrophic compromise and/or collapse of individual elements, series of components, assemblies or entire integrated systems (i.e., roof systems and wall system).

Components or assemblies can reach critical temperatures (irregularly or evenly) which references the point at which the integrity of a fully loaded structural member's integrity becomes questionable. 14, 18 ASTM E119 assumes a critical temperature of 1000° F (538° C) for steel columns; 1100° F (593° C) for steel beams and open web steel joists.8 If steel attains a temperature exposure of 1,022 ° F (550° C), the remaining strength of the steel component is approximately 50% of the value at ambient temperature. [12, 18]

Steel beams and steel joists will elongate and soften when exposed to temperatures at 1000° F (538° C) at a rate of 9.5 inches per 100 linear feet. This also equates to a 0.06% - 0.07% elongation for each increase in 100° F (38° C) rise. Structural steel failure and collapse will typically occur at 1300 ° F (704° C).

Building materials, finishes, construction systems and assemblies will react differently and at different intervals when exposed to elevated temperature gradients and will individually or collectively react to fire, heat and physical load stresses, transfers and resiliencies leading to restraint, movement or loss of material integrity. Structural steel performance in fires is typically measured and characterized by its thermal properties and mechanical behaviors. [12,13,18,22]

Structural steel's stress-strain relationship at elevated temperatures is another import building consideration when considering component or systems based risk (Poisson's ratio is the ratio of the relative contraction strain (or transverse strain) normal to the applied load - to the relative extension strain (or axial strain) in the direction of the applied load).[12,13, 14]

- Flame and heat impingement along the surface area of the open web steel joists results in softening, elongation and compression, buckling of the web members and top or bottom chord failure. The collective movement of the restrained structural components either tied to the steel beam, roof deck or the CMU Perimeter wall (Delta Division) cause assembly separations, load instability, sustainability or transfer. Compromise and collapse follow.
- Flame and heat impingement on the underside of the metal roof deck, resulted in deck joint expansions, structural steel movement results in the roof deck diaphragm to fail, compromise or collapse. The roof deck diaphragm & steel joists interdependence results in cascading compromise and collapse sequences.
- Typical collapse sequencing results in the roof deck remaining relatively intact and failing as a large contiguous semi-attached section(s). Compromise and collapse will follow the line of the major beams.
- Flame and heat impingement affect stability of Steel I Beam, resulting in elongation, unbalanced load transfers and beam deflection: Concurrently Open webs steel joists deflect, webs buckle and bottom and top chord failures occur.
- Beam movement results in tube steel column failure (which causes the steel beam to fail to the south of the column support). This suggests that the beam movement, aligned in sequence or progression to the joist-roof-CMU PWM compromise, displaced-shifted and initiated the compromise and collapse sequencing.
- Limited evidence of flame scarring along beam flanges or web suggests the beam may not have been affected by flame or heat resulting in contributing beam elongation, but may have been affected by the joist and deck deflection, softening and movement causing a loss of bearing at the Charlie Division CMU PM at the support pilaster.
- The location and presence of roof top equipment, HVAC units, gas lines, electrical or entertainment equipment (dishes etc.) will create highly susceptible and vulnerable roof and interior areas that will be affected by roof assembly and system compromise in a much faster time frame. Interior operations are at risk for isolated or catastrophic area collapse and drop-thru.
- The presence and number of RTU over the tenant spaces could escalate and promote an increased time to compromise or collapse due to the imposed dead load of the RTU/HVAC units and the adverse effect on deteriorating structural open web steel joists.
- The deteriorating structural integrity and deflection of the open web joists and movement and RTU influences could result in the joist-deck diaphragm to create instability in the joist-perimeter wall pocket bearing points-causing wall instability and contribute to the CMU wall collapse on the Delta Division.

- An analysis of the structural failure of the roof deck and connected joists at the deck underside suggests that the roof failure was monolithic due to lateral movement and dislocation and a loss of structural support along the steel beam connection line and or the perimeter wall (Delta).
- The elongation, deflection and out of plane movement of impinged structural steel (beam or joist) when connected to a Perimeter Wall (PM) will cause wall instability leading to compromise and isolated or catastrophic collapse. Identification and management of Interior and Exterior Collapse Zones is Critical.
- The approximate 28-30 minutes of fire exposure exceeded critical bench-mark points for structural system, assembly or component stability and integrity that could lead to compromise, failure and collapse.
- The high probability of an isolated or catastrophic roof collapse resulting from a fire within the compartment of one or more tenant spaced was identifiable, predictable and could be manageable, given optional strategic or tactical incident management, risk assessment and predictability of building performance relate to incident fire dynamics.

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

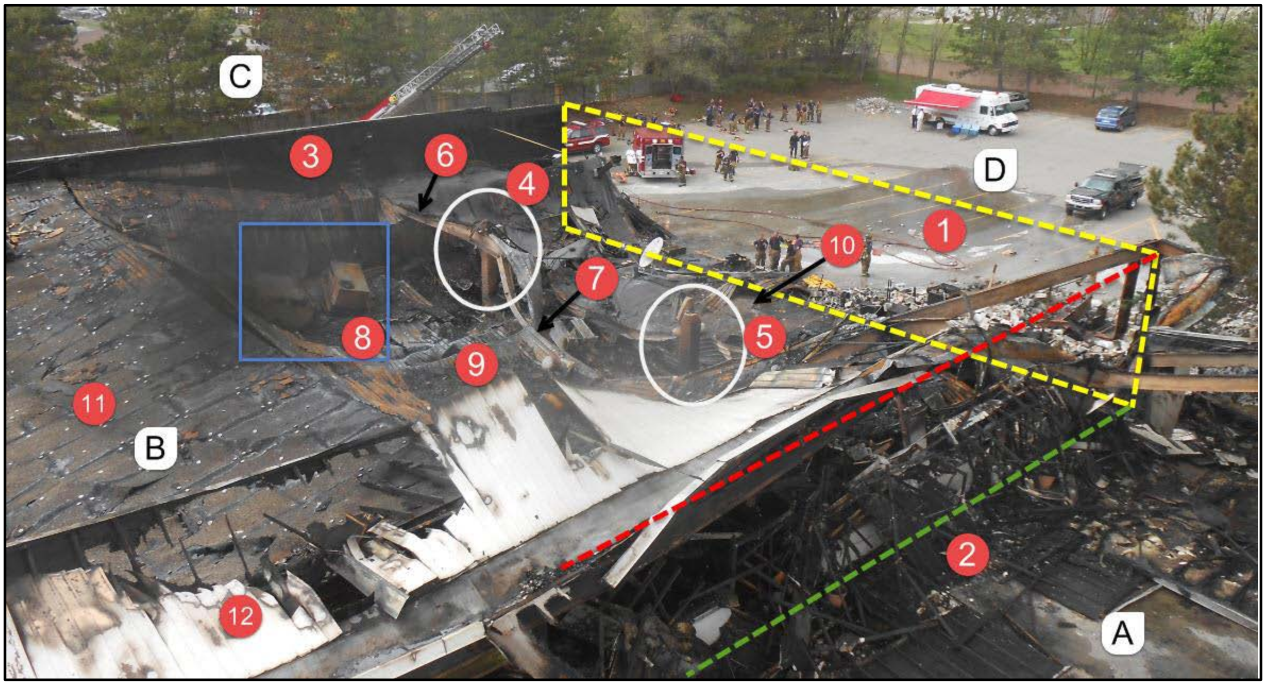

Photo 14. Pool Hall Compartment and Roof Diaphragm –Alpha and Delta Corner.
(Photo: Fire Department / Analysis Diagram Courtesy of Buildingsonfire.com.)

1. Outline of Concrete Masonry Unit (CMU) Perimeter wall –post collapse 19 ft. x 100 ft. (~105,000 lbs. wall assembly weight) Delta Division Collapse Management Zone (CMZ)
2. Façade and store front Collapse Management Zone-Alpha Division (Steel, wood and wood products)
3. Beam Pocket in CMU for Support Steel Beam (Charlie Division wall)
4. Deformed Tube Steel Column- rotated and failed (south)
5. Deformed Tube Steel Column- rotated and failed (south) with brick masonry encasement (up to ACT)
6. Deformed, elongated and rotated steel support I-Beam (Support for steel joists) typical rotated and resting on top of masonry brick encasement
7. Failed and collapsed Steel Support I-Beam
8. Collapsed Roof Top Units (RTU/HVAC) units ~ 1200-1500 lbs. each dislocated & resting on top of exposed metal roof decking
9. Decorative Metal Sheeting Façade skirt (typical around front upper roof perimeter)
10. Collapsed metal roof decking partial pancake collapse with ripple voids over interior furniture and equipment-location of trapped firefighter
11. Lean-to compromised roof deck with installed insulation boards and membrane roofing attached
12. Collapse metal façade skirt
    A- Alpha Division (East)
    B- Bravo Division (South)
    C- Charlie Division (West)
    D- Delta Division (North)

Photo 15. Pool Hall Roof Diaphragm Collapse –Charlie Wall and Delta Corner.
(Photo: Fire Department / Analysis Diagram Courtesy of Buildingsonfire.com.)

1. Deformed Tube Steel Column- rotated and failed (south) with brick masonry encasement,

Deformed, elongated and rotated steel support I-Beam (Support for steel joists) typical rotated and resting on top of masonry brick encasement with Failed and collapsed Steel Support I-Beam.

2. Beam Pocket in CMU for Support Steel Beam (Charlie Division wall)

3. Deformed Tube Steel Column

4. Deformed, compressed and collapsed Steel Joist

5. Collapsed Roof Top Units (RTU/HVAC) units ~ 1200-1500 lbs. each resting on top of exposed metal roof decking, gas line piping intact leading up along wall line

6. Collapsed metal roof decking partial voids and lean-to transitioning to partial pancake collapse with ripple voids over interior furniture and equipment-typical roof deck failure profiles (membrane roofing sheets can be seen intact)

7. Charlie-Delta corner CMU wall collapse

8. Lean-to compromised roof deck with installed insulation boards and membrane roofing attached

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

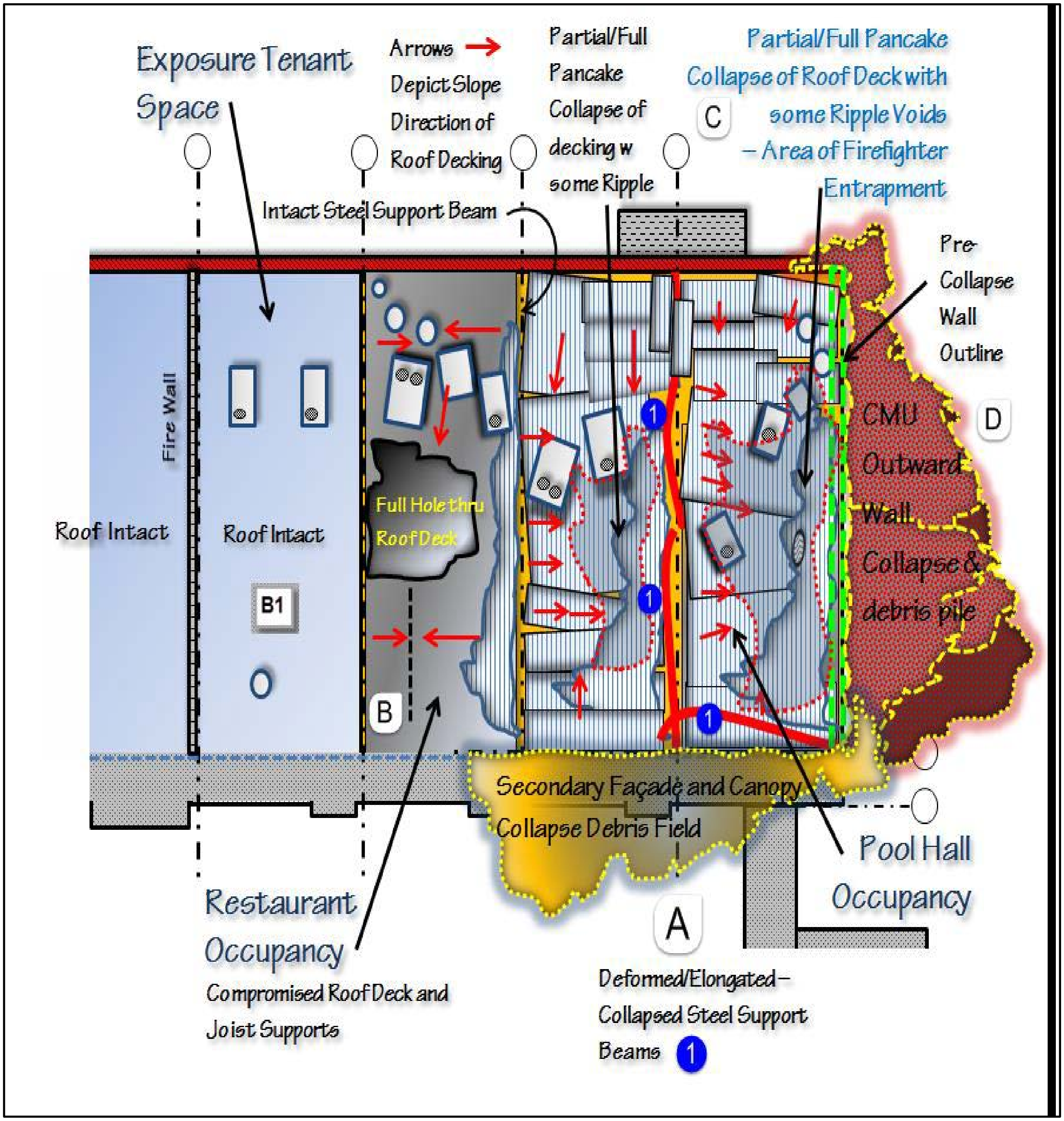

Figure 12. Anatomy of a Roof Assembly Compromise & Collapse.
(Analysis Diagram Courtesy of Buildingsonfire.com.)

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

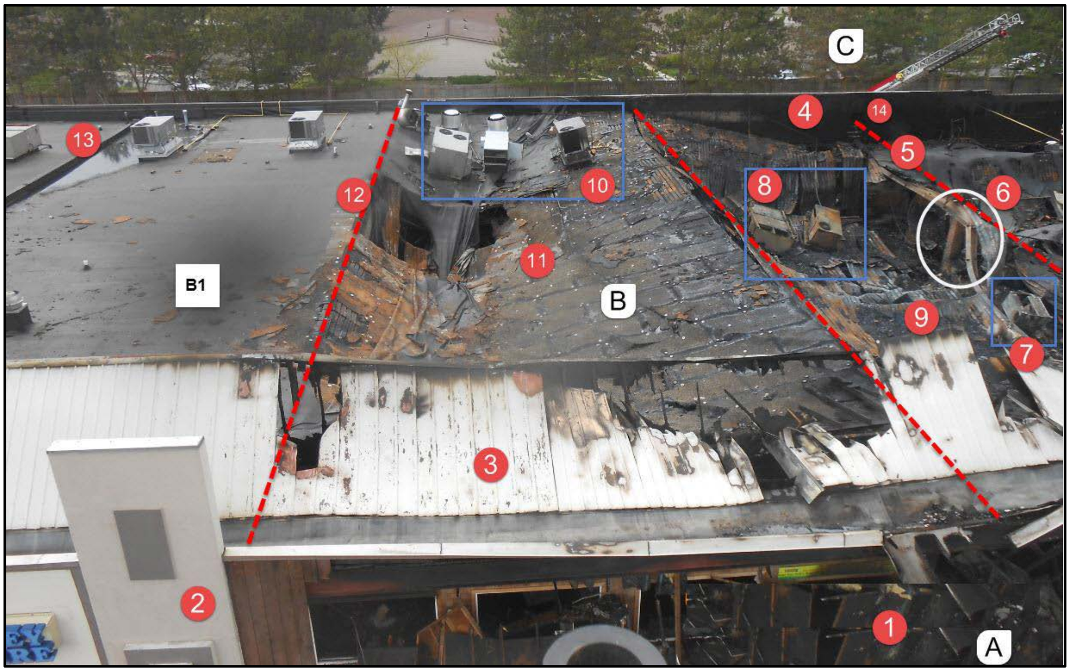

Photo 16. Restaurant Compartment and Roof Diaphragm –Alpha to Charlie View.
(Photo: Fire Department / Analysis Diagram Courtesy of Buildingsonfire.com.)

1. Façade and store front Collapse Management Zone-Alpha Division (Steel, wood and wood products)
2. Architectural façade treatment, typical front perimeter treatment
3. Decorative Metal Sheeting Façade skirt (typical around front upper roof perimeter)
4. Beam Pocket in CMU for Support Steel Beam (Charlie Division wall)
5. Outline of structural steel I-Beam running A-C, 100 ft. span
6. Deformed Tube Steel Column- rotated and failed (south) with brick masonry encasement (up to ACT) With Deformed, elongated and rotated steel support I-Beam (Support for steel joists) typical rotated and resting on top of masonry brick encasement
7. Collapsed Roof Top Units (RTU/HVAC) unit ~ 1000 lbs., next to Failed and collapsed Steel Support I-Beam
8. Two (2) Collapsed Roof Top Units (RTU/HVAC) units ~ 1200-1500 lbs. each resting on top of exposed metal roof decking
9. Compromise and Collapsed metal roof decking partial pancake collapse with ripple voids over interior furniture and equipment-collapsed and compressed steel joists underneath
10. Three (3) Compromised and leaning Roof Top Units (RTU/HVAC) units ~ 1200-1500 lbs. each resting on top of exposed metal roof decking and ventilators exhaust fan housings
11. Lean-to compromised roof deck with installed insulation boards and membrane roofing attached
12. Outline of non-compromised steel I-beam –in place between the Bravo (B) and B1 exposure occupancy

A- Alpha Division (East)
B- Bravo Division (South)
B1- Exposure Occupancy (South)
C- Charlie Division (West)
D- Delta Division (North)

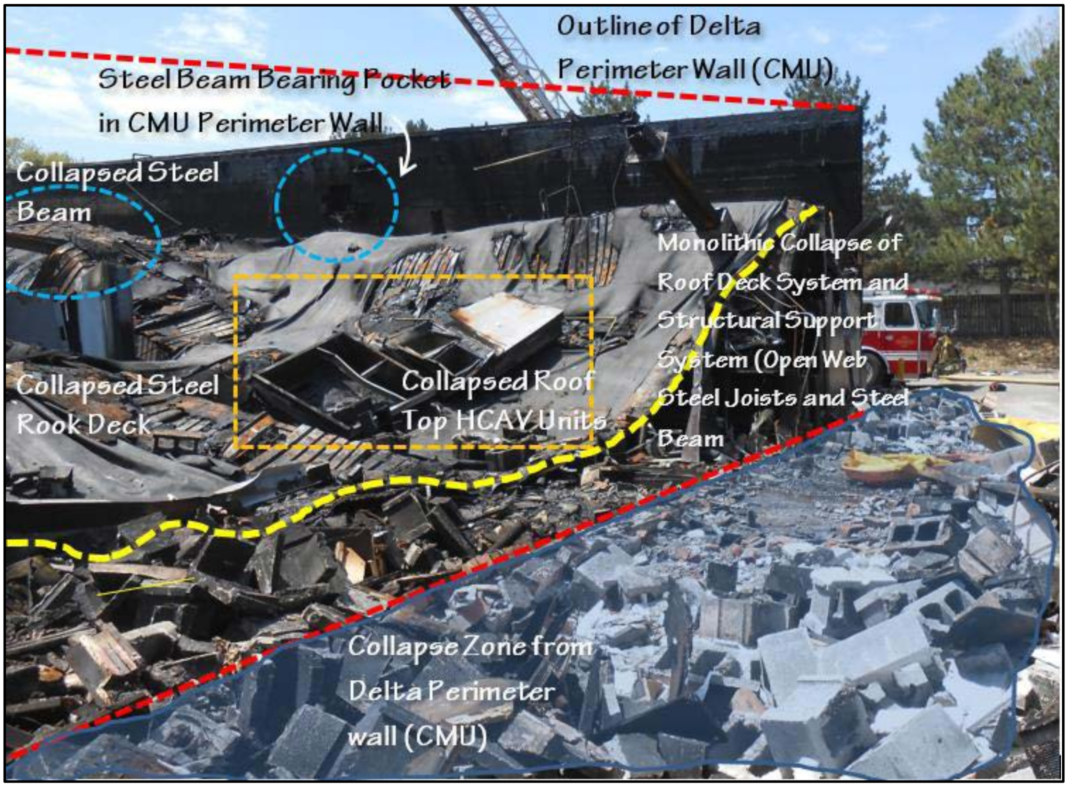

Photo 17. Perimeter Wall and Roof Diaphragm Collapse Zone – Delta Division.
(Photo: Fire Department /Analysis Diagram Courtesy of Buildingsonfire.com.)

Photo 18. Tube Steel Column Failure- Roof Collapse.
(Photo: NIOSH/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Deformed/bent and compromised tube steel column that supported the structural steel I-Beam (A-C) Lower section of masonry brick that encased the column up to just above the ACT line. Steel plate with bolt holes would connect to bottom of I-beam flange.

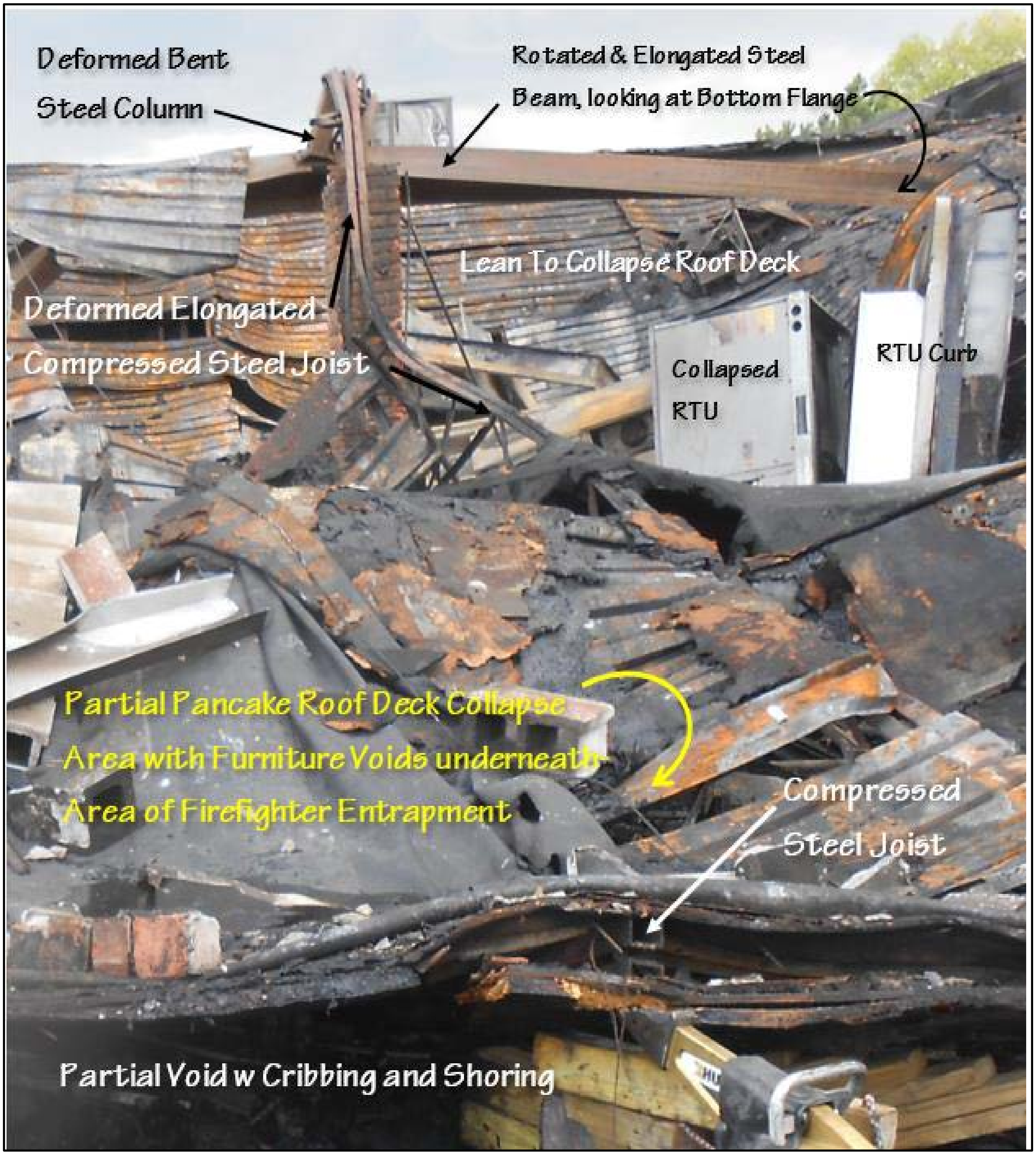

Photo 19. Roof Diaphragm –Steel Joist and Beam Detail.
Looking from the Delta Division, south into the Pool Hall occupancy area.
(Photo: Fire Department /Analysis Diagram Courtesy of Buildingsonfire.com.)

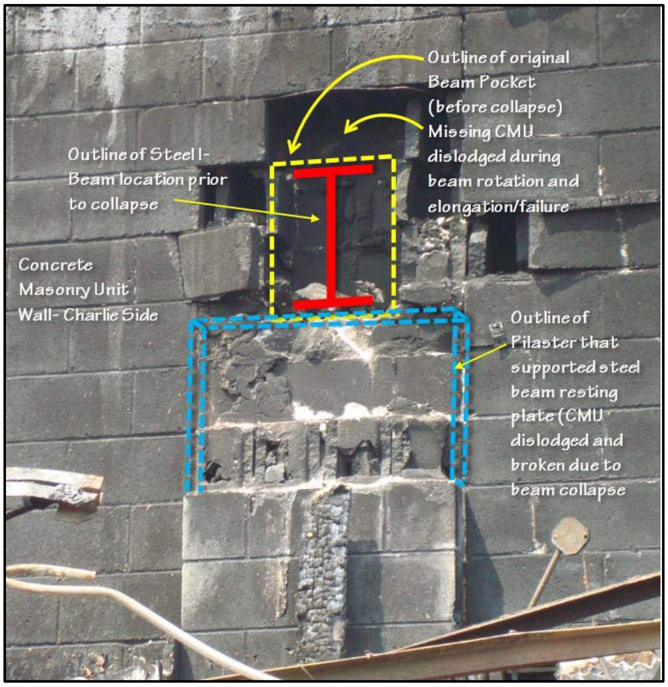

Photo 20. Steel Beam Pilaster Detail at Charlie Wall.
(Photo: NIOSH/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Photo 21. Detail of Truss Compromise and Roof Collapse.
Typical buckled and compressed open web steel joist attached to metal roof deck (diaphragm). Top chord is intact; bottom double L chord is rotated and twisted. Truss bridging is also evident running 90 degrees to the truss.
(Photo: NIOSH/ Analysis Diagram Courtesy of Buildingsonfire.com.)

Adaptive Fireground Management Safety Considerations

Firefighting in commercial buildings and occupancies demands alternate tactical engagement and management that differentiate from residential deployment and operations. Building features and systems and complexities create very distinct and defined incident action parameters that required commanders, officers and firefighters to implement discrete strategies, tactics and awareness that are commonly resource driven, complex, concurrent and high risk.[9]

Commercial building fires and incidents require specific training, skill sets, and experience and risk management protocols. Today's fireground demands, challenges and risks are less forgiving than in the past, leave little to no margin for error and when those errors and omissions manifest themselves-may be very unforgiving in their resulting severity and magnitude. This then requires significant adaptability in the identification, selection of strategic, tactical and task level actions that demand critical thinking skills, based on fluid incident and building assessment and evaluation for conditions.

The importance of implementing Tactical Discipline, Tactical Patience and Adaptive Fireground Management[17] is formative on today's fireground and built upon an established platform of building knowledge, an understanding of the predictability of the building's performance under fire conditions and the integration of critical thinking skills that aligns with the unique given conditions of an incident scene and structural fire in a building.

Firefighting continues to be driven by long established practices and protocols that have a basis on expected building or fire performance and behaviors. These long held beliefs and methodologies have had new perspectives applied based on on-going research, development and emerging practices that suggest adaptive and alternatives methods, practices and protocols that are changing the rules of engagement.

First-due company operations are influenced by a number of parameters and factors; some deliberate and dictated, others prescribed and prearranged and yet others subjective, biased, predisposed or at times accidental, casual and emotional. The connotations and implications are significant and can be characteristic of successful or detrimental operations.

Buildings and occupancies when involved in a structure fire will continue to require the suppression and rescue engagement and intervention of fire department resources and staffing; evolving into an art and science of firefighting that demands greater command and company officer skill sets and understanding of building parameters and fire dynamics.

Learnings

- Understand building construction, fire dynamics and company capabilities
- Lack of building knowledge, ineffective profiling and size-up assessment, inadequate situational awareness, diminished sensitivity to time, intervention and compromise-collapse susceptibility and negligible formulation of predictable building, occupancy, systems feature effects can lead to adverse fireground conditions, operations and command compression.
- Understand a building's anatomy, occupancy risks and the characteristic of the building's internal compartments (occupied rooms and space use) they are integral to effective and efficient firefighting operations within buildings on fire and are essential for all phases of fire engagement and suppression.
- Commercial Building Fires: Require Adequate and sustainable water supplies and optional delivery methods that take into account building size, degree of penetration-to physically access interior areas and apply suppression agents effectively and safely.
- Expect and plan for Building Compromise and Collapse at Commercial Building Fires
- Commercial Building Fires require defined and rigorous Air Management protocols
- Conventional hoseline stretches and residential occupancy tactics do not work at Commercial Building Fires
- Consider implementation Command Management Teams to augment Incident management at Commercial Building Fires
- You can never have too few Safety Officers monitoring assigned divisions at Commercial Building Fires
- Conduct a Risk Assessment Profile and Size-up of the Building and Fire Conditions at all incidents
- Ensure the three-sixty (360 degree) building assessment is conducted or delegated
- The greatest impact on operational integrity, effectiveness and firefighter safety can be
- based on three integral variables; 1) The Building 2) The Compartment and 3) The Company. Understand the relationships, attributes and contributors.
- Identify and manage Interior and Exterior Collapse Management Zones
- Identify secondary collapse potential and don't allow tunnel vision, distractions or command compression to disregard intervention or restriction before they occur; the results could be detrimental
- Understand the operational considerations of large space compartments and their susceptibility to structural compromise and collapse
- Rapid Tactical Decision-making leading to Tactical driven operations must include Risk-Based influences

- Increase proficiencies in Commercial Building design and systems in construction with special attention to roofing systems and support systems; Understand and implement operational and tactical protocols based on presumed or defined assemblies or systems.
- Understand the context of coordinated ventilation and the critical importance it has in today's buildings, occupancies and fires.
- Understand the concept of building volume, space, connectivity, fire load package, occupancy load risks, and fire dynamics; they drive tactical options and selection
- Consider the attributes of smoke tunneling, compartment ventilation, single and multiple flow paths routes, physical compartment configurations and influence of size (SF) and volume (CF) for room and concealed spaces, inherent building characteristics with impacts on ventilation-limited or fuel-limited conditions
- Understand building, system, assembly, component; structural integrity and collapse predictability, precursors and operational considerations; they lead to preparedness, vigilance and actions before bad things occur
- Maintain fluid situational awareness; Prepare for changing conditions and new building recon data that may demand change in your incident action plan, strategies and tactics
- Don't operate under presumed or actual large open span structural systems, with fire in the overhead; they will follow the laws of gravity
- Consider alternate operational options when confronted with a fire in a truss loft
- Assess live and dead loads imposed on a roofing assembly and system and their effect on deployed or operating companies; expect the worst when fire is involved
- The challenge for today's incident commanders and operating companies on the modern fireground is to clearly recognize building performance factors and inherent characteristics fundamental to the manner in which a building's anatomy presents itself at an evolving incident and to ascertain and distinguish how it will subsequently perform during fire duress and the continuum of elapsed incident time
- Learn to Read the Building and comprehend what you see, with required actions; don't let the experience of past successes disguise and mask the distinctive characteristics of the building
- Learn the lessons from the fireground from case studies, LODD reports and close-call, near-miss events; they resonate with learnings that will add to your ability to make effective decisions, with critical thinking under fireground time compression
- Never Underestimate the potential complexity and demands of Commercial Building
- Fires: Tactical Discipline and Tactical Patience define these operations
- Building Knowledge = Firefighter Safety

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Appendix 2

Status Investigation Report of One
Self-Contained Breathing Apparatus
Submitted By the NIOSH Division of Safety Research for the
MI Fire Department
NIOSH Task Number 19165
(Note: The full report is available upon request)

Background

As part of the ***National Institute for Occupational Safety and Health (NIOSH) Fire Fighter Fatality Investigation and Prevention Program***, the Technology Evaluation Branch agreed to examine and evaluate one SCBA identified as the Avon-International Safety Instruments Inc. model Viking Z Seven, 4500 psi, 45-minute, self-contained breathing apparatus (SCBA). This SCBA status investigation was assigned NIOSH Task Number 19165. The Michigan Fire Department was advised that NIOSH would provide a written report of the inspections and any applicable test results.

The SCBA, contained within a paper evidence bag, was received by NIOSH on May 22, 2013 from the Michigan Police Department. After the arrival of the SCBA unit at the NIOSH Bruceton, Pennsylvania, the package was taken to building 20 and stored under lock until the time of the evaluation.

SCBA Inspection

The package was opened from the local Police Department and a general inspection was performed on May 22, 2013. A complete visual inspection was conducted by Tom Pouchot, General Engineer, NPPTL in the General Respirator Inspection Area (building 20) of NPPTL. The SCBA was inspected on June 5, 2013 and was designated as Unit #1. This SCBA was examined, component by component, in the condition as received to determine the conformance of the unit to the NIOSH-approved configuration. The visual inspection process was documented photographically. The SCBA was identified by the companion SCBAs as the Avon-International Safety Instruments model Viking Z Seven, 45 minute, 4500 psi unit, NIOSH approval number TC-13F-0553CBRN.

The complete SCBA inspection is summarized in **Appendix I** of the full report. *The condition of each major component of the SCBA that were photographed with a digital camera is contained in* ***Appendix*** **III** of the full report.

It was judged that the unit could be safely pressurized and tested with replacements to the cylinder and facepiece with second stage regulator attached.

This SCBA unit includes a data logger. The down load of the data logger was performed by Avon-International Safety Instruments Inc. on May 29, 2013 at the NIOSH Bruceton facility with NIOSH personnel present. The results of the data logger download are included for informational purposes only. In addition, two companion SCBAs from the Fire Department had their data loggers downloaded by the Avon-International Safety Instruments personnel on May 29, 2013.

SCBA Testing

The purpose of the testing was to determine the SCBA conformance to the approval performance requirements of Title 42, *Code of Federal Regulations*, Part 84 (42 CFR 84). Further testing was conducted to provide an indication of the SCBA conformance to the National Fire Protection Association (NFPA) Air Flow Performance requirements of NFPA 1981, *Standard on Open-Circuit Self-Contained Breathing Apparatus for the Fire Service*, 1997 Edition.

NIOSH SCBA Certification Tests (in accordance with the performance requirements of 42 CFR 84):

1. Positive Pressure Test [§ 84.70(a)(2)(ii)]
2. Rated Service Time Test (duration) [§ 84.95]
3. Static Pressure Test [§ 84.91(d)]
4. Gas Flow Test [§ 84.93]
5. Exhalation Resistance Test [§ 84.91(c)]
6. Remaining Service Life Indicator Test (low-air alarm) [§ 84.83(f)]

National Fire Protection Association (NFPA) Tests (in accordance with NFPA 1981, 1997 Edition):

7. Air Flow Performance Test [Chapter 5, 5-1.1]

Unit # 1 was tested on June 14, 2013.

Appendix II of the full report contains the complete NIOSH and NFPA test reports for the SCBA.
Tables One and Two summarize the NIOSH and NFPA test results.

Summary and Conclusions

A SCBA was submitted to NIOSH by the MI Fire Department for evaluation. The SCBA was received by NIOSH on May 22, 2013.

The SCBA unit was generally inspected on May 22, 2013 and an in depth inspection was performed on June 5, 2013. The unit was identified as a Avon-International Safety Instruments model Viking Z Seven, 4500 psi, 45-minute, SCBA (NIOSH approval number TC-13F-0553CBRN confirmed by the companion SCBAs). The unit was in poor to fair condition, exhibited some very slight signs of wear and tear, dirt was present on some parts of the unit, the cylinder was black in color, the backframe was damaged, some of the component had heat damage and the facepiece with regulator had extensive heat damage. The cylinder valve as received was damaged and could not be operated. The cylinder gauge was damaged by heat and could not be read. The second stage regulator was mounted securely to the facepiece but both were in very poor condition with extensive heat damage. The inside of the facepiece was very dirty. The head harness was fully attached to the facepiece. The head harness webbing on the unit was in fair condition with no fraying or tears but was black in color. The PASS device on the unit did function and the device functioned properly. The NFPA approval label on the unit was present and readable. The facepiece lens was in very poor condition with extensive heat damage. A large hole encompassed most of the lens. The right shoulder strap cover buckle was damaged.

The manufacture date on the unit air cylinder could not be determined. Under the applicable DOT exemption, the air cylinder is required to be hydro tested every 5 years, starting on or before the last day of the manufactured date. Because the manufactured date could not be determined NIOSH could not verify if the cylinder was in hydro certification when last used. The unit cylinder was in poor condition with some slight scratches present but black in color and extensive damage to the cylinder valve and gauge. A replacement cylinder and facepiece with second stage regulator supplied by the Fire Department were utilized for all testing. No other maintenance or repair work was performed on the unit at any time.

The SCBA unit met the requirements of the NIOSH Positive Pressure Test and the Rated Service Time Test, as the unit facepiece pressure stayed positive and the unit met the required 45 minute rated service time during the rated service time test. The Unit did meet the requirements of all of the other NIOSH tests. The unit did not meet the NFPA test requirement.

This SCBA unit includes a data logger. The down load of the data logger was performed by Avon-International Safety Instruments on May 29, 2013 at the NIOSH Bruceton, Pennsylvania facility with NIOSH DSR personnel present. In addition, two companion SCBAs had their data loggers downloaded at that time. The results of these data logger download are included for informational purposes only.

The Fire Department included a “Posi3” test report on this SCBA for informational purposes only. This report is attached.

In light of the information obtained during this investigation, NIOSH has proposed no further action on its part at this time. Following inspection and testing, the SCBA was returned to storage pending return to the Fire Department. If the unit is to be placed back in service, the SCBA must be cleaned, repaired extensively, tested, and inspected by a qualified service technician, including such testing and other maintenance activities as prescribed by the schedule from the SCBA manufacturer. Typically a flow test is required on at least an annual basis.

Appendix 3

COMMAND WORKSHEET FOR "MAY-DAY"

◘ **Gather**

- Location ____
- Unit____
- Name____
- Air Supply____
- Resources Needed____

◘ **Are other crew members or crews involved?**

◘ **Deploy RIT to area reported or last known work area**

◘ **Announce URGENT radio traffic only**

◘ **Have Dispatch:**

Initiate the May-Day Protocol

□ Send one additional alarm

□ Send tech rescue vehicle

□ Send one more ambulance than the number of missing or trapped Fire Fighters

□ Duty Officer (duty officer will callback other chief officers to support operation)

□ Contact special rescue teams if requested

□ Monitor all radio channels

◘ **Change the Incident Action Plan to high priority rescue effort**

□ Tell fire fighter(s) calling May-Day, crew members' nearby and the RIT team to stay on the fireground channel. The I/C will become the Rescue Branch Director

Career Probationary Fire Fighter Runs Out of Air and Dies in Commercial Structure Fire—Michigan

□ Announce the name__________________of the new I/C and tell everyone else to move to channel______________

◘ New IC

□ Assure that everyone changes to the new fireground channel and conduct a PAR – withdraw only if NECESSARY – DO NOT abandon fire fighting positions

□ Move up or Reinforce fire fighting efforts to support the Rescue Branch

□ Backup RIT for deployed RIT

□ Coordinate a staging area with Rescue Branch for equipment and 2nd alarm companies

□ Next chief officer on scene will take COMMAND

□ Assign a Safety Officer

◘ Monitor Structural Stability of Building

□ Consider the Pro's and Con's on ventilation, forcible entry and fire stream placement on the rescue

□ Consider writing off parts of the building or pushing or drawing the fire into uninvolved areas to support rescue

□ Consider a secondary means of egress for the rescue operation – *while considering how opening the building may negatively affect rescue efforts*

◘ Rescue Support

□ Rescue Branch Director will have a support person log times of personnel entering and exiting rescue area

□ Stage equipment near the entry/exit point

□ Stage EMS and ambulances near the entry/exit point

□ Stage crews to support the RIT/Rescue operation near the entry/exit point

□ Provide lighting at the entry/exit point

◘ Changes on the Fireground

□ Conduct a PAR after the rescue operation is completed

□ Conduct a PAR if an emergency retreat is ordered due to structural stability or fire condition issues

◘ **Assign PIO**

□ Chief Officer

□ Set-up Media Area

□ Control information releases