NIST Response to the World Trade Center Disaster

Federal Building and Fire Safety Investigation of the World Trade Center Disaster

Part IV – Life Safety

April 5, 2005

National Institute of Standards and Technology
Technology Administration
U.S. Department of Commerce

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Analysis of Life Safety

- Nearly 1,200 first person interviews of occupants and emergency responders plus 700 published media accounts
- Review of emergency communication records (radio communications, 9-1-1 calls, 500 plus post-9/11 FDNY interviews)
- Evacuation and occupant behavior:
  - Building population demographics; analysis of decedents
  - Evacuation rates; roof evacuation; communications to occupants; mobility impaired occupants; building damage observations
- Emergency response:
  - First responder roles; situational awareness; access; high-rise operations; radio communications; command and control
- Active fire protection systems:
  - Significant pre-9/11 fires; sprinkler and standpipe system; fire alarm system; smoke management system

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First-Person Interviews

- 1,056 Interviews involving building occupants
  - 225 face-to-face interviews
  - 803 telephone interviews
  - 28 participants in 6 focus groups
- 116 Interviews with emergency responders
  - 68 FDNY interviews
  - 25 NYPD interviews
  - 15 PANYNJ interviews
  - 8 other interviews
- Over 700 published media interviews
- Over 500 interviews conducted by FDNY soon after September 11, 2001

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Communications Sources

- The PANYNJ provided radio and telephone communications recordings related to the emergency response.
- NYPD provided radio communications recordings for the Special Operations Units frequencies and Division 1 frequency that were used in operations at the WTC and the Division 1 citywide frequency.
- New York City provided NIST with opportunity to listen to recordings of telephone calls made to 9-1-1 Emergency Operators and FDNY Fire Dispatchers. The FDNY Manhattan dispatch communications tape was supplied to NIST.
- PANYNJ also supplied a recording from the FDNY high-rise channel 7/Port Authority Police Dept. (PAPD) channel 30 repeater located at the WTC site.

Note: The FDNY Field Communications truck was not in service and recordings of FDNY radio communications at the site were not made.

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Evacuation and Emergency Response

Based on 1,056 interviews of surviving WTC occupants and 116 interviews of emergency responders.

- **It is estimated that 17,400 occupants (± 1,200) were present in the WTC towers on the morning of September 11, 2001.** The initial population of each tower was similar: 8,900 (± 750) in WTC 1 and 8,500 (± 900) in WTC 2. Of those present on September 11, 2001, 16 percent were also present during the 1993 bombing.
  - **About 6 percent of the surviving occupants reported a pre-existing limitation to their mobility.** These limitations included obesity, heart condition, needing assistance to walk, pregnancy, asthma, being elderly, chronic condition, recent surgery or injury, and other.
  - **About 7 percent of the surviving occupants reported having special knowledge about the building.** These included fire safety staff, floor wardens, searchers, building maintenance, and security staff. Searchers assist the floor wardens in facilitating evacuation.
- Approximately **87 percent of the WTC tower occupants, including more than 99 percent of those below the floors of impact, were able to evacuate successfully**.
- Rough estimates indicate that about **20 percent or more of the 2,567 building occupants and emergency responders who were in the WTC towers and lost their lives may have been alive in the buildings just prior to their collapse**. This estimate includes 118 occupants below the floors of impact who died but not the large but unknown number of occupants above the floors of impact who may have been alive prior to collapse.

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Decedent Analysis

September11Victims.com: This site is dedicated to the victims of September 11, 2001 tragedy.

Portraits: 9/11/01: Published by the New York Times in 2003, this book includes short interviews with family members of many decedents.

CNN.com In-Depth Special (http://www.cnn.com/SPECIALS/2001/memorial/index.html): Tribute site for people to write remembrances of decedents.

Badge List maintained by Port Authority of New York and New Jersey: Includes name, employer, building, and floor for all occupants with badge-access to WTC 1 or WTC 2.

Numerous memorial sites maintained by companies which lost employees: Includes names and remembrances of decedents. Examples include the Port Authority, Fire and Police Departments, Marsh & McLennan Companies, EuroBrokers, Fiduciary Trust, and others.

Newsday.com: Includes short stories written about specific decedents.

NIST Interviews with occupants and family members

* Where possible, eyewitness accounts were used to place individuals. Where no specific accounts existed, employer and floor information was used to place individuals.

Likely Location at Time of Impact*	Modified April 5, 2005
World Trade Center 1 Occupants	**1,462**
At or Above Impact	1,355
Below Impact	107
World Trade Center 2 Occupants	**630**
At or Above Impact	619
Below Impact	11
Confirmed Below Impact in WTC 1 or WTC 2	**30**
Unknown Location Inside WTC 1 or WTC 2	**24**
First Responders (Total)	**421**
FDNY	343
NYPD	23
PAPD	37
Hospital/Paramedic	7
Federal	2
Volunteer Responders	9
Bystander/Nearby Building Occupant	**18**
American Flight 11	**87**
United Flight 175	**60**
No Information	**17**
Total	**2,749**

Evacuation Rates in the WTC Towers

- **The overall evacuation rate in WTC 2 (108 survivors per min) was about 50 percent faster than that in WTC 1 (73 survivors per min).** Overall, about 7,900 survivors evacuated WTC 2 in 73 min (i.e., from the instant the WTC 1 was struck by aircraft until WTC 2 collapsed); while about 7,500 survivors evacuated WTC 1 in 103 min.

- **After the first airplane struck WTC 1 and before the second airplane struck WTC 2**, the survivors in WTC 2 were twice as likely as those in WTC 1 to have already exited the building (41 percent versus 21 percent). **The rate of evacuation completion in WTC 2 was twice the rate in WTC 1** during that same period.

  - Approximately 75 percent of WTC 2 occupants above the 78th floor at 8:46 am successfully descended below the 78th floor prior to the aircraft strike at 9:03 am.

  - **Functioning elevators allowed many (roughly 3,000) survivors to self-evacuate WTC 2 during the 16 minutes prior to aircraft impact.** All but one of the 99 elevators in WTC 1 were not functioning, and survivors could only use the stairways.

- Soon after WTC 2 was struck by the airplane until about 20 min before each building collapsed, the survivors in WTC 2 and WTC 1 exited at about the same rate (the prior evacuation rate of WTC 1).

- During the last 20 min before each building collapsed, the evacuation rate in both buildings slowed to about one-fifth the immediately prior evacuation rate. This suggests that **for those seeking and able to reach and use undamaged exits and stairways, the egress capacity (number and width of exits and stairways) was adequate to accommodate survivors**.

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Evacuation Rates in the WTC Towers (2)

- Even though a percentage of evacuees reported that they perceived **counterflow (firefighter ingress)** to be problem, it **was found not to be a significant factor in the total evacuation time of occupants in WTC 1 when compared to other factors,** including evacuation initiation delay, evacuation interruption, and encountering obstacles in the evacuation path (environmental cues) such as smoke, water, or debris.
- Based on use of existing egress models and actual evacuation time on September 11, 2001, it is estimated that **a full capacity evacuation of each WTC tower with 25,000 people—three times the number present on September 11, 2001—would have required about 4 hours**. **Had the buildings been full, it is possible that as many as 14,000 people may have lost their lives based on rough estimates using existing models.** To achieve a significantly faster total evacuation at full capacity would have required increases in egress capacity (number and width of exits and stairways). **The egress capacity required by current building codes and practice is based on a "phased" evacuation strategy, not "full" evacuation.**
- **The average surviving occupants moved slower down stairs and through stairwell exits than previously reported for non-emergency evacuations.**
  - In WTC 1, the average surviving occupant spent 48 seconds per floor descending the stairwell. This translates to approximately 0.2 m/s (0.65 ft/s), which is about 50% of the slowest speed measurement presented in the SFPE Handbook of Fire Protection Engineering for non-emergency evacuations.
  - In WTC 1, each stairwell door exited approximately 37 people per minute, averaged over 100 minutes, which is comparable to the slowest measurement presented in the SFPE Handbook of Fire Protection Engineering for non-emergency evacuations.

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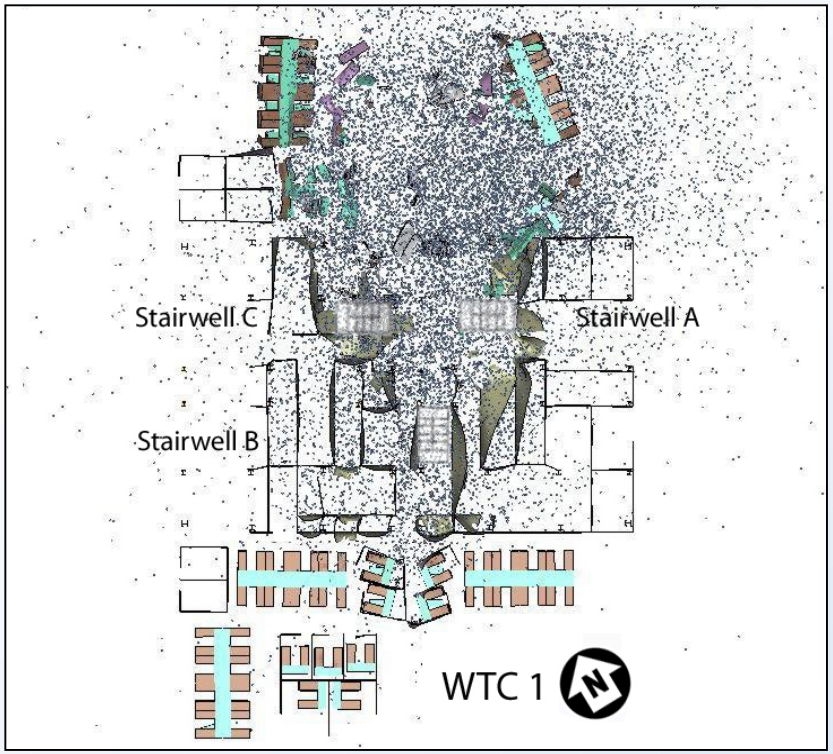
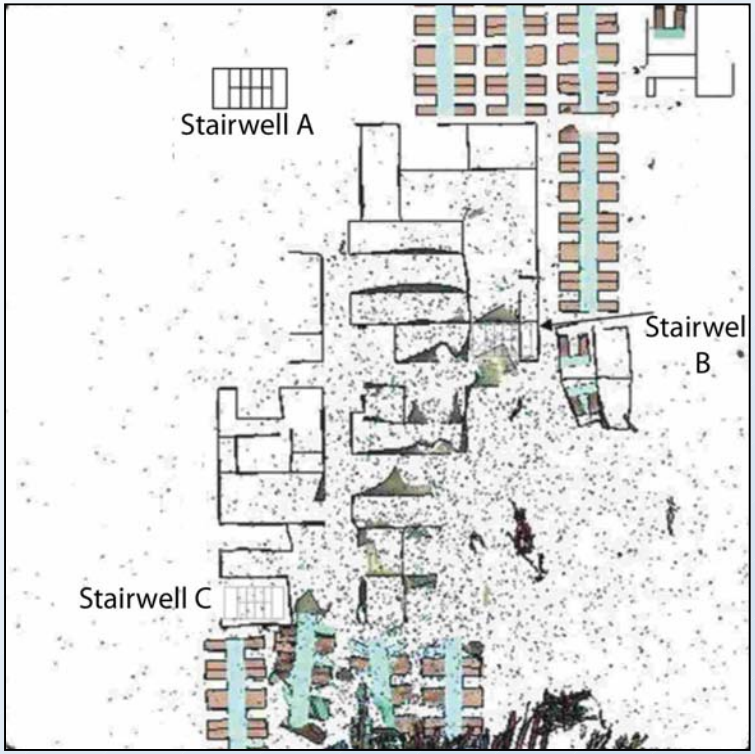
Condition of Stairwells





- The stairwells, with partition wall enclosures that provided a 2 h fire-rating but little structural integrity, were damaged in the region of the aircraft impacted floors.
- **One of the stairwells in WTC 2 (Stairwell A on the Northwest side) was passable in the region of aircraft impact for some period of time after WTC 2 was attacked.**
- All three stairwells in WTC 1 and the two other stairwells in WTC 2 were rendered impassable in the region of aircraft impact.

Stairwell Remoteness Requirements

- The 1968 NYC Building Code required stairwells to be as **'far apart as practicable.'**

- New York City Local Law 16 (1984) amended the 1968 NYC Building Code to require the minimum distance between exit door openings in all buildings to be 30 feet or one-third the maximum travel distance of the floor, whichever is greater.

- IBC 2003, NFPA 5000, & the NFPA Life Safety Code require that at least two stairwells on any floor shall be located at least:
  - One-third of the diagonal of the area served, if fully sprinklered;
  - One-half of the diagonal of the area served, if not fully-sprinklered,

  measured from door edge to door edge along a straight line or along the *walking path* between the doors, if the corridors have walls that are rated for at least one hour.

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Findings on Stairwell Remoteness

- Tenant floors in WTC 1 and WTC 2 had a diagonal distance of 294 ft. Therefore, one-third of the diagonal distance would have been 98 ft and one-half of the diagonal distance would have been 147 ft. The corridor walls in the WTC Towers were two hour rated; the 1996 due diligence review suggests that some of the corridor separation walls did not run slab-to-slab and would have been considered unrated since they terminated at the suspended ceiling.

- **Stairwell separation in WTC 1 and WTC 2 ranged from 70 ft (Floors 83 and above, including the impact region in WTC 1) to 200 ft (Floors 79 – 82, including the impact region in WTC 2), demonstrating that large stairwell separations in the WTC towers were practicable.**

- **On some WTC floors (e.g., the floors of impact in WTC 2), the separation of stairwells A and C *exceeded* the typical model code requirement (98 ft sprinklered; 147 ft unsprinklered); on other floors (e.g., the floors of impact in WTC 1), the stair separation *was not consistent* with these model code criteria.**

- The maximum travel distance for the WTC towers was about 180 ft. **The stairwell separation was consistent with the 2001 NYC building code requirement of one-third the travel distance or 60 ft.**

- The advantages of moving stairwell locations on the floor plan include reclamation of core space for occupant use above terminated elevator shafts and overcoming obstructions posed by equipment installed on mechanical floors.

- A walking path measurement may allow two stairwells to be physically proximate, yet have a significant walking path distance between doors (i.e., scissor stairs), although the IBC credits scissor stairs as a single stairwell.

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Egress Provisions: Windows on the World

- The 106th and 107th floors of WTC 1 contained a restaurant, bar, function rooms, kitchens and support areas, and offices from which the operation was run.
- The design number of occupants for a typical "office use" floor in the WTC towers was 390; **the design number of occupants for the "assembly use" floors was over 1,000 each – 1,130 for floor 106 and 1,013 for floor 107 (Fasullo 1995).**
- **The 1968 NYC Building Code required a minimum of four stairwells serving areas with occupant loads greater than 1,000.**
- Locating assembly space high in a building poses additional challenges since the NYC Building Code does not permit the capacity of an egress component to be decreased in the direction of travel.
- **NIST found no evidence indicating that the Building Code requirements for assembly spaces (floors 106 and 107 of WTC 1; floor 107 of WTC 2) were considered during the original design of the WTC towers.**
- Since the September 11, 2001 attack took place at breakfast time, there were 188 people (guests and staff) in the Windows on the World floors who lost their lives. **If the attack had occurred when floors 106 and 107 were loaded near their capacity, as many as 2,000 occupants could have lost their lives, since there were no survivors above the floors of impact in WTC 1.**

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Egress Provisions: Windows on the World (2)

- **The egress provisions for the Windows on the World floors were not consistent with the NYC Building Code requirements. The PANYNJ and NYC Department of Buildings reached an agreement in December 1994, and a solution was implemented in 1995.**
- The solution implemented in 1995 created areas of refuge on those floors where occupants could wait to get into the stairs that did not have adequate capacity for the numbers of people.
  - Each floor was divided into 3 areas of refuge; each area of refuge containing a stairwell. The areas of refuge were delineated by 2-hour fire-rated separation walls that snaked across the floors (they were not aligned on the two floors of WTC 1).
  - In the NYC Building Code, the allowable stairwell capacity is *doubled* when 2 areas of refuge are provided on a floor and *tripled* when there are 3 or more areas of refuge. Each area of refuge must contain a stairwell and must be totally enclosed in 2-hour fire rated construction. The current national model codes allow a doubling but not a tripling of allowable capacity.
- **There is no evidence that the solution implemented in 1995 considered the NYC Building Code requirement for a minimum of four stairwells serving areas with occupant loads greater than 1,000.**
  - The Code intent could have been met with four 44-inch stairways; a total of 176 inches. Had there been four stairwells, overall capacity would have increased by about 20 percent (the WTC towers had two 44-inch stairwells and one 56-inch stairway for a total of 144 inches); though their remoteness and survivability on September 11, 2001 would not necessarily have changed.
  - It remains unclear how often 1,000 persons occupied a single floor at one time; retrofitting a fourth stairwell would have been difficult and expensive.

Egress Provisions: Top of the World

- The 107th floor of WTC 2 contained a public observation deck called Top of the World operated by the lessee of the space. The facilities included several shops, food vendor, a small theater, exhibits, and a perimeter viewing area. Visitors could also ascend two escalators to an open, roof-top deck which was raised to provide unobstructed views.
- The design number of occupants for this "assembly use" floor was 1,751, about 4-1/2 times the maximum number of occupants permitted under the NYC Building Code. The occupant load of the roof-top deck was not included in this estimate, even though deck occupants could exit the facility only from the 107th floor.
- The proposed solution included subdivision of the area into 3 areas of refuge
  - A 5,610 ft^2 area with Stairwell A and an occupant load of 935 people
  - A 2,430 ft^2 area with Stairwell B and an occupant load of 343 people
  - A 2,940 ft^2 area with Stairwell C and an occupant load of 473 people
- The stairway capacity after subdivision was 360 each for Stairways A and C and 450 for Stairway B. The total capacity for all three stairways was 1,170.
- **The occupant load of the perimeter gallery alone was 1,267 people which exceeded the stairway capacity of 1,170 after subdivision into areas of refuge. Only the area of refuge with Stairwell B had an occupant load less than the maximum capacity of the stairway. Stairwell A had an occupant load more than 2-1/2 times the stair capacity.**

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Egress Provisions: Top of the World (2)

- **Taking advantage of a New York City building code provision which permits a lower basis for occupant load, the PANYNJ permitted a maximum occupant load of 1,170 on the floor, which was to be enforced by the lessee of the space with periodic oversight by the PANYNJ.**

- The PANYNJ provided NIST with the following response with regard to the means it used to limit the number of visitors to the observation deck:

  "For controlling the number of occupants on the observation level in WTC 2, there were turnstiles on the mezzanine before the entrance to the elevators that were used to count the number of people going up, but since the patrons exited via a different route & location, there was no way to count the number of people leaving - and thereby calculate the number actually on the deck. Since the turnstiles were not very effective, their use was discontinued later and the number of ticket sales was used for controlling the number of occupants. The length of the line waiting for the elevators to take people down were constantly observed by staff. If the crowds grew too large, ticket sales were halted until the crowd size was reduced."

- Less than ten people who were present on the observation level at the time of aircraft impact perished on September 11th. The number of people who were present and managed to evacuate is unknown.

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Termination of Stairways

- The termination of stairways A and C at the ***mezzanine*** level was a topic of repeated discussion between the PANYNJ and the NYC Department of Buildings over the years.
- The NYC Building Code required that egress stairs only terminate on a level opening to a ***"public way."***
- The mezzanine opened at the ***Plaza*** level and to the ***concourse,*** one level below via escalators, which **do not meet** the typical definition of a "public way."
- The PANYNJ contended that the NYC DOB agreed in the 1960s that the Plaza was a public way and that the concourse was an underground street. NIST did not find any correspondence or citations detailing these agreements.
- The PANYNJ commissioned a due diligence study in 1996 which cited this issue and identified it as one for which there were no plans to address; the PANYNJ made significant improvements at the concourse level in the shopping mall area after the 1993 bombing via new corridors that reduced the travel distance to exits.

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Stairwell Improvements After the 1993 Bombing

- The PANYNJ made improvements to the stairwells of the WTC Towers in light of the 4 hours needed to evacuate WTC 1 during the 1993 bombing.

- Specific improvements made were:

  - Battery operated emergency lighting in stairwells (and elevators).

  - Photoluminescent paint on handrails, stair treads, and stair centerline indicating the path to be followed.

  - Explicit LED signs on each doorway to indicate where it led.

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Occupant Preparedness

- **Two-thirds of surviving occupants reported having participated in a fire drill in the 12 months prior to September 11, 2001, while 17 percent reported that they received no training during that same period.**
  - Of those participating in fire drills, **93 percent were instructed about the location of the nearest stairwell.**
  - Overall, **slightly over half of the survivors, however, had never used a stairwell at the WTC prior to September 11, 2001** (NYC Local Law 5 prohibits **requiring** occupants to practice stairwell evacuation.)
- **Occupants were often unprepared for the physical challenge of full building evacuation.** Numerous occupants required one or more periods of rest during stairwell descent or turned to elevators after finding the stairwells strenuous.
- **Occupants were often unprepared to encounter transfer hallways during the stairwell descent.** Groups of evacuees occasionally hesitated or debated a course of action upon encountering a transfer hallway.
- **Mobility challenged occupants were not universally identified or prepared for full building evacuation.** One occupant, for example, reported being 'left' on their floor by colleagues, called authorities for assistance, and was eventually assisted by strangers (occupants).

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Roof Evacuation

- The PANYNJ's standard occupant evacuation procedures and drills required the use of stairways to exit at the bottom of the WTC towers. The standard procedures were to keep the doors to the roof locked. **The PANYNJ reports that it never advised tenants to evacuate upward.** Roof access required use of an electronic swipe card to get through the first two doors and a security officer watching a closed-circuit camera on the 22nd floor of WTC 1 to open the third door via a buzzer.

- The 1968 BCNYC required access to roofs with slopes less than 20 degrees from at least one stair in buildings greater than 3 stories (or 40 ft) in height.

  - The Code does not state the purpose of this access but, since it is in the section on Stair Construction and not Means of Egress it does not necessarily imply roof rescue but more likely providing fire department access to flat roofs.

  - The current code (2003) permits such access from a stair, ladder or scuttle, even more clearly not intended for rescue. There is no prohibition of locking this access, which is consistent with fire department use since they have the means to open locked doors.

- There were at least two decedents who had tried to get to the roof and found the roof access locked to both the WTC towers. In addition, a PANYNJ employee trapped on Floor 105 of WTC 2 was unable to walk down the stairs, or go to the roof as instructed on radio by another PANYNJ employee (PANYNJ Channel Y).

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Roof Evacuation (2)

- **The NYPD and FDNY policies for roof operations were focused mainly on providing emergency responders with access into the building above the fire floors for firefighting, conventional rescue, and comforting occupants. Roof rescue was considered a measure of last resort to be used, for example, to assist occupants with medical emergencies.**

- The NYPD aviation unit arrived at the WTC site soon after WTC 1 was attacked. Despite repeated attempts to examine the possibility of roof access/rescue, smoke and heat conditions at the top of the WTC towers prevented the conduct of safe roof operations.

- **Due to the limited capacity of a typical helicopter and travel time, roof rescue was never considered as a viable strategy for general evacuation; even if it had been possible for a helicopter to gain access to the roof, possibly only a very small fraction of the large number of people trapped above the impact zone could have been rescued on September 11, 2001.**

Public Address System Announcements

- Damage to the 22nd floor communication closet likely disabled the building-wide announcement capability in WTC 1. The closet was located in a hallway adjacent to an elevator shaft in the core of the building. Many announcement attempts were made from the lobby command station.

- Announcements in WTC 2 were heard by occupants building-wide before the second aircraft struck at 9:03 am. Announcements were also heard in at least the upper regions (including above the impact area) after the second aircraft struck at 9.03 am.

  - At 9:00 am an announcement stated "There is a fire condition in WTC 1. WTC 2 is secure. **Please return to your offices**."

  - At 9:02 am an announcement stated "May I have your attention please. The situation is in Building 1. However, if conditions on your floor warrant, **you may wish to start an orderly evacuation**."

  - At 9:20 am an announcement was made updating occupants on the condition of the building and progress of the evacuation and informing occupants that **if they wished to leave, they could then use the concourse.**

  - Prior to 9:37 am an announcement instructed occupants to **"go down" the stairs.**

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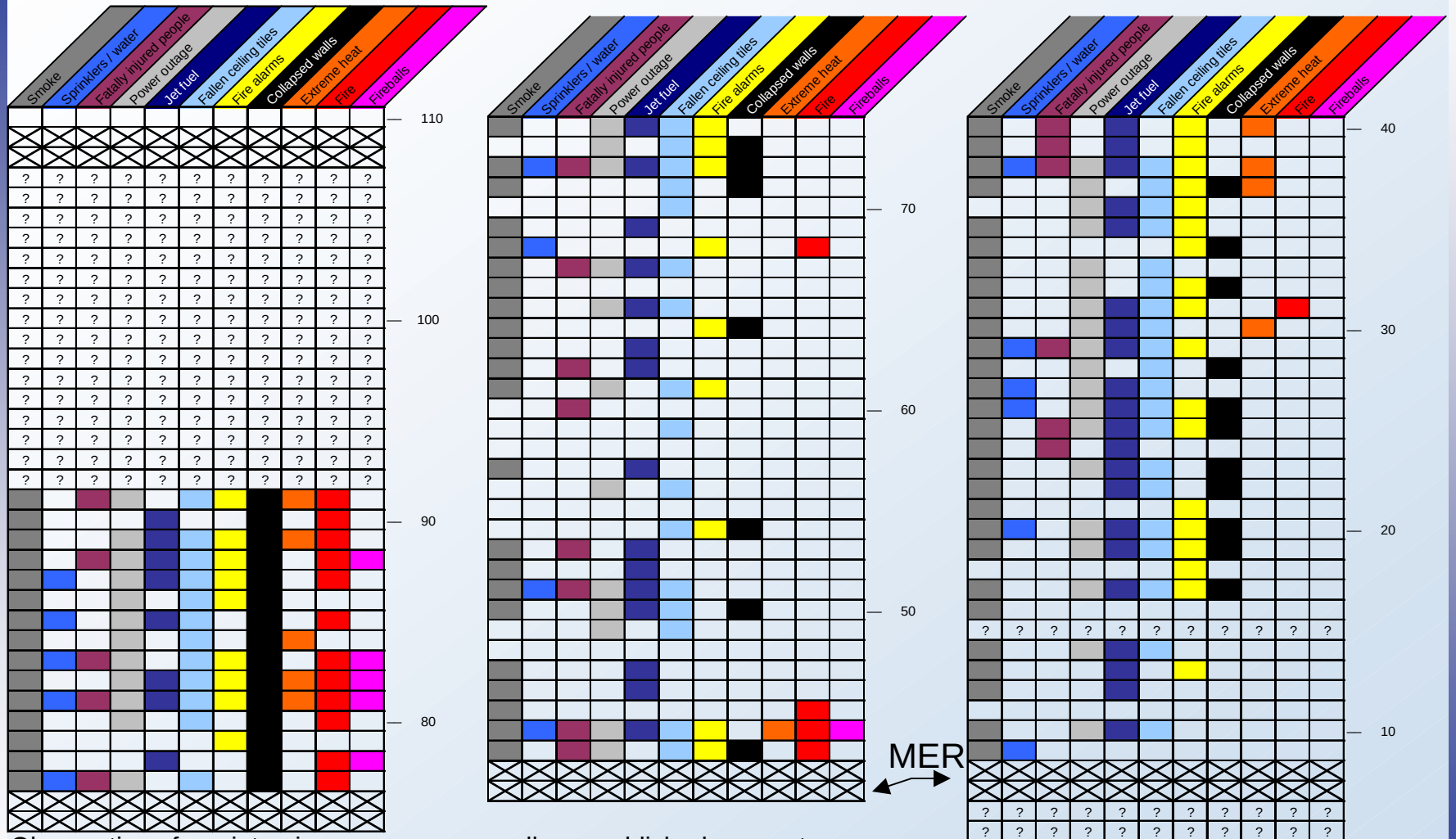
Emergency Communications to WTC Occupants

- Occupants called 9-1-1 and the Port Authority seeking assistance and advice.

- **Opportunities to improve occupant's situational awareness were often lost. Specific knowledge about location of fires and impact damage was only occasionally communicated to occupants who requested the information and was without apparent coordination.**

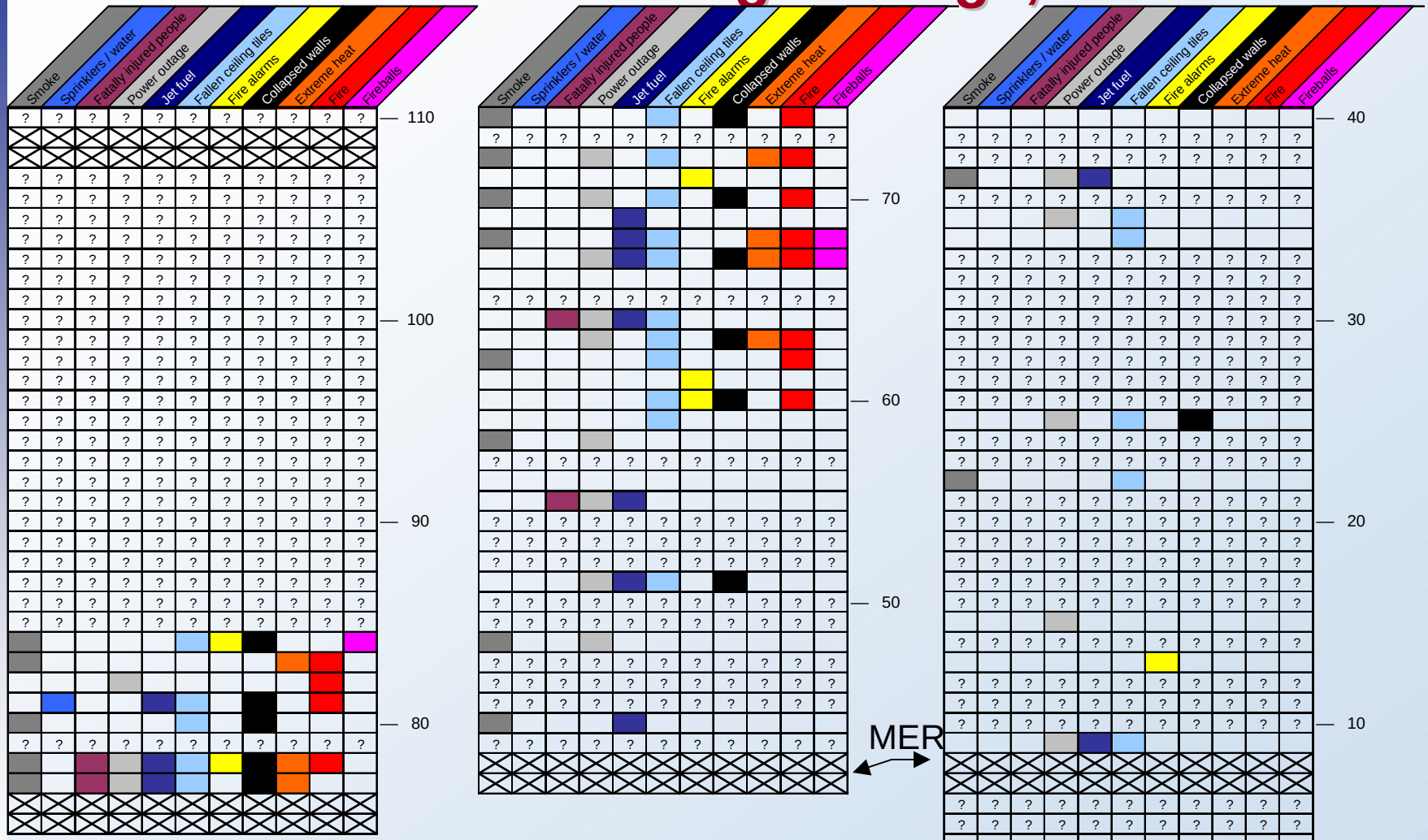
- Some operators advised sheltering (e.g., many 9-1-1 operators), while others advised evacuation (e.g., many PA Police Desk operators); some permitted window breaking while others instructed occupants not to break windows.

Observations of Building Damage, WTC 1



Observations from interviews, emergency calls, or published accounts.
'?' indicates a floor where no observer was found after impact, a blank indicates that an observer did not report that condition. Additional analysis pending.

Observations of Building Damage, WTC 2



Observations from interviews, emergency calls, or published accounts.
'?' indicates a floor where no observer was found after impact, a blank indicates that an observer did not report that condition. Additional analysis pending.

Evacuation of WTC 7

- The decision to evacuate WTC 7 was made by building officials at about 9:00 a.m., although some occupants self-evacuated prior to that time.
- Occupants used both stairwells and elevators to evacuate.
- Full evacuation was completed by about 9:30 a.m., although a small number of individuals (with emergency responsibilities) became entrapped in the building beyond 10:30 a.m.
- Many of the occupants evacuated North through the loading dock to keep as far from WTC 1 and WTC 2 as possible.
- There were no significant injuries reported from the evacuation of, or the fires in, WTC 7.
- Additional findings, if any, will be provided in the final WTC 7 investigation report.

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Role of Emergency Responders

FDNY - Established operational control and the Incident Command Post for the WTC operations, conducted evacuation and rescue operations, and fought fires at the disaster.

PAPD - Established security at the WTC and conducted evacuation and rescue operations.

NYPD - Established traffic control, perimeter security at the site, security for command posts, and conducted evacuation and rescue operations inside the WTC. The aviation units supplied observation capabilities and assessed the potential for roof rescue.

OEM - Functioned as a multi-agency command resource center and provided support for all agencies and departments working at the disaster.

Changes After the 1993 Bombing

- FDNY worked with the PANYNJ to upgrade WTC fire protection
  - FDNY high-rise radio repeater was installed
  - Fire Command Desks installed in WTC 1 and 2
  - Elevator intercom system was upgraded
  - New Operations Control Center was added to the complex on the B1 level of WTC 2
  - Multiple power sources installed for emergency lighting
  - New decentralized fire alarm system was installed at the WTC
  - Various fire drills were conducted at the WTC and some included FDNY participation

Emergency Responder Operations

FDNY's Initial "Size-up" of WTC Conditions:

- A large aircraft had hit the WTC 1 building.
- Large fires were burning on multiple floors at and above the impact zone.
- The elevators were not working and people were trapped inside many of the elevators.
- The sprinkler system and standpipe systems were likely compromised.
- It was likely that no water supply was available to fight the fires at and above the impact zone.
- It was likely that many of the occupants trapped at and above the impact zone were already dead or would die before help could get to them.

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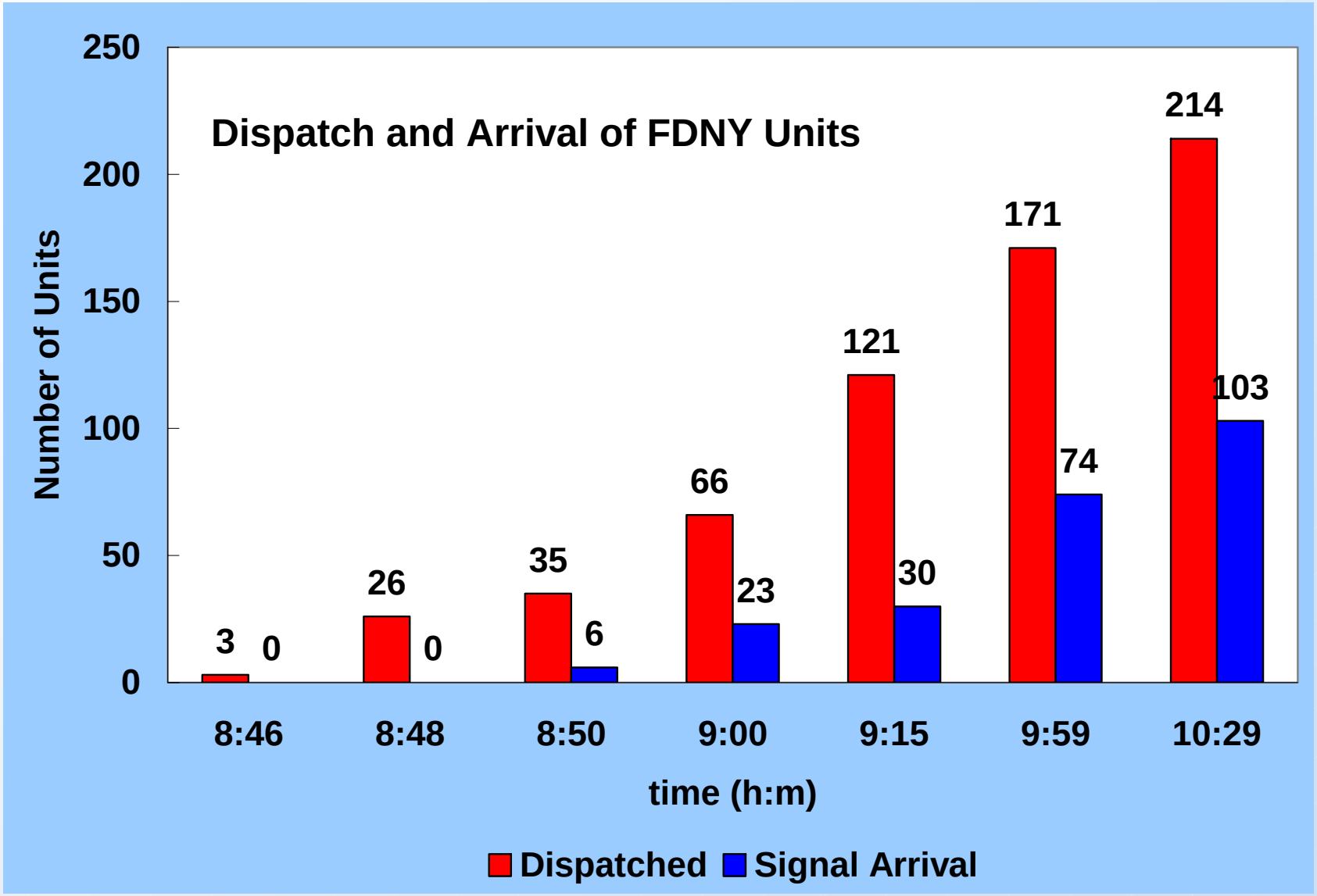
FDNY Units Dispatch to the WTC



FDNY Operations at the WTC

Three operational strategies:

Outside Command Posts & Inside Command Communicating with the Outside Command Post - Fires in the buildings were too large and were located too high in the buildings to accomplish fire fighting activities that could save the lives of occupants above the fires. The objective was to evacuate and rescue all below the fires.

Command Officers for Inside Operations - The fires were too large to extinguish. The objective was to get enough personnel and equipment upstairs to cut a path through the fire to rescue occupants above the fires, and also evacuate and rescue all below the fires.

Company Level Command - They saw this as a conventional but large high-rise fire. The objective was to get up to the fire floors and extinguish the fires. In some cases, firefighters were persuaded by higher ranking officers to switch from the idea of fire fighting to evacuation and rescue operations.

No first responder interviewed by NIST thought that the WTC towers would collapse.

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Emergency Responder Operations

Situational Awareness:

- Emergency responders working outside the WTC buildings who could view building conditions and communicate over radios had adequate situational awareness.
- Situational awareness for personnel who observed the building damage and fires from outside the buildings before entering experienced difficulty maintaining their awareness after entering the buildings.
- Emergency responders working inside of the WTC buildings, who could not see what was happening outside and had poor radio communications, had poor situational awareness.
- Emergency responders working inside of the WTC buildings, who could not see what was happening outside and had good radio communications, had better situational awareness than those with poor radio communications.

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FDNY Access to the WTC Towers

- **After aircraft impact, only two elevators out of 198 were operating inside the two WTC towers.** WTC 1, from the lobby to the 16th floor. WTC 2, from the lobby to the 40th floor.
- The stairways were filled with occupants evacuating the buildings. **FDNY personnel and other emergency responders reported difficulty attempting to climb the stairs due to this counterflow.**
- Counter flow in the staircases made it difficult for emergency responders to carry equipment up the stairways.
- Counter flow in the staircases caused teams of emergency responders to become separated, causing delays and disrupting team operations.

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Emergency Responders & High-Rise Buildings

- First responding FDNY units took from 4 to 10 minutes to get to the WTC complex. They then got their equipment and received assignments, another 3 to 5 minutes. Time to begin operations 7 to 15 minutes.

- Of the 27 emergency responders interviewed that were inside WTC 1, maximum floor height achieved before WTC 2 collapsed, a time period of 1 hour 13 minutes.

  1 – A police officer carrying no extra equipment and in a patrolman's uniform climbed to the 44th floor.

  8 – Emergency responders (FDNY, PAPD, NYPD) climbed to the 30's
  Two FDNY took an elevator to the 16th floor.

  16 – Emergency responders (mostly FDNY) climbed to the 20's.

  2 – Emergency responders (NYPD) climbed to the teens.

- **Estimated climbing rate based on a 60 minute climbing period to their maximum height: 1.4 to 2 minutes/floor**

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High-Rise Buildings & Emergency Response

Example: Fire department response to a 60 story high-rise building, occupants trapped above fires on the 58th floor and no operating elevators.

Firefighters carrying equipment and wearing PPE ~ 125 minutes
Firefighters carrying no equipment and not wearing PPE ~ 90 minutes

Firefighters carrying equipment and wearing PPE ~ 70 minutes
Firefighters carrying no equipment and not wearing PPE ~ 50 minutes

Firefighters begin to climb 10 minutes
Fire department arrival 4 minutes

Radio Communications

- All three of the responding departments, FDNY, NYPD & PAPD experienced difficulties with radio communications.
- Each of the departments was aware of the shortfalls associated with their radio communications systems as they related to operations in high-rise buildings.
- Two basic issues with radio communications:

1. Normal function of the radio equipment in high-rise environments. (Radio signal attenuation in steel and concrete buildings)
2. The volume of radio traffic

NIST

Emergency Communication Recordings

- NIST reviewed audio communications tapes recorded by the PANYNJ, including a recording of the FDNY's city-wide high-rise Channel 7 (Port Authority Police Department's [PAPD] Channel 30) radio repeater that was located at the WTC.
- NIST reviewed audio tapes copied from original NYPD communications tapes, including NYPD internal department operations.
- **FDNY communications recordings from the WTC location on September 11, 2001, are not available because the primary field communication truck was in the shop for repairs. A back-up field-communications van used in its place—which did not have a recording capability—was destroyed when the WTC towers collapsed.**
- **The best record of radio communications reflecting fire department operations at the WTC site came from the FDNY Channel 7/PAPD Channel 30 and first person accounts provided by FDNY personnel during their interviews. In addition, FDNY provided the Manhattan Dispatch communication tape to NIST.**
- The PANYNJ installed the radio repeater system for use by FDNY after the 1993 bombing.

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Analysis of Emergency Communications

- After the first aircraft struck WTC 1, there was an approximate **factor of 5 peak increase in traffic level over the normal level of emergency responder radio communications**, followed by an approximate factor of 3 steady increase in the level of subsequent traffic.

- **A surge in communications traffic volume made it more difficult to handle the flow of communications and delivery of information**.

- Roughly a third to a half of the radio messages transmitted during these radio traffic surge conditions **were not complete messages nor understandable**.

- **FDNY's city-wide high-rise Channel 7 (PAPD Channel 30) radio repeater at the WTC site was operating, although communications problems were perceived in WTC 1.**

- NYPD aviation unit personnel reported critical information about the **impending collapse** of the WTC towers several minutes prior to their collapse. **No evidence has been found to suggest that the information was further communicated to all emergency responders at the scene.**

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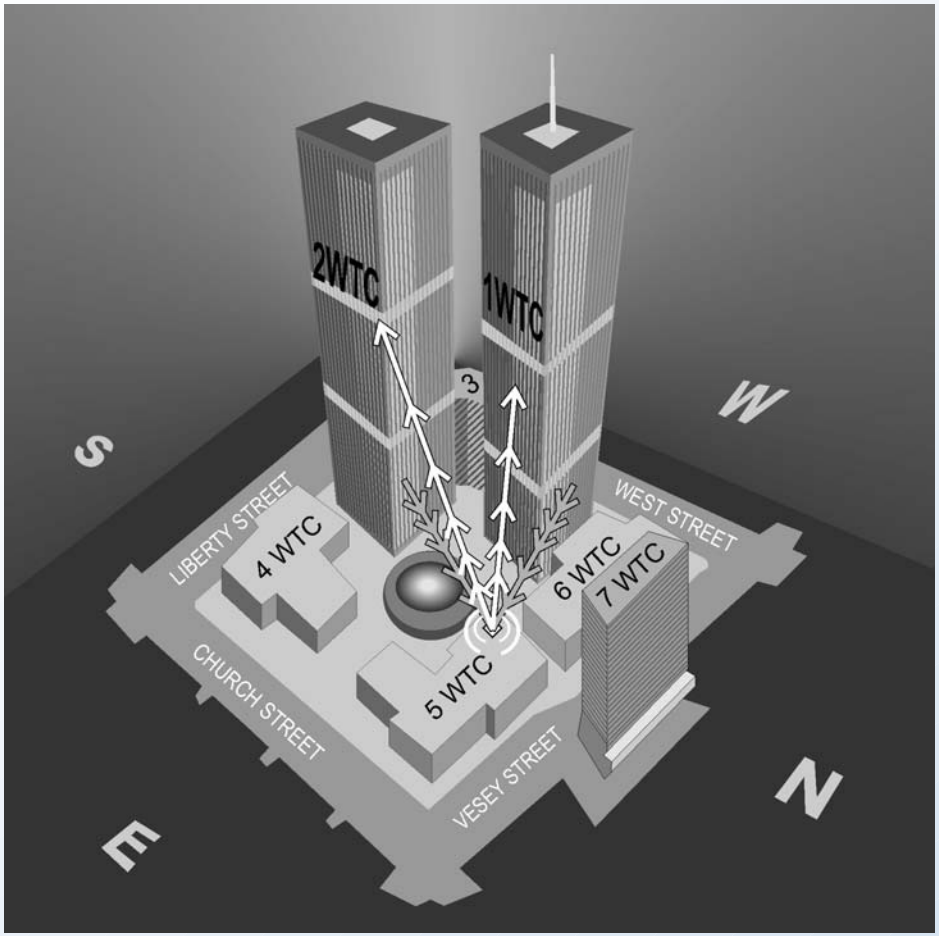
Radio Communications in High-Rise Buildings



Schematic of WTC Radio Repeater System

- Challenging radio-frequency propagation environment: steel and reinforced concrete buildings.
- Large scale operations.
  - Number of first responders.
  - Communications hierarchy and protocols.
  - Surge in traffic; doubling.
- Interoperability of radio communication technologies among different emergency responder organizations.
- Identification, location, tracking first responders.

NIST

WTC High-Rise Radio Repeater System

- **Analysis of the FDNY City-wide, high-rise, channel 7 (PAPD channel 30) repeater recording indicates that the World Trade Center high-rise repeater was operating.**

- At approximately 9:05 a.m. the repeater's recording system recorded the WTC 1 Lobby Command Post attempts to check repeater operations. Handset and handie-talkie radio communications were recorded.

- It is possible that one or both of the following conditions complicated the radio check that took place at the WTC 1 Lobby Command Post:
  - The radio repeater handset earpiece was broken.
  - The radio repeater handset volume was not turned up.

- **It is unlikely that the repeater's antenna was broken or misdirected by debris since radio signals were received during the radio check from inside WTC 1 and the communications that followed from inside WTC 2. Even if the repeater was functioning, it is possible the quality of communications was inadequate.**

- The repeater's system recorded radio communications that took place between several different firefighters and several different FDNY officers as they worked inside WTC 2.

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Command and Control

- **Emergency responders— including key incident commanders—did not have adequate information (voice, video, and data) on, nor an overall perspective of, the conditions in the WTC buildings and what was happening elsewhere at the WTC site. Interagency information sharing was inadequate.**
- **FDNY command and control was seriously affected by the lack of good communications.**
- **A preponderance of evidence indicates that lack of timely information sharing and inadequate communication capabilities likely contributed to the loss of emergency responder lives.** Statement extracted from an emergency responder interview: **If communications were better, more firefighters would have been saved.**
- **Large numbers of fire fighters were dispatched to the WTC site before adequate command posts and staff could be assembled to manage them.**
- **Self-dispatch complicated command and control at the site.** FDNY and EMS command and control was affected by many self-dispatched private and volunteer ambulance units that contributed to clogging the streets so that other responders assigned to the WTC had difficulty getting through.
- FDNY apparatus had to be moved to allow some ambulances to get through and exit the site with victims.

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Command and Control (2)

- **FDNY's system for maintaining records of unit assignments at each command post was not capable of managing the numbers of units and personnel assigned to the incident.**
- **FDNY, NYPD, and PAPD: there was no means to back-up the unit assignment records generated at the command posts.**
- **Interagency operations were detrimentally affected with the loss of the OEM command center that was located inside WTC 7 due to the decision made to evacuate the building at about 9:44 am before WTC 2 collapsed.** First person interview data and photographic data show that OEM functions became dispersed, the computer systems and other supporting systems were lost, and the unified operations structure was diminished. OEM personnel were working with different emergency responder departments and were located at the various department command posts.
- A significant amount of evidence (first person interviews, reports, and photographic data) shows that:
  - **In general, all departments attempted to work together to save as many lives as possible and protect the citizens of New York City on the morning of September 11, 2001.**
  - At times some issues related to a given department's operational responsibility and the competitive nature of departments did exist during the WTC operations; some of the problems experienced were due to personnel not understanding the operating practices of other agencies.
- **Emergency responder interviews suggest that inter-agency competition had minimal effect on operations at the WTC complex before the towers collapsed.**

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Mobility Impaired Occupants

- As the emergency responders started evacuating WTC 1 after the collapse of WTC 2, they found mobility impaired occupants still in the staircases going down.

- Ambulatory mobility impaired occupants typically walked down the stairs with one hand on each hand rail and took one step at a time going down. In addition, they were typically accompanied by one person, another occupant or an emergency responder. This blocked others behind them from moving more rapidly down the stairs.

- **FDNY and PAPD personnel found 40 to 60 mobility impaired occupants on the 12th floor of WTC 1 as they went down and attempted to clear each floor on their way out.** These impaired individuals had been placed on this floor in an attempt to clear the stairways.

- **Emergency responders were assisting approximately 20 of these mobility impaired people down the staircase just prior to the collapse of WTC 1.** It is unknown how many fatalities occurred with this group.

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Significant Fires Prior to September 11, 2001

- FDNY provided information from 397 operations fire reports from 1970 to 2001 and 112 fire investigation records from 1977 to 2001; PANYNJ records destroyed during collapse of WTC 1.

- Most significant incidents:
  - Major 1975 fire in WTC 1 prior to installation of sprinklers.
  - 1993 bombing in B-1 level below south face of WTC 1.

- 47 other substantial fires; activated a sprinkler or required hoses to suppress:
  - 16 exercised multiple sprinklers or standpipe connected hoses (with or without at least one sprinkler activation);
    - 12 in WTC 1, 3 in WTC 2, and 1 in WTC 7.
    - 12 fires occurred between 6 pm and 4 am; remainder included 2 dumpster fires, 1 kitchen fire, and 1 overheating of fan motor bearing.
    - 5 unlisted/unclassified, 6 suspicious/incendiary, 2 discarded material, 3 electrical/mechanical failure.
    - Only two fires extended to as much as 15% of the space on the floor.
  - 31 fires involved use of one standpipe hose or one hose and discharge of one sprinkler.
    - 23 in WTC 1, 7 in WTC 2

- Available evidence suggests that no fire activated more than 3 sprinklers in areas protected by automatic sprinklers.

- There is no known loss of life as a result of any of these fires (not including the 1993 bombing incident and the September 11, 2001 terrorist attacks)

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Noteworthy Significant Fires

- February 14, 1975:
  - Fire started on the 11th floor of WTC 1.
  - Fire damage occurred on the 10th through the 19th floors.
  - Approximately 9,000 ft^2 of 11th floor contents in the southeast quadrant was destroyed or damaged.
  - Sprinklers had not been installed in the office spaces.
  - Fire barriers divided the floor into quadrants.
- April 19, 1980:
  - Fire started on the 106th floor of WTC1.
  - Approximately 300 occupants from Windows of the World restaurant on the 107th floor were evacuated.
- April 17, 1981:
  - Fire started on the 7th floor of WTC 1.
  - Approximately 1,500 occupants were evacuated from floors 9 to 23.

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Sprinkler and Standpipe Systems

- Sprinklers had been installed throughout WTC 1, 2, and 7 by September 11, 2001, except for areas that were exempted from required sprinkler coverage.
- Storage tanks with direct connections to the NYC water distribution system supplied water to the WTC towers and to floors 21 to 47 of WTC 7; **Floors 1 to 20 of WTC 7 were supplied via the NYC system and an automatic fire pump with no secondary supply.**
- The supply piping from the 100th floor of the WTC towers resulted in restricted water supply to several floors; this installation was not consistent with current best practices, although this inconsistency had no impact on the outcome on September 11, 2001.
- Manual initiation of the electrical fire pumps was required to provide supplemental water in all three buildings, while automatic initiation is required by NFPA 14, it is unlikely to have made a difference on September 11, 2001; the sprinkler systems were automatic from the water tanks.
- The water supply risers were configured to provide redundancy; the sprinkler floor level controls were vulnerable to single point failures since there was only one connection to the sprinkler water riser.

NIST

Sprinkler and Standpipe Systems (2)

- Analysis indicated that the sprinkler systems were capable of controlling a typical fire with a coverage area up to 4,500 ft^2 which is three times the design area specified, but represents less than 15% of the area of a single floor.
- The 5^{th} floor generator room in WTC 7 was not equipped with a sprinkler system; nor was it required by the NYCBC.
- No evidence was found that the generator/fuel day-tank enclosures elsewhere in WTC 7 were protected by a fire suppression system.
- Primary and backup power were provided in all three buildings; system operability could have been affected by the lack of redundancy of the power lines to the emergency fire pumps once power was lost.
- Due to the magnitude of the initial fires and the likely aircraft impact damage, the suppression systems in the WTC towers could not have been expected to control the fires on September 11, 2001.

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Fire Alarm Systems

- The **fire alarm systems** in WTC 1 and 2 provided for automatic fire detection, but required manual activation of notification devices. The fire alarm system in WTC 7 provided automatic detection and notification.
- The fire alarm systems in WTC 1, 2, and 7 were only capable of determining and displaying (1) areas that had at some time reached alarm point conditions, and (2) areas that had not.
- The fire alarm systems collected information that is valuable for understanding the fire and smoke development in a building:
  - The system in WTC 1 and 2 had extensive back-up command capabilities and hardware that provided multiple places where some alarm history data were stored; up to 13 storage locations were identified.
  - The system in WTC 7 recorded information at 1 location, the fire command station (FCS) in the 3rd floor lobby; the system was monitored offsite, but provided only one piece of information: "a fire alarm was triggered in the building."
- The fire alarm systems in WTC 1 and WTC 2 were monitored by the PANYNJ; in WTC 1 **an overwhelming number of alarms registered and displayed at the FCS, however, fire and other automatic alarm information at the FCS was not used to manage evacuation;** there was no means at the FCS to determine whether or not announcements reached or could be heard on intended floors.

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Fire Alarm Systems

- The **fire alarm signal was delayed until 12 minutes after impact of WTC 1 since manual activation of the system was required** in the WTC towers to notify building occupants.
- The **notification appliance circuit** (which provided the voice message or alarm tone to the speakers) and the **warden/standpipe telephone circuit were not required to have the higher performance of the signaling line circuits** (that monitored the detection and supervisory devices and could turn on the notification appliance circuits).
- The firefighter telephone systems in the WTC towers were not used on September 11, 2001; this is not uncommon since firefighters are trained to use their radios as the preferred means of communications.
- Although the fire alarm systems in the WTC towers used multiple communication path risers, the systems experienced performance degradation, especially in WTC 1 where all notification and communication functions appeared to have been lost above the impact floors.
- **The fire alarm system in WTC 7 sent only one signal (at 10:00:52 a.m. shortly after WTC 2 collapsed) to the monitoring company indicating a fire condition. The signal did not contain any specific information about the location of the fire within the building.** Since the system was in a test condition that morning (a routine condition when building maintenance is underway), the signal was recorded and did not appear on the operator's screen at the monitoring company.

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Smoke Management Systems

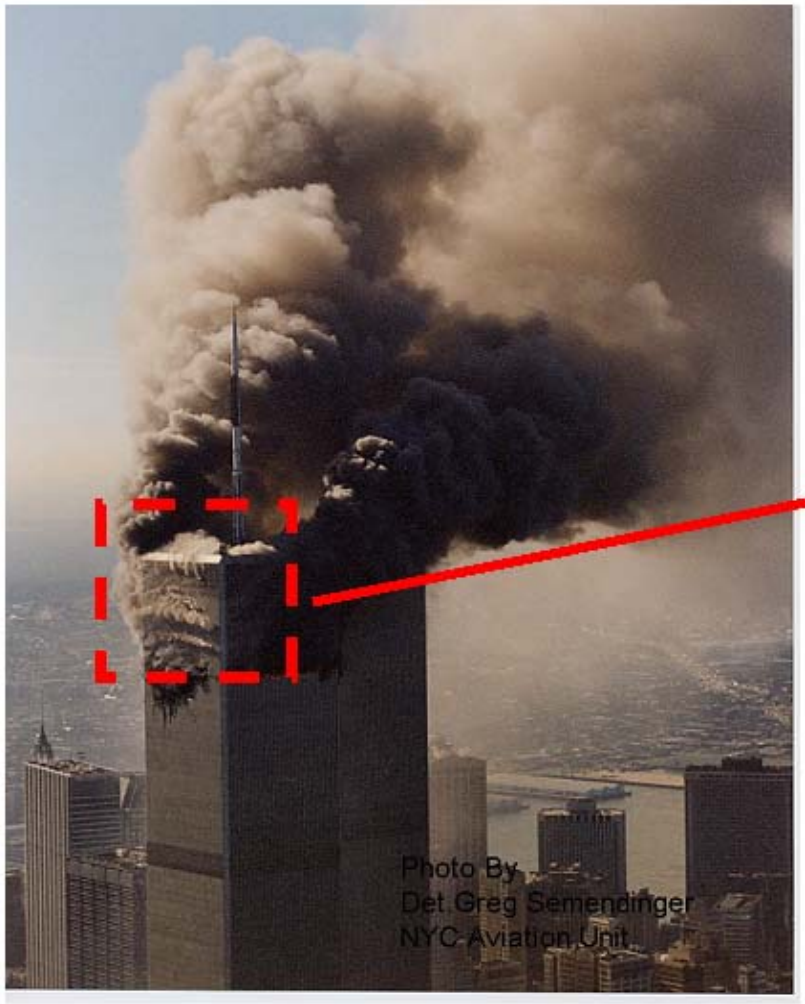
- **Smoke purge systems** were installed in WTC 1, 2, and 7; these systems, which used the components of the main HVAC (heating, ventilation, and air-conditioning) systems, were intended to remove smoke and other gaseous combustion products from the fire area after a fire was extinguished. These systems were to be activated manually at the direction FDNY.

- The smoke management systems in the WTC towers, which provided the capability for a manual smoke purge within an individual HVAC zone on a quadrant-by-quadrant basis, **were not initiated on September 11, 2001**. It was determined that the likelihood of these systems being functional was very low due to the damage inflicted by the aircraft impacts.

- Analysis indicates that the disruption of the **HVAC system, particularly the aircraft impact rupture of large return air shafts and related ductwork, created a major path for vertical smoke spread in the buildings.**

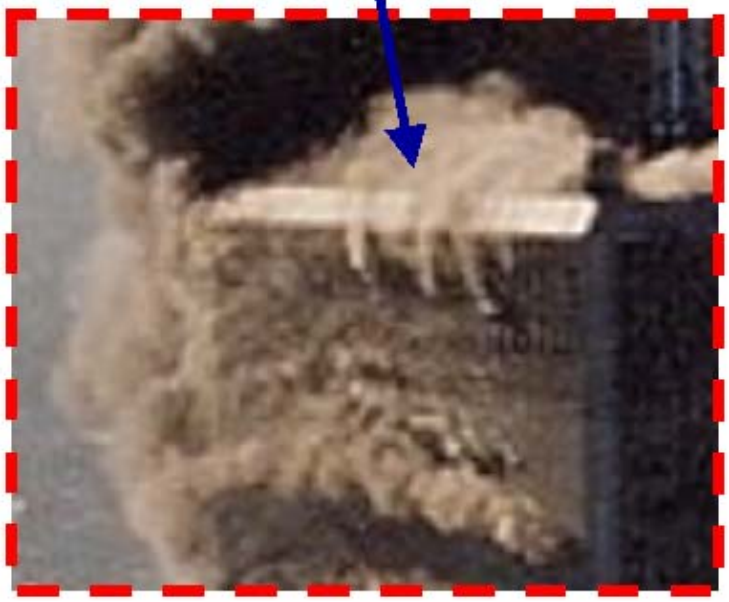
- If the **smoke purge sequence had been initiated** in the WTC towers, it is **unlikely that the system would have functioned as designed** due to loss of electrical power and/or damage to the HVAC shafts and other structural elements in the impact zone that were an integral part of the smoke purge system.

Example of Vertical Smoke Spread



North Face – WTC 1

Smoke Exits NW Interior
Ventilation Zone Supply Inlet



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Smoke Management System (2)

- The 1968 NYCBC, or retroactive provisions in the various local laws enacted after the WTC towers were built, did not require buildings like the WTC towers to have active smoke management systems and/or combination fire/smoke dampers if they contained automatic sprinklers throughout.

- The PANYNJ commissioned a due diligence study in 1996 which cited the lack of vents in the stairs that were required in lieu of stair pressurization by Local Law 5 (1973). The PANYNJ cites a study that, due to the height of the stair shafts, the required vents would be ineffective. As an alternative, the PANYNJ pressurized the corridors with outside air (which was not required).

Smoke Management Systems (3)

- **None of the potential alternative smoke management systems evaluated would have prevented smoke spread** for the postulated aircraft impact damage scenarios, even if these systems were capable of operation after the buildings sustained damage from aircraft impact. Design fire scenarios evaluated were: sprinklered fire; full-floor burnout; two-floor fire; 9/11 fire scenario without shaft damage; and 9/11 with shaft damage. Systems evaluated include:
  - Smoke purge (exhaust fans in the core; entire ventilation zone, not floor-by-floor; smoke detectors at exhaust duct inlets; sequence in WTC instruction manual)
  - Core pressurization (supply fans rather than exhaust fans pressurize the core)
  - Building pressurization (supply fan in entire building; exhaust fans only in ventilation zone of fire origin)
  - Sandwich pressurization (concept involves exhausting floor of fire origin and pressurizing the floors above and below; sandwich achieved by ventilation zones)
  - Zoned smoke control with stair pressurization (hypothetical approach based on best practices; stair pressurization; capable of exhausting on a floor-by-floor basis; normal operation in other ventilation zones; fire/smoke dampers in all supply/exhaust ducts; dampers closed in zone of fire origin)
- **Stair pressurization would have been ineffective** in improving conditions for occupants trying to exit the buildings during the events of September 11, 2001.
- **Installation of combination fire/smoke dampers in HVAC ductwork**, which was not required by the NYC Building Code, **would have acted to slow the development of hazardous conditions on the uppermost floors of the building**, but would likely not have had a significant effect on the ability of occupants to egress the buildings due to the impassability of the exit stairways.

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Factors that Enhanced Life Safety on September 11, 2001

- Since the buildings were occupied by only about 1/3 of the building's full capacity of 25,000 occupants, the egress capacity (number and width of exits and stairways) was adequate for those survivors seeking and able to reach and use undamaged exits and stairways.
- Functioning elevators in WTC 2 enabled nearly 3,000 occupants to self-evacuate prior to aircraft impact.
- Greater remoteness of stairwells in the impact areas of WTC 2 that enabled one of the stairwells to remain marginally passable after aircraft impact.
- Participation of a large number (two-thirds) of surviving occupants in a fire drill in the prior 12 months, with almost all of those (93 percent) instructed about the location of the nearest stairwell.
- Upgrades made to the life safety system components after the 1993 bombing.
- Evacuation assistance provided by emergency responders to building occupants.
- **As a result of the above factors, approximately 87 percent of the WTC tower occupants, including more than 99 percent of those below the floors of impact were able to evacuate successfully.**

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Future Practices and Technologies that Potentially Could Have Improved Life Safety on September 11, 2001 (Requires Analysis)

- Improved performance to delay or prevent building collapse.
- Improved stairwell integrity via increased remoteness of stairwells and/or enhanced structural integrity of stairwell enclosures.
- Better communications to occupants and among first responders via improved systems and timely information sharing.
- Better command and control for large-scale incident management (e.g., location of command posts and physical assets; interagency coordination).
- Better evacuation training (e.g., practice stairwell evacuation, roof rescue not presently feasible as a standard option, existence of transfer hallways).
- Other life safety features (e.g., fire protected and structurally hardened elevators available for occupant use during emergencies; vibration protected elevators such as those used in seismic regions; self-evacuation capability for mobility impaired occupants; operational smoke and fire control systems).

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Uncertainties and Limitations Associated with Evacuation and Emergency Response

- NIST recognized the inherent limitations and uncertainties in its analyses of the evacuation and emergency response:
  - Human factors associated with building occupants (training; situational awareness; evacuation initiation time)
  - Human factors associated with emergency response (situational awareness; effective communications; command and control; interagency coordination)
  - Effect of building design on evacuation and emergency response (collapse time; stairwells; elevators; sprinkler and standpipe systems; self-evacuation systems for mobility impaired; emergency communication systems)
- **In developing its findings and results, NIST carefully considered these uncertainties within the context of available factual evidence from documents, recordings, first-person interviews, analyses, and visual data.**

NIST

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