Fire Behavior Case Study

CFBT-US
Not just what and how, but why!™

Introduction

Developing mastery of the craft of firefighting requires experience. However, it is unlikely that we will develop the base of knowledge required simply by responding to incidents. Case studies provide an effective means to build our knowledge base using incidents experienced by others. This incident provides an excellent learning opportunity as it was one of the first times that the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS) and Smokeview were used in forensic fire scene reconstruction to investigate fire dynamics involved in a line-of-duty death.

Aim

Firefighters and fire officers recognize and respond appropriately to the interrelated hazards presented by building configuration, fire location and burning regime when confronted with fires in residential occupancies.

References

Dele´mont, O. & Martin, J. (2007). Application of Computational Fluid Dynamics modelling in the process of forensic fire investigation: Problems and solutions. *Forensic Science International,* 167, 127–135

District of Columbia (DC) Fire & EMS. (2000). *Report from the reconstruction committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999. Washington, DC: Author.*

Madrzykowski, D. & Vettori, R. (2000). *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510. August 31, 2009 from http://fire.nist.gov/CDPUBS/NISTIR_6510/6510c.pdf

National Institute for Occupational Safety and Health (NIOSH). (1999). *Death in the line of duty*, Report 99-21. Retrieved August 31, 2009 from http://www.cdc.gov/niosh/fire/reports/face9921.html

National Institute for Occupational Safety and Health (NIOSH). (2005). *NIOSH Alert: Preventing Injuries and Deaths of Fire Fighters Due to Truss System Failures. Retrieved* August 31, 2009 from http://www.cdc.gov/niosh/fire/reports/face9921.html

Underwriters Laboratory. (2009). *Structural Stability of Engineered Lumber in Fire Conditions* [on-line training program]. Retrieved August 27, 2009 from http://www.ul.com/global/eng/pages/offerings/industries/buildingmaterials/fire/courses/structural/

Foster, J. & Roberts, G. (1995) *Measurements of the firefighting environment. Central Fire Brigades Advisory Council Research Report 61/1994*. Retrieved September 9, 2009 from http://www.communities.gov.uk/documents/fire/pdf/154728.pdf

Donnelly, M., Davis, W., Lawson, J., & Selpak, M. (2006). *Thermal environment for electronic equipment used by first responders, NIST Technical Note 1474*. Retrieved August 19, 2009 from http://www.fire.nist.gov/bfrlpubs/fire06/PDF/f06001.pdf

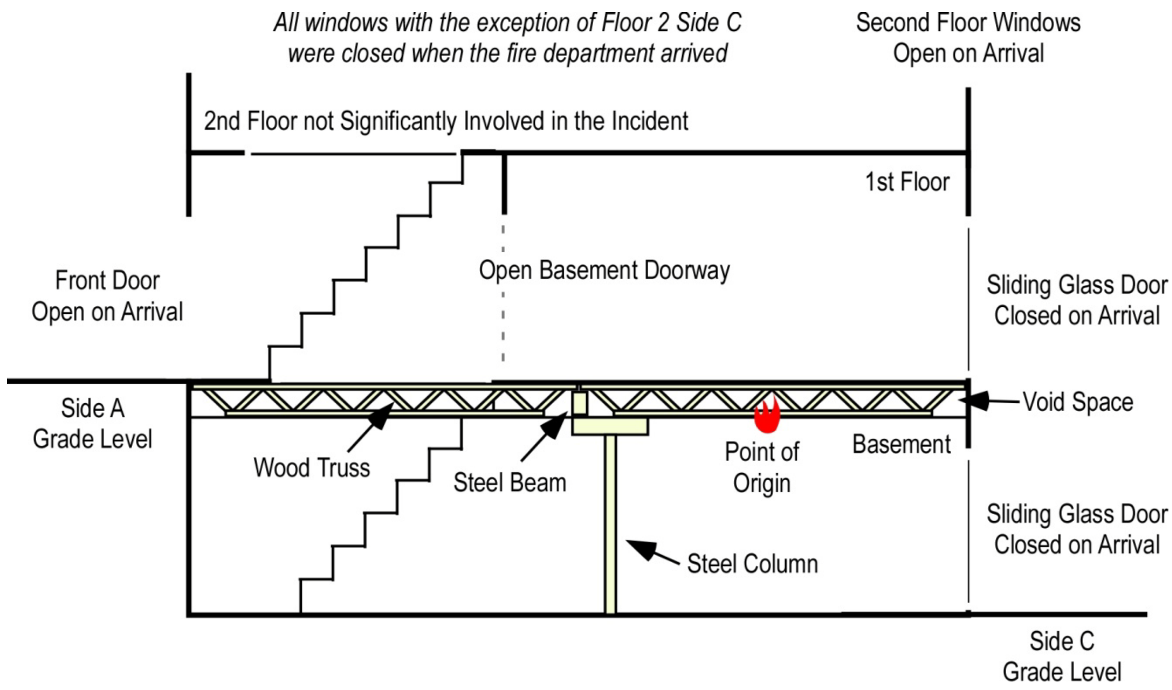
Learning Activity

This case is comprised of two parts, incident information and data on computer modeling of fire dynamics. Review the incident information and answer the questions provided prior to reading the section of the case related to the fire dynamics computer model. Focus your efforts on understanding the interrelated factors that influenced the outcome of the incident. Even more important than understanding what happened in this incident is the ability to apply this knowledge in your own tactical decision-making.

The Case

In 1999, two firefighters in Washington, DC died and two others were severely injured as a result of being trapped and injured by rapid fire progress. The fire occurred in the basement of a two-story, middle of building, townhouse apartment with a daylight basement (two stories on Side A, three stories on Side C).

Figure 1. Cross Section of 3146 Cherry Road NE

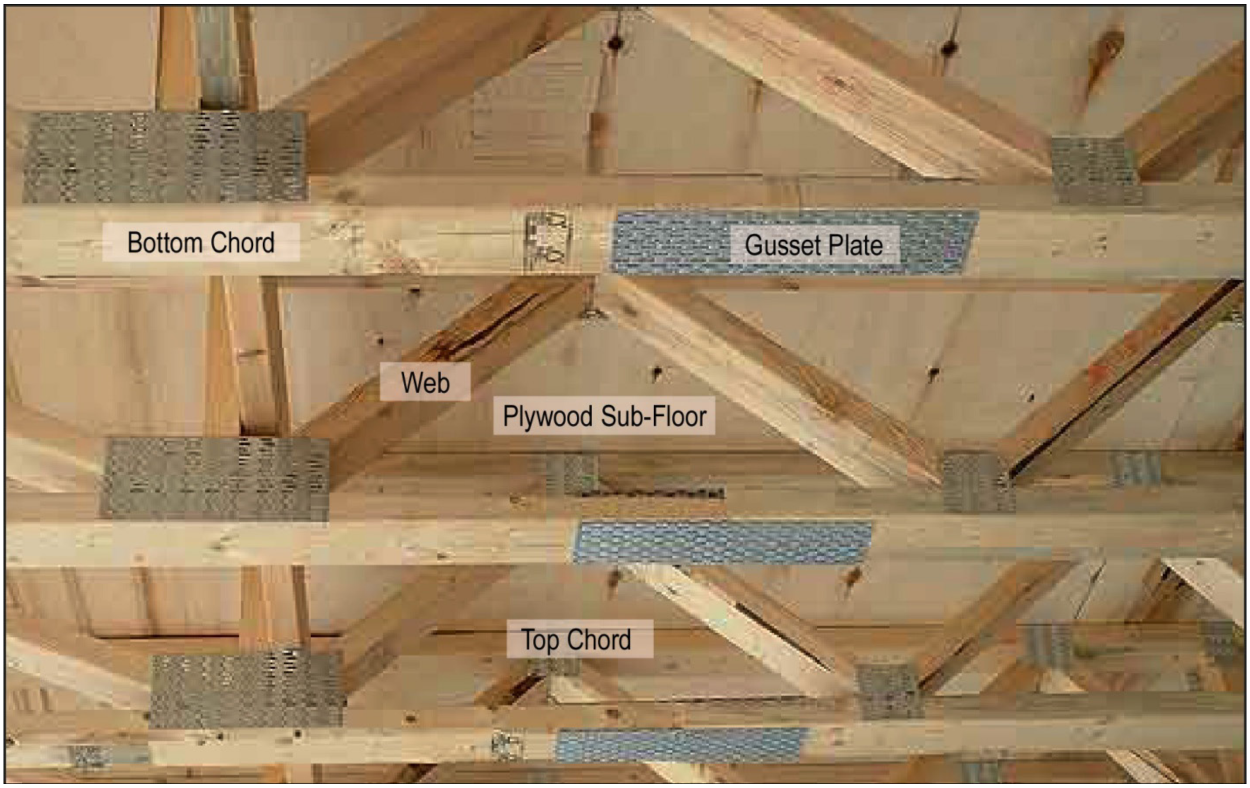


The first arriving crews entered Floor 1 from Side A to search for the location of the fire. Another crew approached from the rear and made entry to the basement through a patio door on Side C. Due to some confusion about the configuration of the building and Command's belief that the crews were operating on the same level, the crew at the rear was directed not to attack the fire. During fireground operations, the fire in the basement intensified and rapidly extended to the first floor via the open, interior stairway.

Building Information

The unit involved in this incident was a middle of row 18’ x 33’ (5.6 m x 10.1 m) two-story townhouse with a daylight basement (see Figures 1 and 3). The building was of wood frame construction with brick veneer exterior and non-combustible masonry firewalls separating six individual dwelling units. The first floor was plywood supported by lightweight, parallel chord wood trusses. This type of engineered floor support system provides substantial strength, but has been demonstrated to fail quickly under fire conditions (NIOSH, 2005). In addition, the design of this type of engineered system results in a substantial interstitial void space between the ceiling and floor as illustrated in Figure 2.

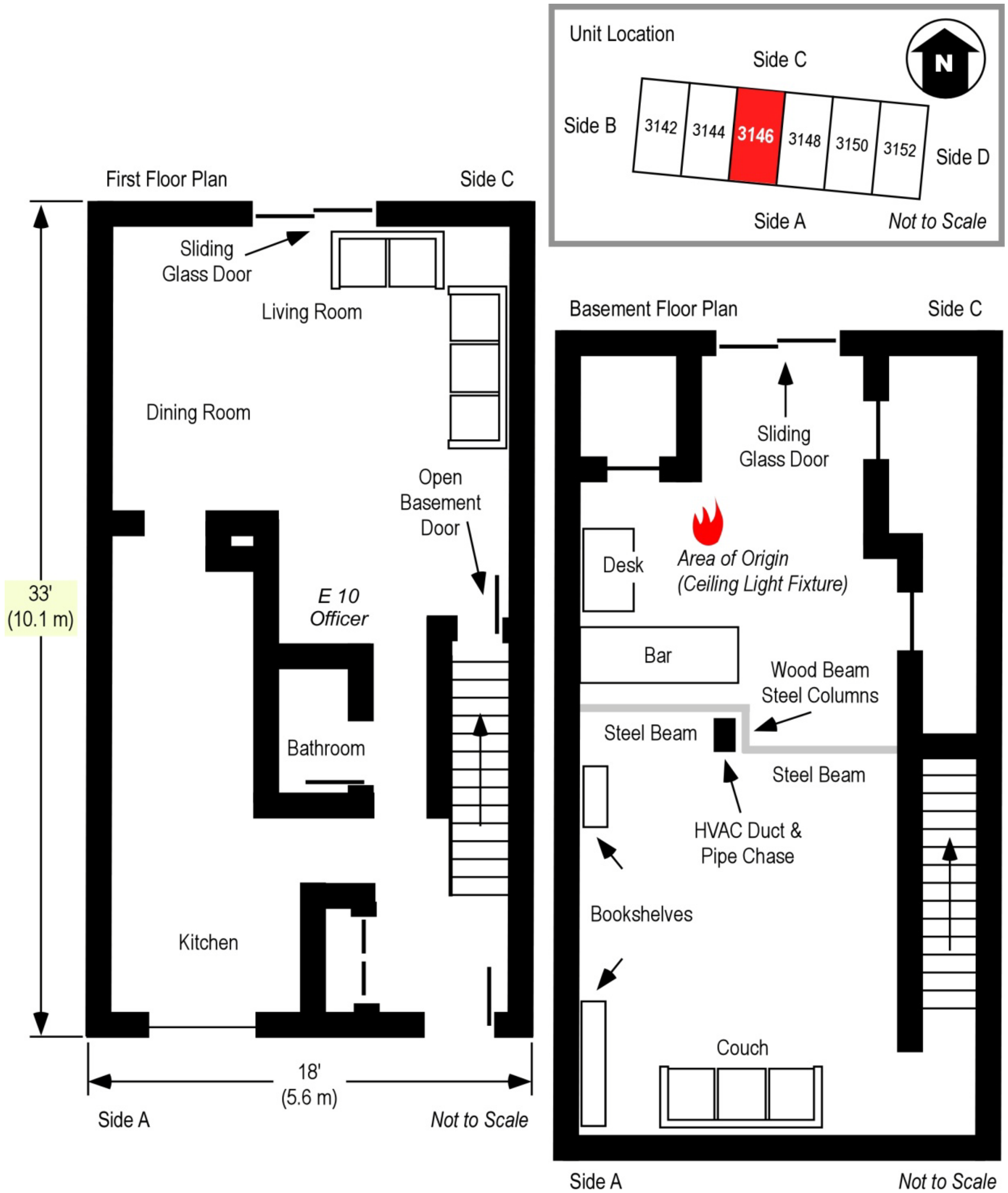
Figure 2. Parallel Chord Truss Construction



Note: This is not an illustration of the floor assembly in the Cherry Road Townhouse. It is provided to illustrate the characteristics of wood, parallel chord truss construction.

The trusses ran from the walls on Sides A and C and were supported by steel beams and columns at the center of the unit (See Figure 3). The basement ceiling consisted of wood fiber ceiling tiles on wood furring strips which were attached to the bottom chord of the floor trusses. Basement walls were covered with gypsum board (sheetrock) and the floor was carpeted. A double glazed sliding glass door protected by metal security bars was located on Side C of the basement, providing access from the exterior. Side C of the structure (see Figure 3) was enclosed by a six-foot wood and masonry fence. The finished basement was used as a family room and was furnished with a mix of upholstered and wood furniture.

Figure 3. Plot and Floor Plan-3146 Cherry Road NE



Note: Adapted from *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 18 & 20. District of Columbia Fire & EMS, 2000; Simulation of the *Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999*, p. 12-13, by Daniel Madrzykowski & Robert Vettori, 2000. Gaithersburg, MD: National Institute of Standards and Technology, and NIOSH Death in the Line of Duty Report 99 F-21, 1999, p. 19.

Figure 4. Side A 3146 Cherry Road NE

Note: Adapted from *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 17. District of Columbia Fire & EMS, 2000 and Simulation of the *Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999*, p. 5, by Daniel Madrzykowski & Robert Vettori, 2000. Gaithersburg, MD: National Institute of Standards and Technology.

Figure5. Side C 3146 Cherry Road NE

Note: Adapted from *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 19. District of Columbia Fire & EMS, 2000 and Simulation of the *Dynamics of the Fire at 3146 Cherry Road NE, Washington D.C., May 30, 1999*, p. 5, by Daniel Madrzykowski & Robert Vettori, 2000. Gaithersburg, MD: National Institute of Standards and Technology.

The first floor of the townhouse was divided into the living room, dining room, and kitchen. The basement was accessed from the interior via a stairway leading from the living room to the basement.

The door to this stairway was open at the time of the fire (see Figures 1 and 3). The walls and ceilings on the first floor were covered with gypsum board (sheetrock) and the floor was carpeted. Contents of the first floor were typical of a residential living room and kitchen. A double glazed sliding glass door protected by metal security bars similar to that in the basement was located on Side C of the first floor. An entry door and double glazed kitchen window were located on Side A (see Figure 3). A stairway led to the second floor from the front entry. The second floor contained bedrooms (but was not substantively involved in this incident). There were double glazed windows on Sides A and C of Floor 2.

The Fire

The fire originated in an electrical junction box attached to a fluorescent light fixture in the basement ceiling (see Figures 1 and 3). The occupants of the unit were awakened by a smoke detector. The female occupant noticed smoke coming from the floor vents on Floor 2. She proceeded downstairs and opened the front door and then proceeded down the first floor hallway towards Side C, but encountered thick smoke and high temperature. The female and male occupants exited the structure, leaving the front door open, and made contact with the occupant of an adjacent unit who notified the DC Fire & EMS Department at 00:17 hours.

Dispatch Information

At 00:17, DC Fire & EMS Communications Division dispatched a first alarm assignment consisting of Engines 26, 17, 10, 12, Trucks 15, 4, Rescue Squad 1, and Battalion 1 to 3150 Cherry Road NE. At 0019 Communications received a second call, reporting a fire in the basement of 3146 Cherry Road NE. Communications transmitted the update with the change of address and report of smoke coming from the basement. However, only one of the responding companies (Engine 26) acknowledged the updated information.

Weather Conditions

Temperature was approximately 66^{o} F (19^{o} C) with south to southwest winds at 5-10 mi/hr (8-16 km/h), mostly clear with no precipitation.

Conditions on Arrival

Approaching the incident, Engine 26 observed smoke blowing across Bladensburg Road. Engine 26 arrived at a hydrant at the corner of Banneker Drive and Cherry Road at 00:22 hours and reported smoke showing. A short time later, Engine 26 provided an updated size-up with heavy smoke showing from Side A of a two story row house. Based on this report, Battalion 1 ordered a working fire dispatch and a special call for the Hazmat Unit at 00:23. This added Engine 14, Battalion 2, Medic 17 and EMS Supervisor, Air Unit, Duty Safety Officer, and Hazmat Unit.

Firefighting Operations

DC Fire and EMS Department standard operating procedures (SOP) specify apparatus placement and company assignments based on dispatch (anticipated arrival) order. *Note that dispatch order (i.e., first due, second due) may de different than order of arrival if companies are delayed by traffic or are out of quarters.*

Standard Operating Procedures[1]

Operations from Side A[2]

The first due engine lays a supply line to Side A, and in the case of basement fires, the first line is positioned to protect companies performing primary search on upper floors by placing a line to cover the interior stairway to the basement. The first due engine is backed up by the third due engine. The apparatus operator of the third due engine takes over the hydrant and pumps supply line(s) laid by the first due engine, while the crew advances a backup line to support protection of interior exposures and fire attack from Side A.

The first due truck takes a position on Side A and is responsible for utility control and placement of ladders for access, egress, and rescue on Side A. If not needed for rescue, the aerial is raised to the roof to provide access for ventilation.

The rescue squad positions on Side A (unless otherwise ordered by Command) and is assigned to primary search using two teams of two. One team searches the fire floor, the other searches above the fire floor. The apparatus operator assists by performing forcible entry, exterior ventilation, monitoring search progress, and providing emergency medical care as necessary.

Operations from Side C

The second due engine lays a supply line to the rear of the building (Side C), and in the case of basement fires, is assigned to fire attack if exterior access to the basement is available and if it is determined that the first and third due engines are in a tenable position on Floor 1. The second due engine is responsible for checking conditions in the basement, control of utilities (on Side C), and notifying Command of conditions on Side C. Command must verify that the first and third due engines can maintain tenable positions before directing the second due engine to attack basement fires from the exterior access on Side C.

The second due truck takes a position on Side C and is responsible for placement of ladders for access, egress, and rescue on Side C. The aerial is raised to the roof to provide secondary access for ventilation (unless other tasks take priority).

Command and Control

The battalion chief positions to have an unobstructed view of the incident (if possible) and uses his vehicle as the command post. On greater alarms, the command post is moved to the field command unit.

[1] This summary of DC Fire & EMS standard operating procedures for structure fires is based on information provided in the reconstruction report and reflects procedures in place at the time of the incident.

[2] DC Fire & EMS did not use alpha designations for the sides of a building at the time of this incident. However, this approach is used here (and throughout the case) to provide consistency in terminology.

First due, Engine 26 laid a 3” (76 mm) supply line from a hydrant at the intersection of Banneker Drive and Cherry Road NE, positioned in the parking lot on Side A, and advanced a 200’ 1-1/2” (61 m 38 mm) pre-connected hoseline to the first floor doorway of the fire unit on Side A (see Figure 6). A bi-directional air track was evident at the door on Floor 1, Side A with thick (optically dense) black smoke from the upper area of the open doorway. Engine 26’s entry was delayed due to a breathing apparatus facepiece malfunction. The crew of Engine 26 (Firefighters Mathews and Morgan and the Engine 26 Officer) made entry at approximately 00:24.

Engine 10, the third due engine arrived shortly after Engine 26, took the hydrant at the intersection of Banneker Drive and Cherry Road, NE, and pumped Engine 26’s supply line. After Engine 10 arrived at the hydrant, the firefighter from Engine 26 who had remained at the hydrant proceeded to the fire unit and rejoined his crew. Engine 10, advanced a 400’ 1-1/2” (122 m 38 mm) line from their own apparatus as a backup line. Firefighter Phillips and the Engine 10 officer entered through the door on Floor 1, Side A (see Figure 6) while the other member of their crew remained at the door to assist in advancing the line.

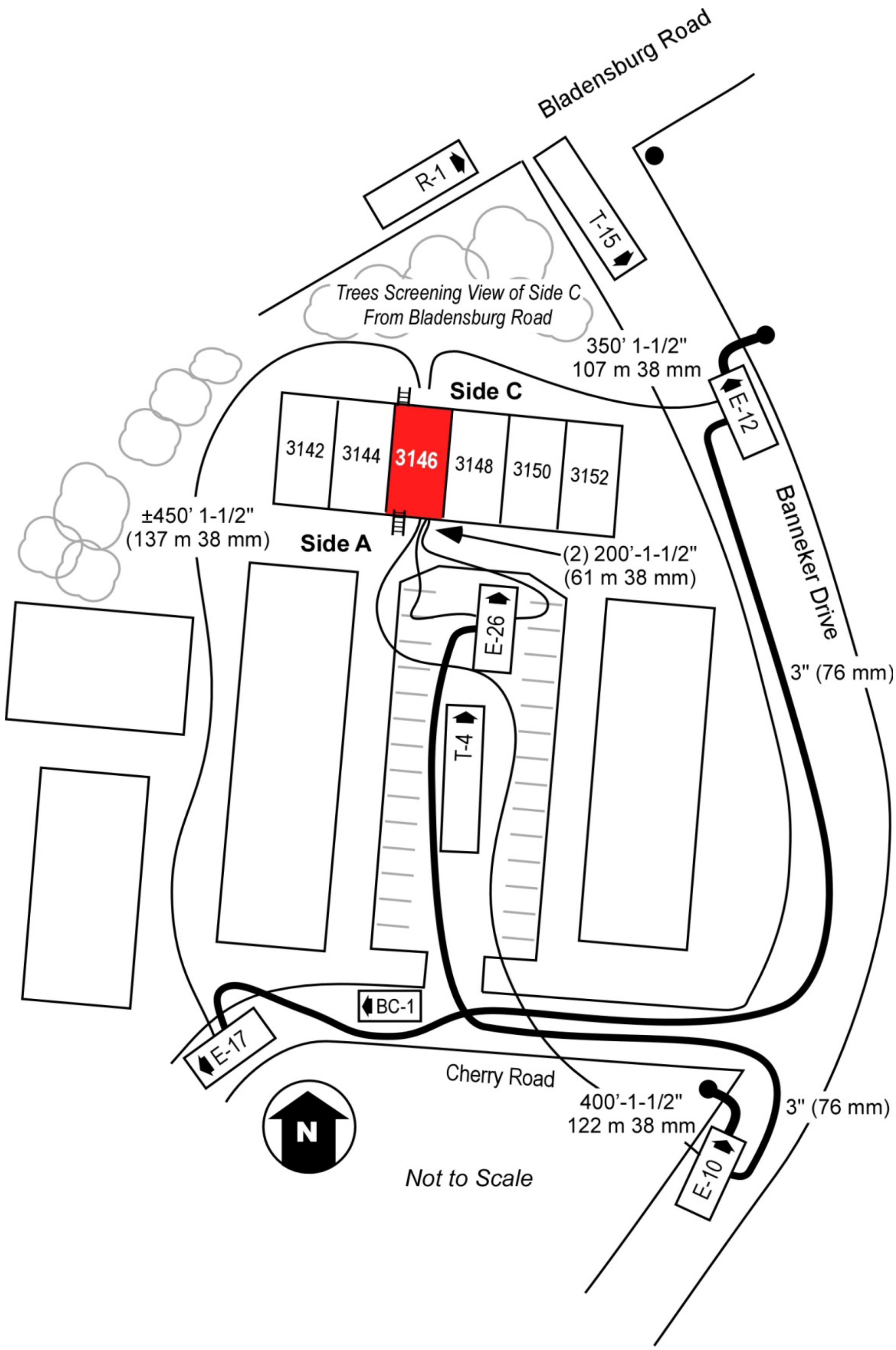
Truck 15, the first due truck arrived at 00:23 and positioned on Side A in the parking lot behind Engine 26. The crew of Truck 15 began laddering Floor 2, Side A, and removed kitchen window on Floor 1, Side A (see Figure 6). Due to security bars on the window, one member of Truck 15 entered the building and removed glass from the window from the interior. After establishing horizontal ventilation, Truck 15 accessed the roof via a portable ladder and began vertical ventilation operations.

Engine 17, the second due engine, arrived at 00:24, laid a 3” (76 mm) supply line from the intersection of Banneker Drive and Cherry Road NE, to a position on Cherry Road NE just past the parking lot, and in accordance with department procedure, stretched a 350’ 1-1/2” (107 m 38 mm) line to Side C (see Figure 6).

Approaching Cherry Road from Banneker Drive, Battalion 1 observed a small amount of fire showing in the basement and assigned Truck 4 to Side C. Battalion 1 parked on Cherry Road at the entrance to the parking lot, but was unable to see the building, and proceeded to Side A and assumed a mobile command position.

Second due, Truck 4 proceeded to Side C and observed what appeared to be a number of small fires in the basement at floor level (this was actually flaming pieces of ceiling tile which had dropped to the floor). The officer of Truck 4 did not provide a size-up report to Command regarding conditions on Side C. Truck 4, removed the security bars from the basement sliding glass door using a gasoline powered rotary saw and sledgehammer. After clearing the security grate Truck 4, broke the right side of the sliding glass door to ventilate and access the basement (at approximately 00:27) and then removed the left side of the sliding glass door. The basement door on Side C was opened prior to Engine 17 getting a hoseline in place and charged. After opening the sliding glass door in the basement, Truck 4 attempted to ventilate windows on Floor 2 Side C using a the tip of a ladder. They did not hear the glass break and believing that they had been unsuccessful; they left the ladder in place at one of the second floor windows and continued with other tasks.

Figure 6. Location of First Alarm Companies and Hoselines



Note: Adapted from *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 27. District of Columbia Fire & EMS, 2000.

Unknown to Truck 4, these windows had been left open by the exiting occupants. Truck 4B[3] returned to their apparatus for a ladder to access the roof from Side C. Rescue 1 arrived at 00:26 and reported to Side C after being advised by the male occupant that everyone was out of the involved unit (this information was not reported to Command). Rescue 1 and Truck 4 observed inward air track (smoke and air) at the exterior basement doorway on Side C and an increase in the size of the flames from burning material on the floor.

Engines 26 and 10 encountered thick smoke and moderate temperature as they advanced their charged 1-1/2" (38 mm) hoselines from the door on Side A towards Side C in an attempt to locate the fire. As they extended their hoselines into the living room, the temperature was high, but tolerable and the floor felt solid. It is important to note that engineered, lightweight floor support systems such as parallel chord wood trusses do not provide reliable warning of impending failure (e.g., sponginess, sagging), failure is often sudden and catastrophic (NIOSH, 2005; UL, 2009).

Prior to reaching Side C of the involved unit, Engine 17 found that their 350' 1-1/2" (107 m 38 mm) hoseline was of insufficient length and needed to extend the line with additional hose.

Engine 12, the fourth arriving engine, picked up Engine 17's line, completed the hoselay to a hydrant on Banneker Drive (see Figure 6). The crew of Engine 12 then advanced a 200' 1-1/2" (61 m 38 mm) hoseline from Engine 26 through the front door of the involved unit on Side A and held in position approximately 3' (1 m) inside the doorway. This tactical action was contrary to department procedure, as the fourth due engine has a standing assignment to stretch a backup line to Side C.

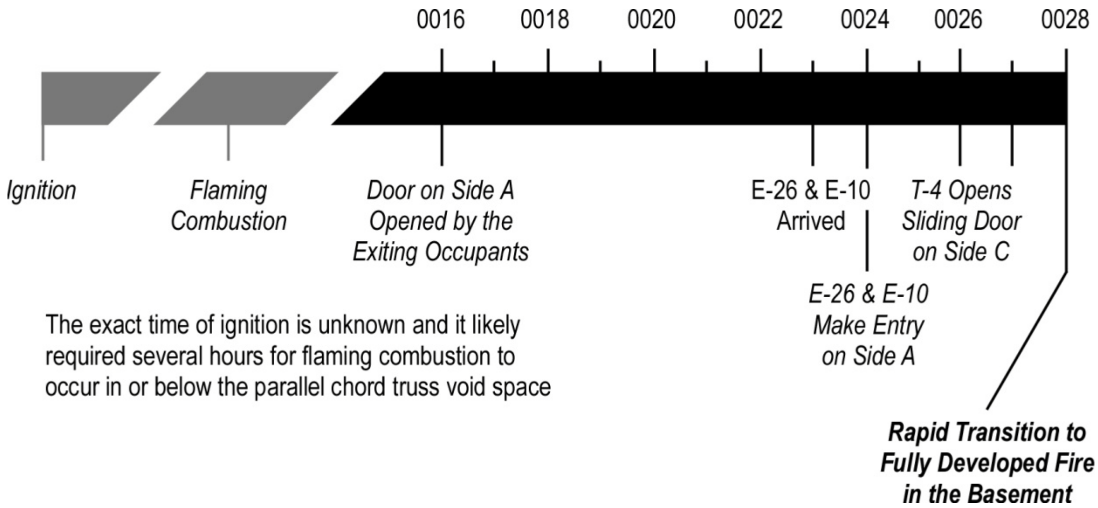
Rescue 1's B Team (Rescue 1B) and a firefighter from Truck 4 entered the basement without a hoseline in an effort to conduct primary search and access the upper floors via the interior stairway. Engine 17 reported that the fire was small and requested that Engine 17 apparatus charge their line.

Extreme Fire Behavior

Proceeding from their entry point on Side C towards the stairway to Floor 1 on Side A, Rescue 1B and the firefighter from Truck 4 observed fire burning in the middle of the basement room. Nearing the stairs, temperature increased significantly and they observed fire gases in the upper layer igniting. Rescue 1B and the firefighter from Truck 4 escaped through the basement doorway on Side C as the basement rapidly transitioned to a fully developed fire.

[3] Washington DC Fire & EMS engine and truck companies staffed with four or more personnel can be split into two person teams designated A and B (i.e., T-4A Officer and Firefighter and T-4B Apparatus Operator and Tiller Driver).

Figure 7. Timeline Leading Up to the Extreme Fire Behavior Event



The timeline illustrated in Figure 7 is abbreviated and focuses on a limited number of factors. A detailed timeline, inclusive of tactical operations, fire behavior indicators, and fire behavior is provided in a subsequent section of the case.

After Engine 17's line was charged, the Engine 17 officer asked Command for permission to initiate fire attack from Side C. Command denied this request due to lack of contact with Engines 26 and 10 and concern regarding opposing hoselines. Due to their path of travel around Side B of the building, Engine 17 had not had a clear view of Side A and thought that they were at a doorway leading to Floor 1 (rather than the Basement). At this point, neither the companies on Side C nor Command recognized that the building had three levels on Side C and two levels on Side A.

At this point crews from Engine 26 and 10 are operating on Floor 1 and conditions begin to deteriorate. Firefighter Morgan (Engine 26) observed flames at the basement door (Figure 8 illustrates conditions visible from Side C at approximately the same time). Firefighter Phillips (Engine 10) knocked down visible flames at the doorway, but conditions continued to deteriorate. Temperature increased rapidly while visibility dropped to zero.

As conditions deteriorated, Engine 26's officer feels his face burning and quickly exits (without notifying his crew). In his rapid exit through the hallway on Floor 1, he knocked the officer from Engine 10 over. Confused about what was happening Engine 10's officer exited the building as well (also without notifying his crew). Engine 26's officer reports to Command that Firefighter Mathews was missing, but did not report that Firefighter Morgan was also missing. Appearing dazed, Engine 10's officer did not report that Firefighter Phillips was missing.

Figure 8. Conditions on Side C at Aproximately 00:28

Note: From *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 32. District of Columbia Fire & EMS, 2000.

Figure 9. Conditions on Side A at Aproximately 00:28

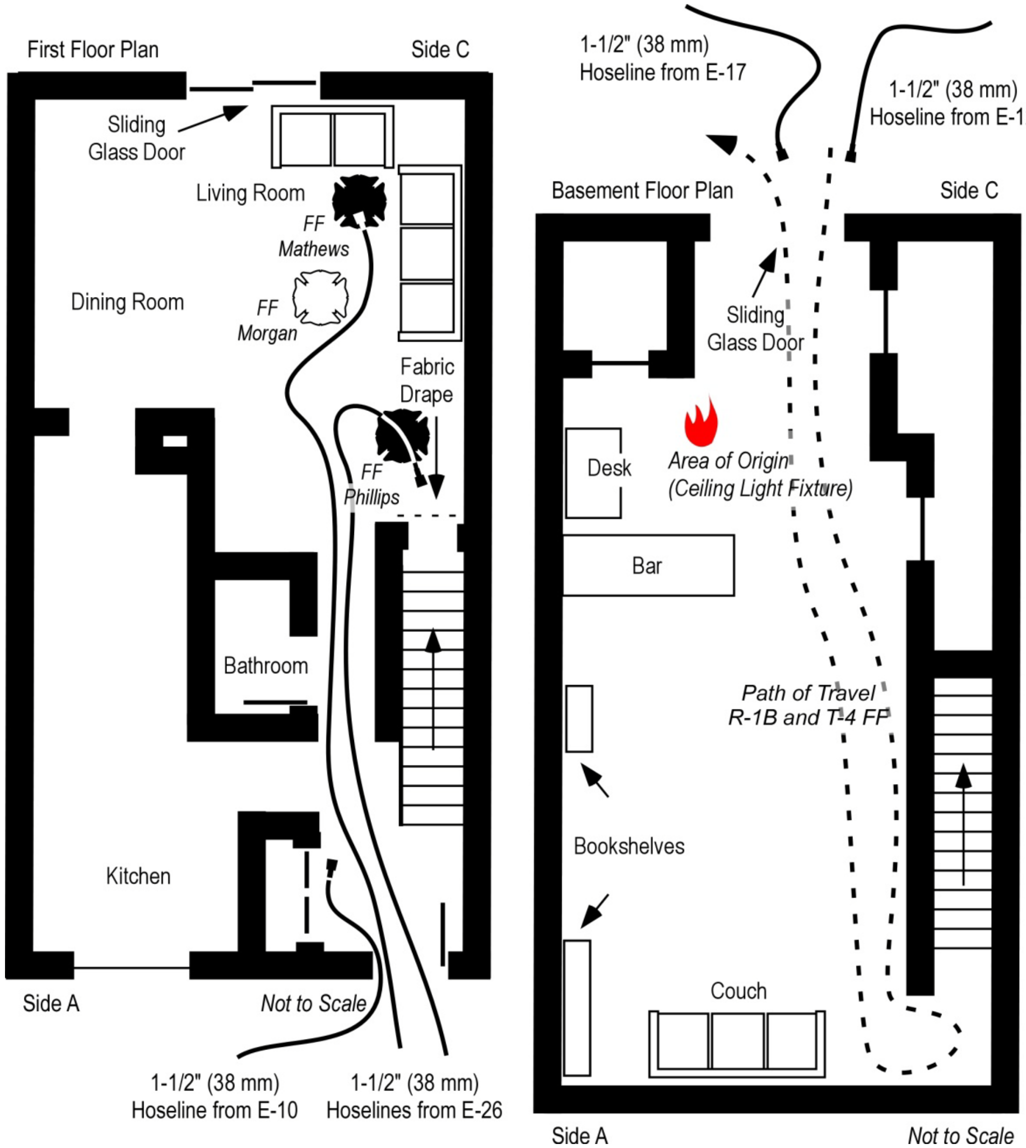
Note: From *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 29. District of Columbia Fire & EMS, 2000.

Firefighter Rescue Operations

After the exit of the officers from Engine 26 and Engine 10, the three firefighters (Mathews, Phillips, and Morgan) remained on Floor 1. However, neither Command (Battalion 1) nor a majority of the other personnel operating at the incident recognized that the firefighters from Engines 26 and 10 had been trapped by the rapid extension of fire from the Basement to Floor 1 (see Figure 10).

While at their apparatus getting a ladder to access the roof from Side B, Truck 4B observed the rapid fire development in the basement and pulled a 350’ 1-1/2” (107 m 38 mm) line from Engine 12 to Side C, backing up Engine 17 (see Figures 6 and 10).

Figure 10. Location of Firefighters on Floor 1



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Engine 17 again contacted Command (Battalion 1) and requested permission to initiate an exterior attack from Side C. However, the officer of Engine 17 mistakenly advised Command that there was no basement entrance and that his crew was in position to attack the fire on Floor 1. Unable to contact Engines 10 and 26, Command denied this request due to concern for opposing hoselines. With conditions worsening, Command (Battalion 1) requested a Task Force Alarm at 00:29, adding another two engine companies, truck company, and battalion chief to the incident.

Firefighter Phillips (E-10) attempted to retreat from his untenable position at the open basement door. He was only able to travel a short distance before he collapsed. Firefighter Morgan (E-26) heard a loud scream to his left and then a thud as if someone had fallen to the floor (possibly Firefighter Mathews (E-26)). Firefighter Morgan found the attack line and opened the nozzle on a straight stream, penciling the ceiling twice before following the hoseline out of the building (to Side A). Firefighter Morgan exited the building at approximately 00:30.

Rescue 1B entered the structure on Floor 1, Side A to perform a primary search. They crawled down the hallway on Floor 1 towards Side C until they reached the living room and attempted to close the open basement door but were unable to do so. *Rescue 1 B did not see or hear Firefighters Mathews (E-26) and Phillips (E-10) while working on Floor 1.* Rescue 1B noted that the floor in the living room was spongy. The Rescue 1 Officer ordered his B Team to exit, but instead they returned to the front door and then attempted to search Floor 2, but were unable to because of extremely high temperature.

Unaware that Firefighter Phillips (E-10) was missing, Command tasked Engine 10 and Rescue 1A, with conducting a search for Firefighter Mathews (E-26). The Engine 10 officer entered Floor 1 to conduct the search (alone) while instructing another of his firefighters to remain at the door. Rescue 1A followed Engine 26's 1-1/2" (38 mm) hoseline to Floor 1 Slide C. Rescue 1B relocated to Side B to search the basement for the missing firefighter.

The Engine 26 Officer again advised Command (Battalion 1) that Firefighter Mathews was missing. Engine 17 made a final request to attack the fire from Side C. Given that a firefighter was missing and believing that the fire had extended to Floor 1, Command instructed Engine 17 to attack the fire with a straight stream (to avoid pushing the fire onto crews working on Floor 1). Approximately two minutes later, at 00:33, Battalion 2 reported (from Side C) that the fire was darkening down. Engine 14 arrived and staged on Bladensburg Road.

Command ordered a second alarm assignment at 00:34 hours. At 00:36, Command ordered Battalion 2 (on Side C) to have Engine 17 and Truck 4 search for Firefighter Mathews in the Basement. Engine 10's officer heard a shrill sound from a personal alert safety system (PASS) and quickly located Firefighter Phillips (E-10). Firefighter Phillips was unconscious, lying on the floor (see Figure 10) with his facepiece and hood removed. Unable to remove Firefighter Phillips by himself, the officer from Engine 10 unsuccessfully attempted to contact Command (Battalion 1) and then returned to Side A to request assistance.

Command received a priority traffic message at 00:37, possibly attempting to report the location of a missing firefighter. However, the message was unreadable.

The Hazmat Unit and Engine 6 arrived and staged on Bladensburg Road and a short time later were tasked by Command to assist with rescue of the downed firefighter on Floor 1. Firefighter Phillips (E-10) was removed from the building by the Engine 10 officer, Rescue 1A, Engine 6, and the Hazardous Materials Unit at 00:45. After Firefighter Phillips was removed to Side A, Command discovered that Firefighter Mathews (E-26) was still missing and ordered the incident safety officer to conduct an accountability check. Safety attempted to conduct a personnel accountability report (PAR) by radio, but none of the companies acknowledged his transmission.

The Deputy Chief of the Firefighting Division arrived at 00:43 and assumed Command, establishing a fixed command post at the Engine 26 apparatus. Battalion 4 arrived a short time later and was assigned to assist with rescue operations along with Engines 4 and 14.

Firefighter Mathews was located simultaneously by several firefighters. He was unconscious leaning over a couch on Side C of the living room (see Figure 10). Firefighter Mathews breathing apparatus was operational, but he had not activated his (non-integrated) personal alert safety system (PASS). Firefighter Mathews was removed from the building by Engine 4, Engine 14, and Hazardous Materials Unit at 00:49.

Command (Deputy Chief) ordered Battalions 2 and 4 to conduct a face-to-face personnel accountability report on Sides A and C at 00:53.

Incident Timeline

The clock icon is used to identify events for which a specific time was available. Events which were estimated based on the narrative, photographic evidence, or other information are shown in italic text. Due to poor radio communications (limited data captured in transcript of the recordings of the dispatch and fireground channels), arrival times of companies and overhead beyond the first alarm were estimated based on the transcript of radio transmissions and sequence of tactical operations.

Fire Behavior Indicators & Conditions	Time		Response & Fireground Operations
Smoke detector activation and smoke from the heating, ventilation, and air conditioning (HVAC) vents in the floor on Floor 2 (Female Occupant).	00:14		
	00:15		*The female occupant opened the door on Floor 1 Side A,*
Thick (optically dense) smoke and high temperature in the hallway on Floor 1 (Female Occupant)	00:16		*Male and female occupants exited the building and asked a neighbor to call 911.*
	00:17	(clock)	Initial 911 call reported fire at 3150 Cherry Road, NE
	00:18	(clock)	E-26, E-17, E-10, & E-12, T-15, &T-4, BC1-, and R-1 are dispatched.

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
	00:19	Second 911 call reported “fire in the basement” at 3146 Cherry Road, NE Communications announced on Fire Channel 1 the address change and reported that fire was in the basement. Communications received acknowledgment from E-26 of the address change only.
	00:20	
	00:21	
Smoke blowing across Bladensburg Road and visible from the intersection of Banneker Drive and Cherry Road (E-26).	00:22	E-26 gave a size-up report and laid a 3” supply line from the hydrant at the intersection of Banneker Drive and Cherry Road.
A large volume of thick (optically dense) smoke showing from the doorway on Floor 1, Side A (E-26, E-10)	00:23	E-26 positioned in the parking lot on Side A and reported “heavy smoke showing from a two-story row [house]” E-10 arrived, connected to the hydrant at Banneker Drive and Cherry Road and pumped E-26’s supply line. Battalion 1 requested a Working Fire Dispatch (Safety Officer, Engine, Air Unit, Ambulance, Fire Investigator, and EMS Supervisor) and a Special Alarm for the Hazmat Unit. T-15 arrived on scene and positioned behind Engine 26 on Side A
Bi-directional air track (smoke out the top and air in at the bottom) at the door of the townhouse (E26, T-15)	00:24	E-17 arrived on scene and gave their layout information as “same intersection as E-26.” [Banneker Drive and Cherry Road] *E-26 and E-10 entered the front door on Floor 1, Side A with charged 1-1/2” hose lines* *E-17 began advancing their hose line to the rear of the building*

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
Small amount of fire showing in the basement observed from Banneker Drive(BC-1)	00:25	BC-1 and T-4 arrived on scene. BC-1 assigns T-4 to Side C and then assumes a mobile command position on Side A. E-12 arrived and laid a 3" supply line to a hydrant on Banneker Drive, north of Cherry Road, completing E-17's lay. E-14, BC- 2, Fire Investigation Unit, Air Unit, Safety Officer, EMS Supervisor and an EMS unit dispatched as the Working Fire Assignment *R-1 arrived and positioned on Bladensburg Road* *T-4 informed by the occupant that everyone is out of the involved unit.*
Floor 1 was substantially smoke logged with moderate temperature (E-26 and E-10). Temperature increased as crews reached the living room. The floor in the living room felt solid (FF Morgan, E-26). Small flames observed on the floor of the basement and it appeared that the fire was "running out of air" (Truck 4)	00:26	Command assigned BC-2 to "Rear Sector" (i.e. Division C). *T-15 vents windows on Side A and places ladders on Side A to access the roof.* *R-1 arrives on Side C and is informed by the occupant that everyone is out of the involved unit.* *T4 begins forcible entry to remove the security grate from the Basement door on Side C.*
Strong inward air track after the sliding glass door in the Basement, Side C was broken. Flaming combustion increased after the basement door was opened (T-4 and R-1).	00:27	*T-4 broke out the left and then right sides of the sliding glass door in the Basement and attempted to ventilate the second floor windows using a ladder (Side C)* *R-1B and a firefighter from T-4 entered the Basement in an unsuccessful attempt to reach the interior stairway to Floor 1.* *E-12 advances a 200' 1-1/2" line from Engine 26 to the door on Floor 1, Side A.*

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
Rapid transition to fully developed fire conditions in the Basement. (R-1B, T-4, E-17). Extremely high temperature on Floor 1, FF Morgan was concerned that the living room was about to flashover (FF Morgan, E-26)	00:27 (continued)	E-17 reports (radio) that the fire is small and requests that E-17 apparatus charge the attack line. *R-1B and a firefighter from T-4 exit the basement due to worsening fire conditions.*
Flames are visible on Floor 1 at the basement doorway, appearing to fill the doorway and then disappeared, visibility decreases as the volume and thickness (optical density) of smoke increases. Temperature on floor 1 increases dramatically (FF Morgan, E-26). Fully developed fire in the Basement with flames from the Basement sliding glass door on Side C as illustrated in Figure 8 (Engine 17) and extending up the basement stairway to Floor 1 (FF Morgan, E-26).	00:28	*R-1 proceeds to Side A and removes security bars from windows.* *E-12 enters the door on Floor 1, Side A with a charged 1-1/2" hoseline, advances a short distance and then withdraws to Side A.* *E-26's officer is burned and exits the building.* *Firefighter Morgan (E-26) operates the 1-1/2" hoseline on a straight stream, applying water to the ceiling in a circular pattern several times.*
Thick (optically dense) smoke discharging from the door on Floor 1, Side A with substantial turbulence and a bi-directional air track as illustrated in Figure 9.	00:29	E-17 reported that there was no basement entrance, that the fire was on Floor 1 extending to Floor 2, and requested permission to initiate attack from Side C which was denied due to concerns about opposing lines. Command requests a Task Force Alarm (2 Engines, 1 Truck, Battalion Chief) *E-10's officer exited the building and orders a member of his crew working at the doorway to attempt to pull E-10's hoseline from the building to alert Firefighter Phillips to exit.* *Command unsuccessfully attempted to locate E-26 and E-10 by radio* *E-26 advises Command (face-to-face) that F/F Matthews is still in the building*

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
	00:29 (Continued)	*T-15A accesses the roof to perform vertical ventilation, T-15B proceeds to Side C.* *Truck 4 and Truck 15B stretch a 350’ 1-1/2” line from Engine 12 to backup E-17.*
Note: While the report of the Reconstruction Committee (DC Fire & EMS, 2000) indicated that R-1B entered to conduct primary search and attempted to close the basement door at approximately 0030, temperature and velocity of hot gas movement through the stairwell and into the living room would have made operations in this area extremely difficult, if not impossible.	00:30	*Firefighter Morgan (E-26) exits the building on Side A.* *R-1B enters through the door on Floor 1, Side A to conduct primary search, advances to the living room, notes the open basement door and unsuccessfully attempts to close it. R-1B also notes that the floor in the living room is spongy. Ordered to exit by R-1, they return to the doorway on Side A, but then attempt to search Floor 2, but are unable to complete the search due to extreme temperature.* *E-14 arrives (location unknown, possibly on Bladensburg Road)*
	00:31	Communications announced the Task Force Alarm that consisted of: E-4, E-24, T-7,and BC-4. Communications dispatched E-6 as first due unit on the Task Force Alarm and returned E-24. BC- 2 (Working Fire Battalion Chief) arrived and is assigned to Side C. *E-17 received permission to attack the fire from the basement entrance using a straight stream* *E-10’s officer enters through the door on Floor 1, Side A to search for the missing firefighters and directs a member of his crew to stay at the doorway.* *R-1A enters through the door on Floor 1, Side A to search for the missing firefighters and follows E-26’s line down the hall towards Side C.*

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
Flaming combustion in the Basement is reduced (E-17)	00:32	E-17 reported that the fire attack had begun and "we're trying to get to it now." E-14 (Working Fire engine) arrived. *The Deputy Fire Chief (DC) responded on the box alarm.* *R-1B exits Floor 1 on Side A and moves to Side C to search in the basement for the missing firefighters.*
Further reduction of flaming combustion in the Basement (BC-2).	00:33	BC-2 (Side C) reported the fire was "darkening down quite a bit."
	00:34	Command (BC-1) requested a Second Alarm (4 Engines, 2 Trucks, 1 Battalion Chief).
	00:35	
Fire knocked down in the basement (BC-2).	00:36	BC-2 reported all visible fire in the rear was extinguished. Command (BC-1) ordered Battalion 2 (on Side C) to have E-17 and T-4 work together to look for Firefighter Matthews (E-26). *Hazmat Unit arrived staged on Bladensburg Road* *Engine 4 arrived staged on Bladensburg Road*
	00:37	Unidentified radio transmission of a priority message believed to be reporting a firefighter down on the first floor Command (BC-1) acknowledged the priority message and assigned several companies to assist in rescue operations (possibly E-12 and E-6). Command (BC-1) requested an additional medic unit and BLS ambulance.

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
	00:38	Unidentified fire officer reported fire fighter down on the first floor. Command (BC-1) responded that Hazmat Unit was on the way to assist with rescues. Communications announced the Second Alarm, which consisted of: E-8, E-18, E-24, E-11, T-6, T-17, Mobile Command Unit, Canteen Unit, and Rehab Unit. *E-6 arrived, staged on Bladensburg Road*
	00:39	Command (BC-1) ordered E-4 to disregard protection of exposures and assist with rescues.
Thick (optically dense), black smoke showing from the vertical ventilation openings on the roof (T-15A and T-4B).	00:40	*T-15A and T-4B complete several vertical ventilation openings on the roof.* *T-7 arrived, staged on Bladensburg Road.*
	00:41	*BC-4 arrived (location unknown)*
	00:42	
	00:43	*The DC arrived on scene assumed Command after meeting face-to-face with BC-1.*
	00:44	
	00:45	*F/F Phillips was removed from the building and CPR was initiated. BC-1 was informed that the rescued fire fighter was Phillips, and that F/F Matthews was still missing.*
	00:46	BC-1 ordered the On-Duty Safety Officer to initiate the first roll call, which was unsuccessful
	00:47	
	00:48	
	00:49	

Fire Behavior Indicators & Conditions	Time	Response & Fireground Operations
	00:50	*F/F Matthews was removed from the building*
	00:51	
	00:52	
	00:53	Command (DC) ordered Battalion 2 to conduct a face to face accountability check of all companies in the rear.
	00:54	Command (Deputy Chief) ordered Battalion 4 to conduct a face to face accountability check of all companies in the front

Injuries and Cause of Death

Firefighters Phillips, Mathews, and Morgan, along with the Engine 26 officer were treated by paramedics (ALS level of care) at the incident scene and transported to the Medstar Hospital burn unit.

Firefighter Phillips was pronounced dead at 0108 and Firefighter Mathews died the next day. Both firefighters had extensive thermal injuries to the skin and airways. Firefighter Morgan suffered burns over 60% of his body and was released from the hospital on August 23, 1999. The officer from Engine 26 was treated for burns to his face, hands, and back and was released two days later. One other firefighter was treated for smoke inhalation and released.

Fire Investigation

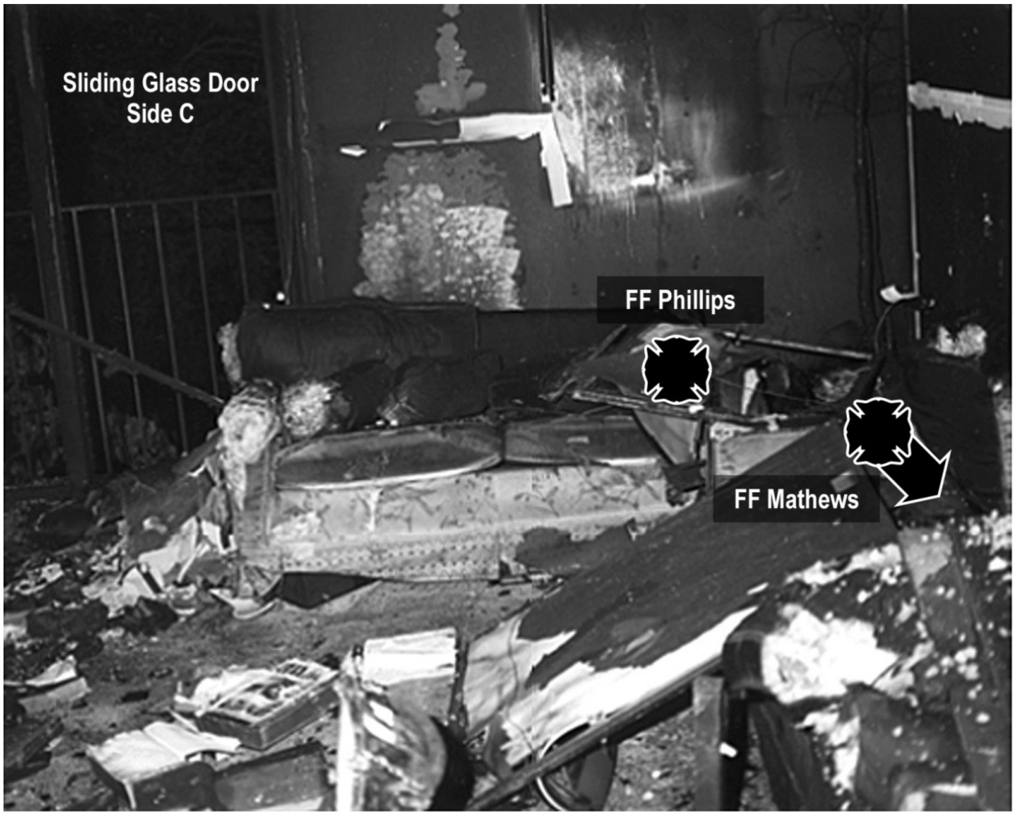
Fire investigators determined that the fire in the basement of 3146 Cherry Road, NE started in an electrical junction box located in the truss space between the basement ceiling and first floor. The fire spread to the combustible ceiling tiles and lightweight open web wooden floor trusses. A number of ceiling tiles dropped to the basement floor and started small secondary fires (DC Fire & EMS, 2000).

The basement had severe fire damage from floor to ceiling, indicating a well-mixed, post-flashover fire. The stairway from the basement to the first floor showed evidence of flame impingement on the ceiling and walls. The door at the top of the basement stairs was open during the fire and was partially burned through (NIST, 1999)

The living room had significant deposits of soot, with limited thermal damage. Most of the paper on the gypsum board walls and ceiling remained intact and sofas in the room only showed signs of pyrolization or limited burning on upper surfaces of back cushions and top surfaces of seat cushions. Areas of the living room distant from the basement door opening had less thermal damage (NIST, 1999).

Figure 11 illustrates post fire conditions on Floor 1 and the approximate locations of Firefighters Phillips and Mathews.

Figure 11. Post-Fire Conditions on Floor 1



Note: Adapted from *Report from the Reconstruction Committee: Fire at 3146 Cherry Road NE, Washington DC, May 30, 1999*, p. 20. District of Columbia Fire & EMS, 2000.

Questions (Part 1)

The following questions focus on fire behavior, influence of tactical operations, and related factors involved in this incident.

1. What fire behavior indicators were present when Engine 26 arrived? How did this change as the incident progressed?

B
Building

S
Smoke

A
Air Track

H
Heat

F
Flame

2. At the time Engines 26 and 10 entered the townhouse through the door on Floor 1, Side A, what was the stage of fire development and burning regime in the basement? What leads you to this conclusion?

3. Did any of the B-SAHF fire behavior indicators point to the potential for extreme fire behavior? If so, how? If not, how could the firefighters and officers operating at this incident have anticipated this potential?

4. What type of extreme fire behavior occurred? Justify your answer?

5. What event or action initiated the extreme fire behavior? Why do you believe that this is the case?

6. How did building design and construction impact on fire behavior and tactical operations during this incident?

7. Analyze the data provided in the case and develop a hypothesis as to how the conditions and events resulted in the extreme fire behavior that occurred in this incident. Support your hypothesis by outlining known and suspected information as well as your assumptions.

8. How might a building pre-plan and/or 360° reconnaissance have impacted the outcome of this incident?

9. Complete one of following tables and determine what impact the length of the 1-1/2” (38 mm) hoselines run from Engines 10, 17, and 12 may have had on nozzle pressure and flow rate? These lines ranged from 350’ to 450’ (lengths in the SI chart have been rounded based on standard sections of 30 m and/or 15 m).

		Friction Loss/100’		**Required Line Pressure**
Nozzle Pressure	**Length of Line**	**100 gpm**	**125 gpm**	**in psi or kPa**
100 psi	200’	30 psi	50 psi	
	350’			
	400’			
	450’			

		Friction Loss/30 m		**Required Line Pressure**
Nozzle Pressure	**Length of Line**	**375 lpm**	**475 gpm**	**in psi or kPa**
700 kPa	60 m	200 kPa	350 kPa	
	105 m			
	120 m			
	135 m			

10. How might the outcome of this incident have changed if Engine 17 had been in position and attacked the fire in the basement prior to Engines 26 and 10 committing to Floor 1?

11. What strategies and tactics might have been used to mitigate the risk of extreme fire behavior during this incident?

12. What do the findings of the fire investigation relative to the compartment linings and contents on floor 1 indicate? How does this correlate to your conclusions regarding the type of extreme fire behavior that occurred and hypothesis as to how this occurred?

Modeling of the Cherry Road Incident

National Institute for Standards and Technology (NIST) performed a computer model of fire dynamics in the fire at 3146 Cherry Road (Madrzykowski and Vettori, 2000) using the NIST Fire Dynamics Simulator (FDS) software. This is one of the first cases where FDS was used in forensic fire scene reconstruction.

Fire Modeling

Fire modeling is a useful tool in research, engineering, fire investigation, and learning about fire dynamics. However, effective use of this tool and the information it provides requires understanding of its capabilities and limitations.

Models, such as the National Institute of Standards and Technology (NIST) Fire Dynamics Simulator (FDS) relay on computational fluid dynamics (CFD). CFD models define the fire environment by dividing it into small, rectangular cells. The model simultaneously solves mathematical equations for combustion, heat transfer, and mass transport within and between cells. When used with a graphical interface such as NIST Smokeview, output can be displayed in a three-dimensional (3D) visual format.

Models must be validated to determine how closely they match reality. In large part this requires comparison of model output to full scale fire tests under controlled conditions. When used for forensic fire scene reconstruction, it may not be feasible to recreate the fire to test the model. In these situations, model output is compared to physical evidence and interview data to determine how closely key aspects of model output matched events as they occurred. If model output reasonably matches events as they occurred, it is likely to be useful in understanding the fire dynamics involved in the incident.

> It is crucial to bear in mind that fire models do not provide a reconstruction of the reality of an event. They are simplified representation of reality that will always suffer from a certain lack of accuracy and precision. Under the condition that the user is fully aware of this status and has an extensive knowledge of the principles of the models, their functioning, their limitations and the significance attributed to their results, fire modeling becomes a very powerful tool (Dele´mont & Martin, J., 2007, p. 134).

FDS output included data on heat release rate, temperature, oxygen concentration, and velocity of gas (smoke and air) movement within the townhouse. As indicated above, model output is an approximation of actual incident conditions.

> In large scale fire tests (McGrattan, Hamins, & Stroup, 1998, as cited in Madrzykowski and Vettori, 2000), FDS temperature predictions were found to be within 15% of the measured temperatures and FDS heat release rates were predicted to within 20% of the measured values. For relatively simple fire driven flows such as buoyant plumes and flows through doorways, FDS predictions are within experimental uncertancies (McGrattan, Baum, & Rehm, 1998, as cited in Madrzykowski and Vettori, 2000).

Results presented in the NIST report on the fire at 3146 Cherry Road were presented as ranges to account for potential variation between model output and actual incident conditions.

Heat release rate is dependent on the characteristics and configuration of the fuel packages involved and available oxygen. In a compartment fire, available oxygen is dependent on the ventilation profile (i.e., size and location of compartment openings). The ventilation profile can change over time due to the effects of the fire (e.g., failure of window glazing) as well as human action (i.e., doors left open by exiting occupants, tactical ventilation, and tactical anti-ventilation)

In this incident there were a number of changes to the ventilation profile. Most significant of which were, 1) the occupant opened the second floor windows on Side C, 2) the occupant left the front door open as they exited, 3) tactical ventilation of the first floor window on Side A, and opening of the sliding glass door in the basement on Side C. In addition, the open door in the basement stairwell and open stairwell between the Floors 1 and 2 also influenced the ventilation profile.

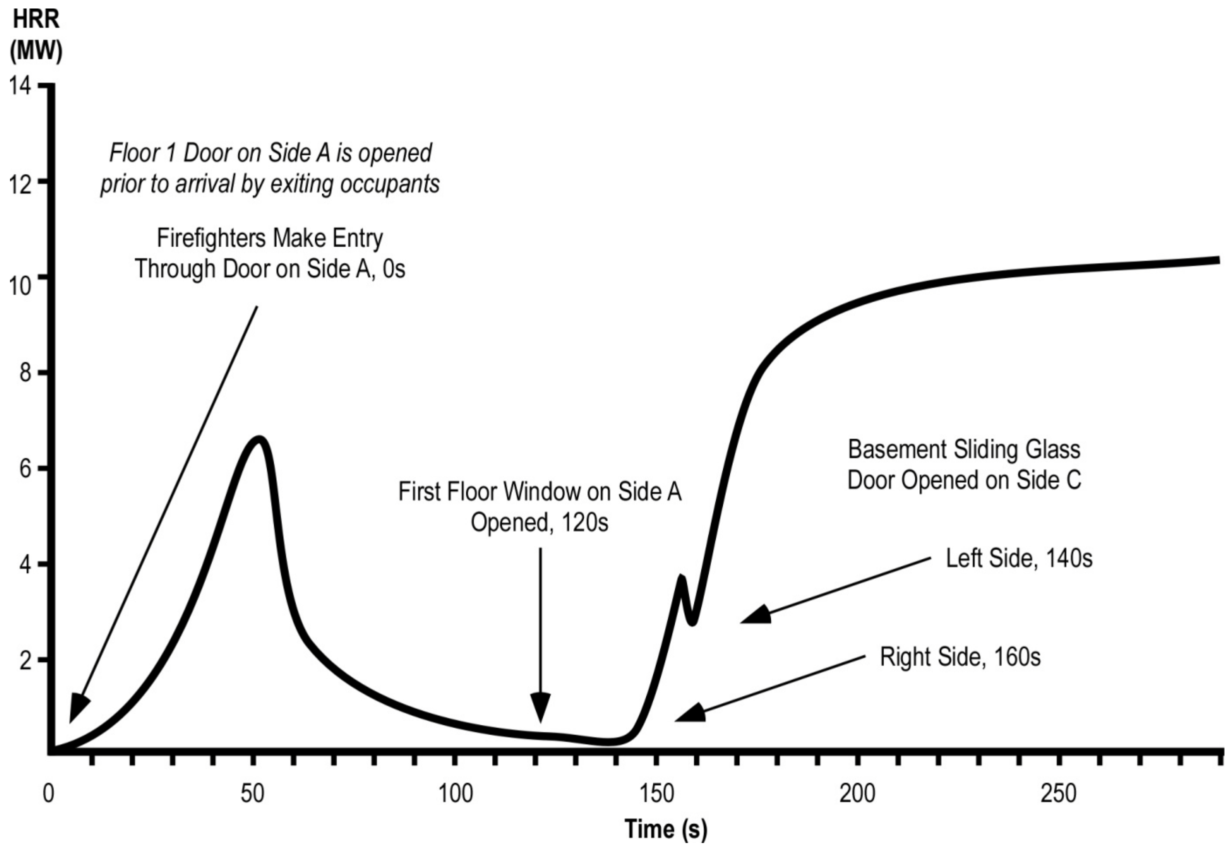
Table 1. Changes to the Ventilation Profile for the FDS Simulation

	Time of Change			
Vent	**Initial (0 s)**	**120 s**	**140 s**	**160 s**
Side A Floor 1 Door 3’ x 6’7” (0.9 m x 2.0 m)	Open	Open	Open	Open
Side A Floor 1 Window 5’7” x 3’ (1.7 m x 0.9 m)	Closed	Open	Open	Open
Side C Basement Door First Half 3’ 3-1/2” x 6’7” (1.35m x 2.0 m)	Closed	Closed	Open	Open
Side C Basement Door Second Half 3’ 3-1/2” x 6’7” (1.35 m x 2.0 m)	Closed	Closed	Closed	Open
Floor 1 Interior Door to Basement Stairs 2’7” x 6’7” (0.8 m x 2.0 m)	Open	Open	Open	Open
Stairway between Floor 1 and Floor 2 2’7” x 6’7” (0.8 m x 2.0 m)	Open	Open	Open	Open

Note: Adapted from *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 14) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 12 illustrates the timing of changes to the ventilation profile and resulting influence on heat release rate in modeling this incident. A small fire with a specific heat release rate (HRR) was used to start fire growth in the FDS simulation. In the actual incident it may have taken hours for the fire to develop flaming combustion and progression into the growth stage. Direct comparison between the simulation and incident conditions began at 100 seconds into the simulation which corresponds to approximately 00:25 during the incident.

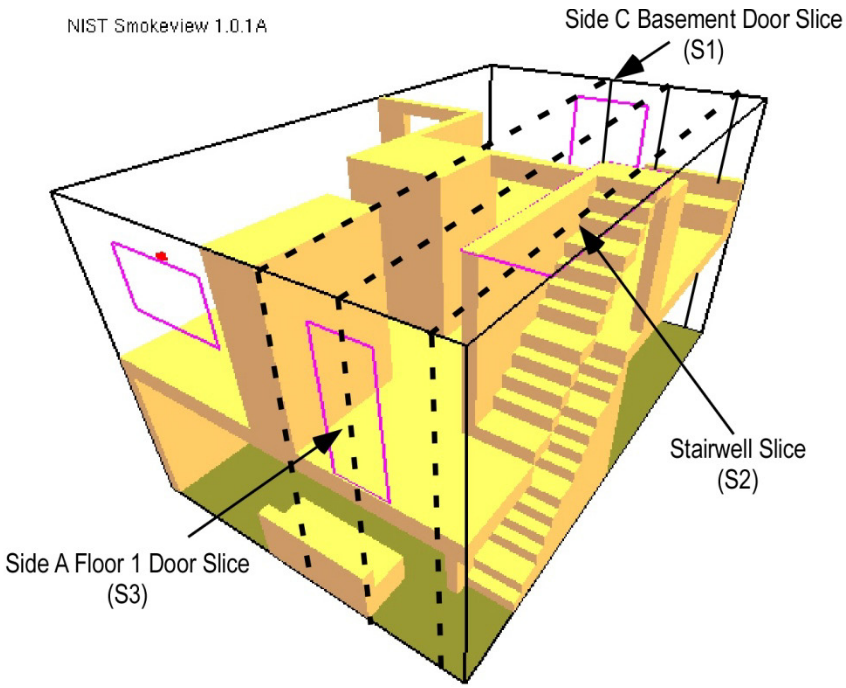
Figure12. FDS Heat Release Rate Curve



Note: Adapted from *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 14) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Smokeview is a visualization program used to provide a graphical display of a FDS model simulation in the form of an animation or snapshot. Snapshots illustrate conditions in a specific plane or slice within the building. Three vertical slices are important to understanding the fire dynamics involved in the Cherry Road incident, they are: 1) midline of the door on Floor 1, Side A, 2) midline of the Basement Door, Side C, and midline of the Basement Stairwell (see Figure 13). Imagine that the building is cut open along the slice and that you can observe the temperature, oxygen concentration, or velocity of gas movement within that plane.

Figure 13. Perspective View of 3146 Cherry Road and Location of Slices

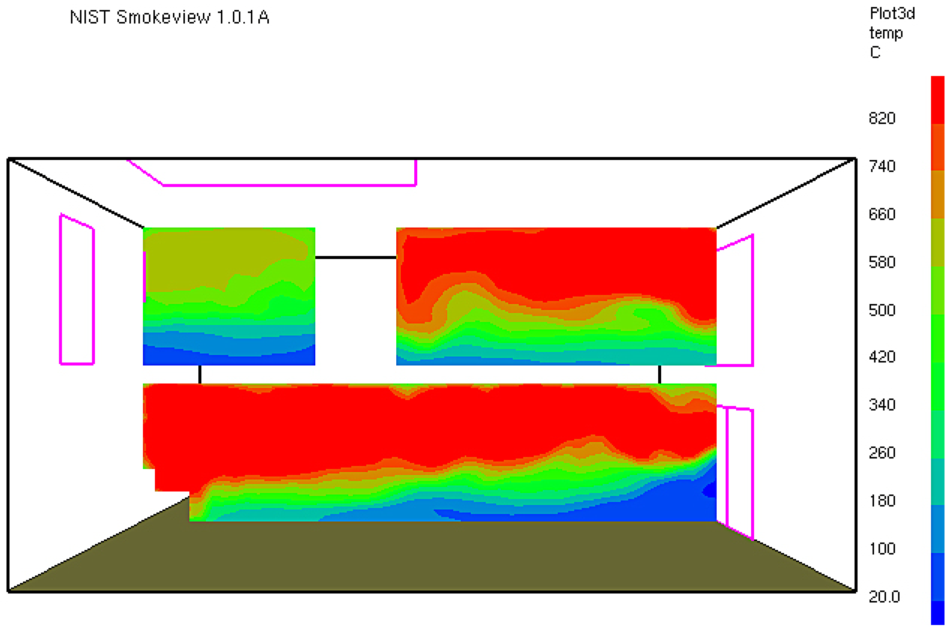


Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 15) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

In addition to having an influence on heat release rate, the location and configuration of exhaust and inlet openings determines air track (movement of smoke and air) and the path of fire spread. In this incident, the patio door providing access to the basement at the rear acted as an inlet, providing additional air to the fire. The front door and windows on the first floor opened for ventilation served as exhaust openings and provided a path for fire travel when the conditions in the basement rapidly transitioned to a fully developed fire.

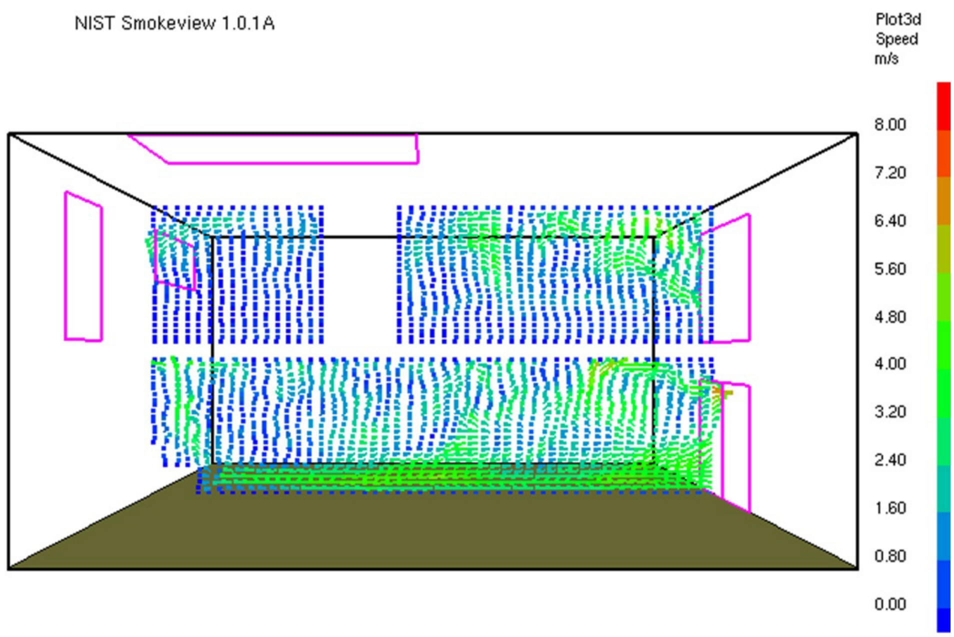
Figures 14-21 illustrate conditions at 200 seconds into the simulation, which relates to approximately 00:27 during the incident, the time at which the fire in the basement transitioned to a fully developed stage and rapidly extended up the basement stairway to Floor 1. Data is presented as a snapshot within a specific slice. Temperature and velocity data are provide for each slice (S1, S2, & S3 as illustrated in Figure 13). Oxygen (O2) concentration data is provided for the basement (S1) and stairwell (S2).

Figure 14. Temperature Along Centerline of Basement Door Side C (S1) at 200 s



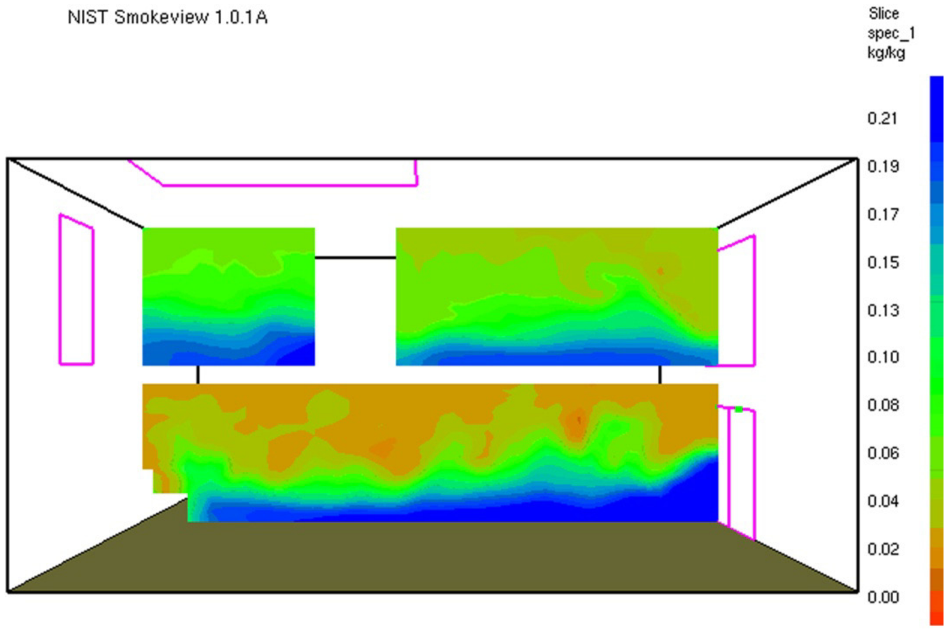
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 17) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 15. Vector Representation of Velocity Along Centerline of Basement Door Side C (S1) at 200 s



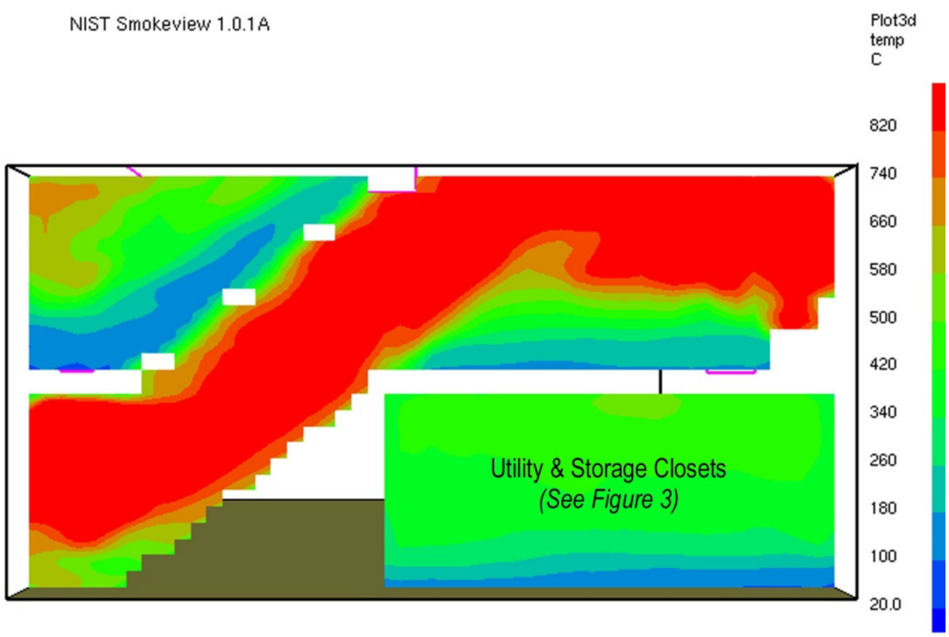
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 18) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 16. Oxygen Concentration Along Centerline of Basement Door Side C (S1) at 200 s



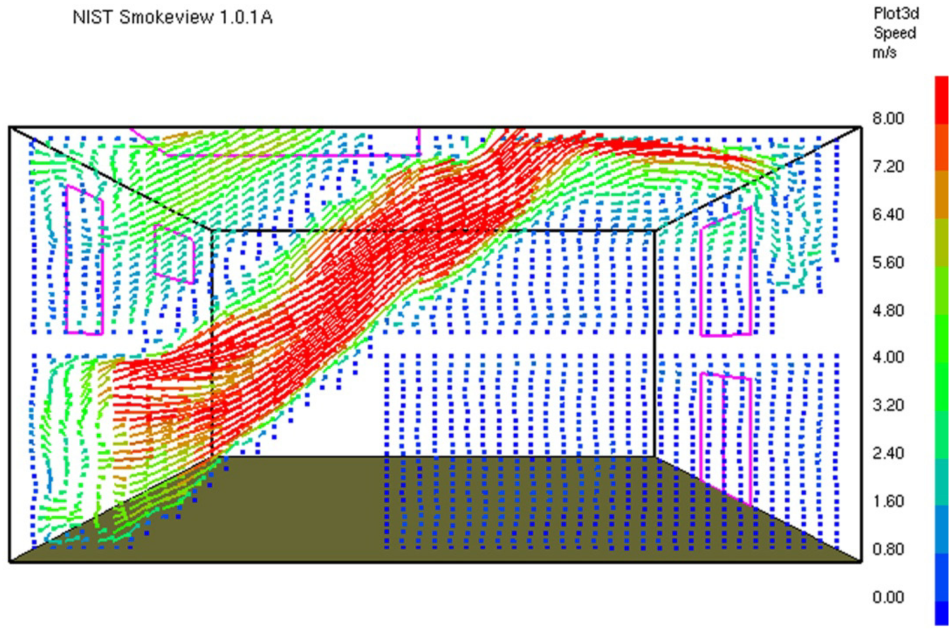
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 23) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure17. Temperature Slice Along Centerline of Basement Stairwell (S2) at 200 s



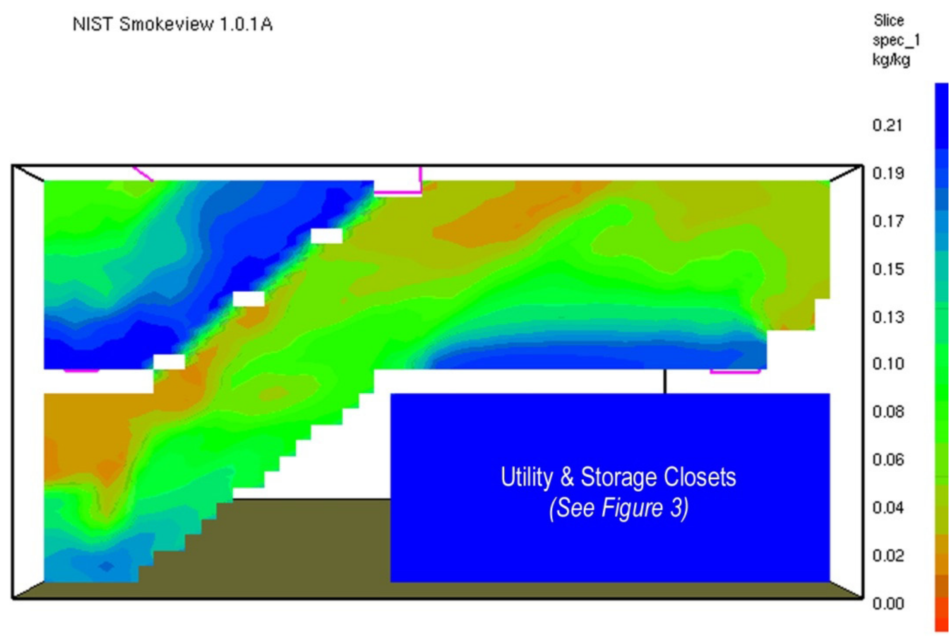
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 21) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 18. Vector Representation of Velocity Along Centerline of Basement Stairwell (S2) at 200 s



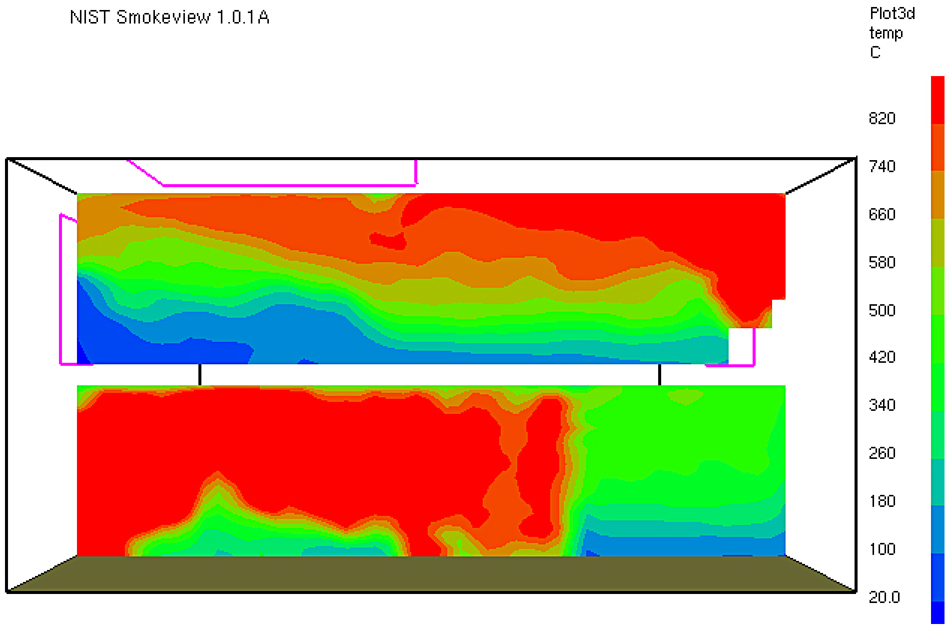
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 22) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 19. Oxygen Concentration Along Centerline of Basement Stairwell (S2) at 200 s



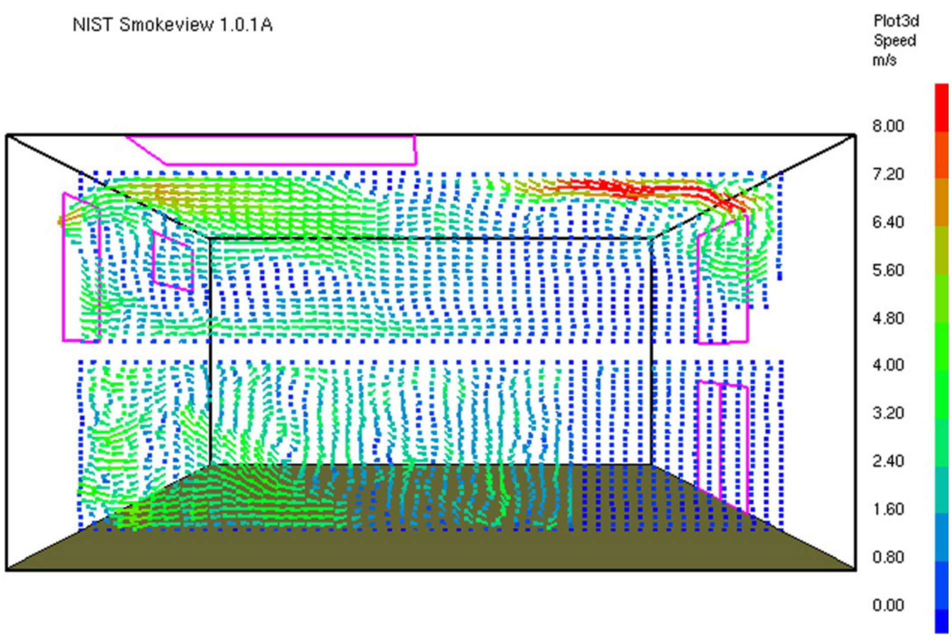
Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 24) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 20. Temperature Slice Along Centerline of Floor 1 Door Side A (S3) at 200 s



Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 19) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 21. Vector Representation of Velocity Along Centerline of Floor 1 Door Side A (S3) at 200 s



Note: From *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 20) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

Figure 22. Perspective Cutaway, Flow/Temperature, Velocity, and O_2 Concentration

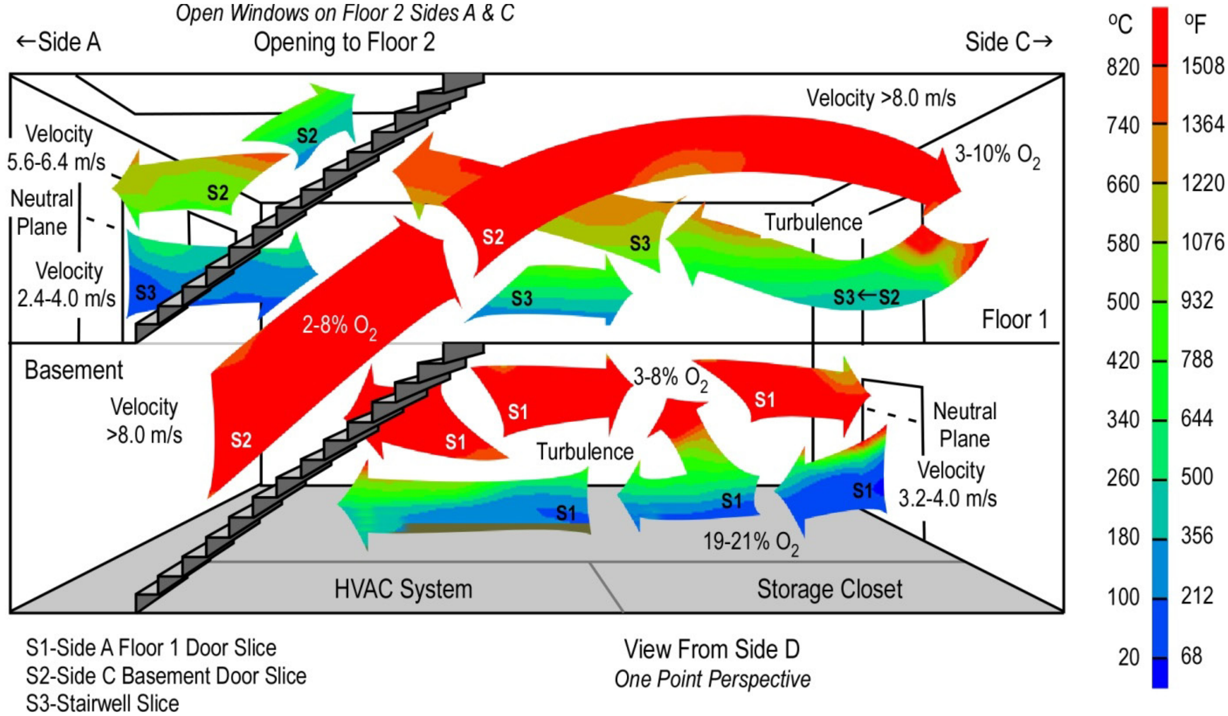
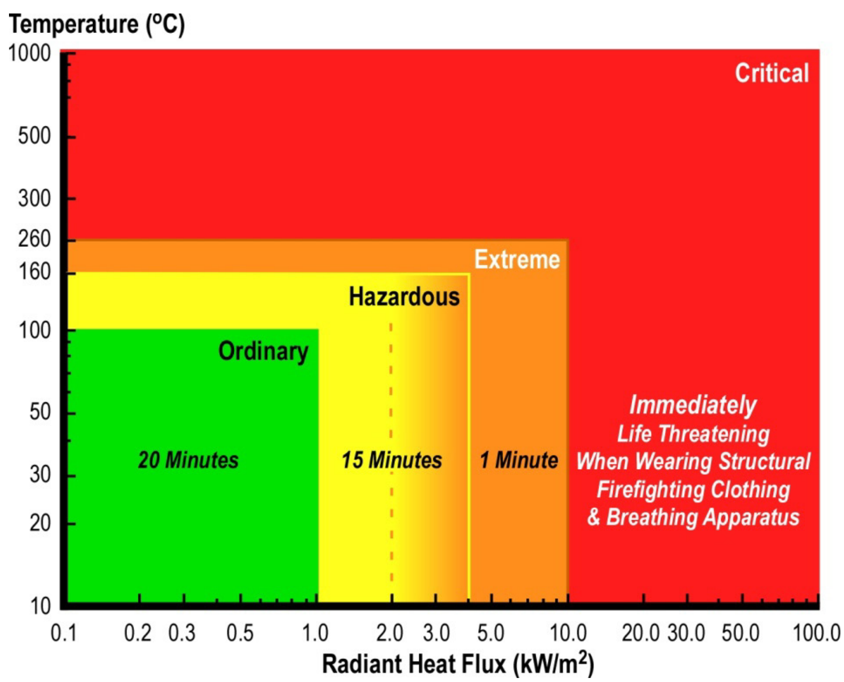


Figure 23. Thermal Exposure Limits in the Firefighting Environment



Note: Adapted from *Measurements of the firefighting environment. Central Fire Brigades Advisory Council Research Report 61/1994* by J.A. Foster & G.V. Roberts, 1995. London: Department for Communities and Local Government and *Thermal Environment for Electronic Equipment Used by First Responders* by M.K. Donnelly, W.D. Davis, J.R. Lawson, & M.J. Selepak, 2006, Gaithersburg, MD: National Institute of Standards and Technology.

Compartment Fire Thermal Hazards

The temperature of the atmosphere (i.e., smoke and air) is a significant concern in the fire environment, and firefighters often wonder or speculate about how hot it was in a particular fire situation. However, gas temperature in the fire environment is a bit more complex than it might appear on the surface and is only part of the thermal hazard presented by compartment fire.

Tissue temperature and depth of penetration determine the severity of a thermal burn. Temperature and penetration are dependent on the amount of energy absorbed and the duration of the thermal insult as well as the properties of human tissue. In a compartment fire, firefighters absorb energy from any substance that has a temperature above 37^{o} C (98.6^{o} F), including hot compartment linings, contents, the hot gas layer, and flames. The dominant mechanisms of heat transfer involved in this process are convection and radiation (although conduction through personal protective equipment is also a factor to be considered).

The total thermal energy received is described in joules per unit area. However, the speed or rate of energy is transferred may be more important when assessing thermal hazard. Heat (thermal) flux is used to define the rate of heat transfer and is expressed in kW/m^2 (Btu/hr/ft^2).

One way to understand the interrelated influence of radiant and convective heat transfer is to consider the following scenario. Imagine that you are standing outside in the shade on a hot, sunny day when the temperature is 38^{o} C (100^{o} F). As the ambient temperature is higher than that of your body, energy will be transferred to you from the air. If you move out of the shade, your body will receive additional energy as a result of radiant heat transfer from the sun.

Convective heat transfer is influenced by gas temperature and velocity. When hot gases are not moving or the flow of gases across a surface (such as your body or personal protective equipment) is slow, energy is transferred from the gases to the surface (lowering the temperature of the gases, while raising surface temperature). These lower temperature gases act as an insulating layer, slowing heat transfer from higher temperature gases further away from the surface. When velocity increases, cooler gases (which have already transferred energy to the surface) move away and are replaced by higher temperature gases. When velocity increases sufficiently to result in turbulent flow, hot gases remain in contact with the surface on a relatively constant basis, increasing convective heat flux.

Radiant heat transfer is influenced by proximity and temperature of the radiating body. Radiation increases by a factor of four when distance to the hot material is reduced by half. In addition, radiation increases exponentially (as a function of the fourth power) as absolute temperature increases.

Thermal hazard may be classified based on hot gas temperature and radiant heat flux (Foster & Roberts, 1995; Donnelly, Davis, Lawson, & Selpak, 2006) with temperatures above 260^{o} C (500^{o} F) and/or radiant heat flux of 10 kW/m^2 (3172 Btu/hr/ft^2) being immediately life threatening to a firefighter wearing a structural firefighting ensemble (including breathing apparatus). National Institute of Standards and Technology (NIST) experiments in a single compartment show post flashover gas temperatures in excess of 1000^{o} C (1832^{o} F) and heat flux at the floor may exceed 170 kW/m^2 (Donnelly, Davis, Lawson, & Selpak, 2006). Post flashover conditions in larger buildings with more substantial fuel load may be more severe!

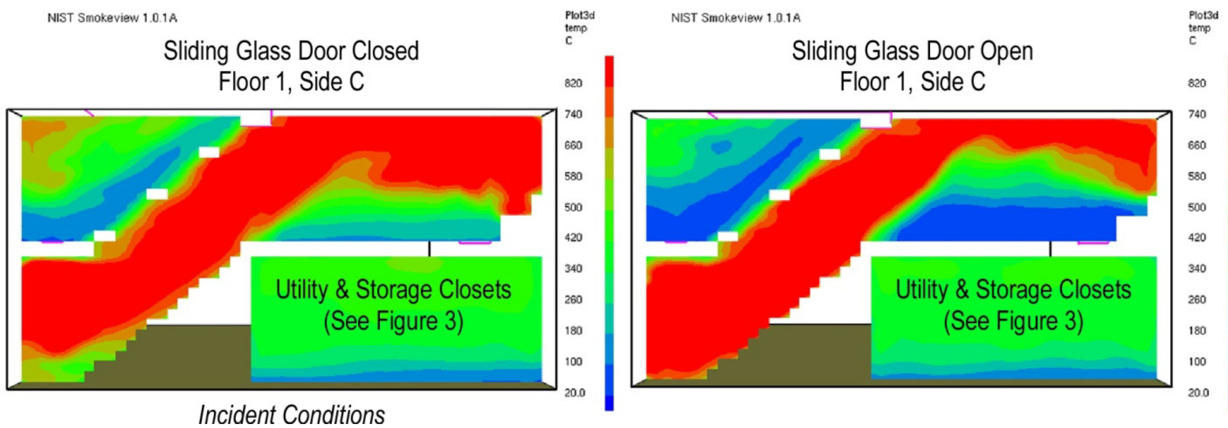
Figure 22 integrates temperature, velocity, and oxygen concentration data from the simulation (Figures 14-21). Detail and accuracy is sacrificed to some extent in order to provide a (somewhat) simpler view of conditions at 200 seconds into the simulation (approximately 00:27 incident time). Note that as in individual slices, data is presented as a range due to uncertainty in the computer model.

Alternative Model

In addition to modeling fire dynamics based on incident conditions and tactical operations as they occurred, NIST also modeled the incident with a slightly different ventilation profile.

The basic input for the alternate simulation was the same as the simulation of actual incident conditions. Ventilation openings and timing was the same, with one exception; the sliding glass door on Floor 1, Side C was opened at 120 s into the simulation. Conditions in the basement during the alternative simulation were similar to the first. However, on Floor 1, the increase in ventilation provided by the sliding glass door on Side C resulted in a shallower hot gas layer and cooler conditions at floor level. A side-by-side comparison of the temperature gradients in these two simulations is provided in Figure 24.

Figure 24. Comparison of Temperature Gradients Along Centerline of Basement Stairwell (S2) at 200 s



Note: Adapted from *Simulation of the Dynamics of the Fire at 3146 Cherry Road NE Washington D.C., May 30, 1999*, NISTR 6510 (p. 21 & 27) by Dan Madrzykowski and Robert Vettori, 2000, Gaithersburg, MD: National Institute for Standards and Technology.

The NIST Report (Madrzykowski & Vettori, 2000) identified that the significant difference between these two simulations is in the region close to the floor. In the alternative simulation (Floor 1, Side C Sliding Glass Door Open) between the doorway to the basement and the sofa, the temperatures from approximately 0.6 m (2 ft) above the floor, to floor level are in the range of 20 °C to 100 °C (68°F to 212 °F), providing at least an 80 °C (176 °F) temperature reduction.

While this is a considerable reduction in gas temperature, it is essential to also consider radiant heat flux from the hot gas layer. Given the temperature of the hot gases from the ceiling level to a depth of approximately 3’ (0.9 m), the heat flux at the floor would likely have been in the range of 15-20 kW/m^2 (or greater).

Questions (Part 2)

The following questions focus on fire behavior, influence of tactical operations, and related factors involved in this incident as informed by the investigation and computer modeling conducted by NIST (2000).

13. What was the relationship between changes in ventilation profile and heat release rate (see Table 1 and Figure 12)? Why?

14. Temperatures vary widely at a given elevation above the floor. Consider the slices illustrated in Figures 14, 17, and 20, and identify factors that may have influenced these major differences in temperature.

15. How might the variations in temperature illustrated in Figures 14, 17, and 20 have influenced the injuries received by Firefighters Mathews, Phillips, and Morgan? See Figure 10 for the position of the firefighters on Floor 1 between 00:27 and 00:28 hours.

16. Examine the velocity of gas movement illustrated in Figures 15, 18, and 21 and integrated illustration conditions in Figure 22. How does this correlate to the photos illustrating incident conditions at approximately 00:28 (Figures 8 and 9)?

17. Explain how the size and configuration of ventilation openings resulted in a bi-directional air track at the basement door on Side C.

18. How did the velocity of hot gases in the stairwell and living room influence the thermal insult to Firefighters Phillips, Mathews, and Morgan? What factors caused the high velocity flow of gases from the basement stairwell doorway into the living room?

19. Rescue 1B noted that the floor in the living room was soft while conducting primary search at approximately 00:30. Why didn't the parallel chord trusses in the basement fail sooner? Is there a potential relationship between fire behavior and performance of the engineered floor support system in this incident?

20. How might stability of the engineered floor support system have differed if the sliding glass door in the basement had failed prior to the fire departments arrival? Why?

21. How might the double pane glazing on the windows and sliding glass doors have influenced fire development in the basement? How might fire development differed if these building openings had been fitted with single pane glazing?

22. What was the likely influence of turbulence in the flow of hot gases and cooler air on combustion in the basement? What factors influenced this turbulence (examine Figures 15, 18, and 21) illustrating velocity of flow and Figure 3 illustrating the unit floor plan)?

23. How did conditions in the area in which Firefighters Phillips, Mathews, and Morgan were located correlate to the thermal exposure limits defined in Figure 23? How did this change in the alternate scenario? Remember to consider both temperature and heat flux.

Extended Learning Activity

This case study provides an excellent opportunity to develop an understanding of the influence of building factors, burning regime, ventilation, and tactical operations on fire behavior. These lessons can be extended by comparing and contrasting this case with other cases to identify common elements and critical differences. Consider examining the following incidents to extend your knowledge:

- Keokuk, IA: Residential Fire
- Poinciana, FL: Live Fire Training
- Blaina, Wales: Terrace Apartment Fire