Questions and Answers about the NIST WTC 7 Investigation (Updated 04/21/2009)

What was WTC 7?

The original World Trade Center Building 7 (WTC 7) was a 47-story office building located immediately to the north of the main World Trade Center (WTC) complex. Completed in 1987, it was built on top of an existing Con Edison substation and located on land owned by The Port Authority of New York and New Jersey.

When did WTC 7 collapse?

On Sept. 11, 2001, WTC 7 endured fires for almost seven hours, from the time of the collapse of the north WTC tower (WTC 1) at 10:28:22 a.m. until 5:20:52 p.m., when WTC 7 collapsed.

What caused the fires in WTC 7?

Debris from the collapse of WTC 1, which was 370 feet to the south, ignited fires on at least 10 floors in the building at its south and west faces. However, only the fires on some of the lower floors-7 through 9 and 11 through 13-burned out of control. These lower-floor fires-which spread and grew because the water supply to the automatic sprinkler system for these floors had failed-were similar to building fires experienced in other tall buildings. The primary and backup water supply to the sprinkler systems for the lower floors relied on the city's water supply, whose lines were damaged by the collapse of WTC 1 and WTC 2. These uncontrolled lower-floor fires eventually spread to the northeast part of WTC 7, where the building's collapse began.

How did the fires cause WTC 7 to collapse?

The heat from the uncontrolled fires caused steel floor beams and girders to thermally expand, leading to a chain of events that caused a key structural column to fail. The failure of this structural column then initiated a fire-induced progressive collapse of the entire building.

According to the report's probable collapse sequence, heat from the uncontrolled fires caused thermal expansion of the steel beams on the lower floors of the east side of WTC 7, damaging the floor framing on multiple floors.

Eventually, a girder on Floor 13 lost its connection to a critical column, Column 79, that provided support for the long floor spans on the east side of the building (see Diagram 1). The displaced girder and other local fire-induced damage caused Floor 13 to collapse, beginning a cascade of floor failures down to the 5th floor. Many of these floors had already been at least partially weakened by the fires in the vicinity of Column 79. This collapse of floors left Column 79 insufficiently supported in the east-west direction over nine stories.

The unsupported Column 79 then buckled and triggered an upward progression of floor system failures that reached the building's east penthouse. What followed in rapid succession was a series of structural failures. Failure first occurred all the way to the roof line-involving all three interior columns on the easternmost side of the building (79, 80, 81). Then, progressing from east to west across WTC 7, all of the columns failed in the core of the building (58 through 78). Finally, the entire façade collapsed.

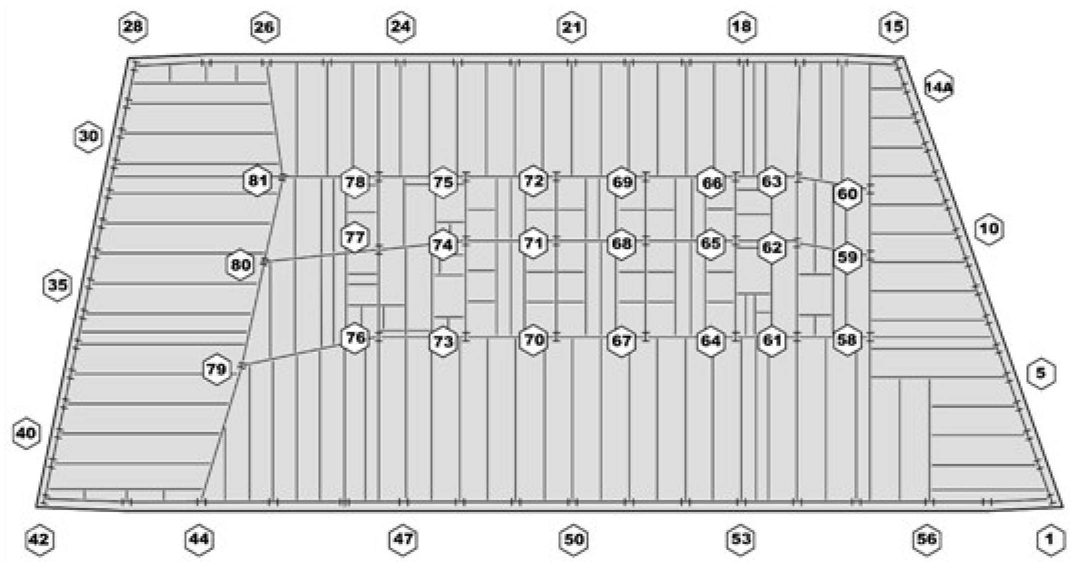

Diagram 1-Typical WTC 7 floor showing locations of columns (numbered). The buckling of Column 79 was the initiating event that led to the collapse of WTC 7. The buckling resulted from fire-induced damage to floors around column 79, failure of the girder between Columns 79 and 44, and cascading floor failures.

What is progressive collapse?

Progressive collapse is defined as the spread of local damage from a single initiating event, from structural element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it. The failure of WTC 7 was an example of a fire-induced progressive collapse.

Progressive collapse did NOT occur in the WTC towers, for two reasons. First, the collapse of each tower was not triggered by a local damage or a single initiating event. Second, the structures were able to redistribute loads from the impact and fire-damaged structural components and subsystems to undamaged components and to keep the building standing until a sudden, global collapse occurred. Had a hat truss that connected the core columns to the exterior frame not been installed to support a TV antenna atop each WTC tower after the structure had been fully designed, it is likely that the core of the WTC towers would have collapsed sooner, triggering a global collapse. Such a collapse would have some features similar to that of a progressive collapse.

How did the collapse of WTC 7 differ from the collapses of WTC 1 and WTC 2?

WTC 7 was unlike the WTC towers in many respects. WTC 7 was a more typical tall building in the design of its structural system. It was not struck by an aircraft. The collapse of WTC 7 was caused by a single initiating event-the failure of a northeast building column brought on by fire-induced damage to the adjacent flooring system and connections-which stands in contrast to the WTC 1 and WTC 2 failures, which were brought on by multiple factors, including structural damage caused by the aircraft impact, extensive dislodgement of the sprayed fire-resistive materials or fireproofing in the impacted region, and a weakening of the steel structures created by the fires.

The fires in WTC 7 were quite different from the fires in the WTC towers. Since WTC 7 was not doused with thousands of gallons of jet fuel, large areas of any floor were not ignited simultaneously as they were in the WTC towers. Instead, separate fires in WTC 7 broke out on different floors, most notably on Floors 7 to 9 and 11 to 13. The WTC 7 fires were similar to building contents fires that have occurred in several tall buildings where the automatic sprinklers did not function or were not present.

Why did WTC 7 collapse, while no other known building in history has collapsed due to fires alone?

The collapse of WTC 7 is the first known instance of a tall building brought down primarily by uncontrolled fires. The fires in WTC 7 were similar to those that have occurred in several tall buildings where the automatic sprinklers did not function or were not present. These other buildings, including Philadelphia's One Meridian Plaza, a 38-story skyscraper that burned for 18 hours in 1991, did not collapse due to differences in the design of the structural system.

Factors contributing to WTC 7's collapse included: the thermal expansion of building elements such as floor beams and girders, which occurred at temperatures hundreds of degrees below those typically considered in current practice for fire-resistance ratings; significant magnification of thermal expansion effects due to the long-span floors in the building; connections between structural elements that were designed to resist the vertical forces of gravity, not the thermally induced horizontal or lateral loads; and an overall structural system not designed to prevent fire-induced progressive collapse.

What are the major differences between "typical" major high rise building fires that have occurred in the United States and the fire in the WTC 7 building on September 11, 2001?

There are more similarities than differences between the uncontrolled fires that burned in WTC 7 and those that occurred in the following buildings: First Interstate Bank Building (1988), One Meridian Plaza Building (1981), One New York Plaza (1970), and WTC 51 (2001).

The following factors describe the fire events that occurred in both WTC 7 and the referenced buildings: 1) the fuel for the fires was ordinary office combustibles at ordinary combustible load levels; 2) there was no use of accelerants; 3) the spread of fire from combustible to combustible was governed by ordinary fire physics; 4) fire-induced window breakage provided ventilation for continued fire spread and growth; 5) there were simultaneous fires on multiple floors; 6) the fires on each floor occupied a substantial portion of the floor; 7) the fires on each floor had passed the point of flashover and the structure was subjected to typical post-flashover temperatures; 8) the sprinklers were inoperative or ineffective; and 9) the fires burned for sufficient time to cause significant distortion and/or failure to the building structure.

There were some differences between the fires in WTC 7 and those in the referenced buildings, but these differences were secondary to the fire factors that led to the collapse of WTC 7: 1) Fires in high rise buildings typically have a single point of origin on a single floor, whereas the fires in WTC 7 likely had a single point of origin on multiple (10) floors; 2); fires in other high rise buildings were due to isolated events, whereas the fires in WTC 7 followed the collapse of WTC 1; 3) water was available to fight fires in the other high rise buildings, but the water supply to fight fires in WTC 7 was impaired; and 4) while the fires in the other buildings were actively fought by fire fighters to the extent possible, in WTC 7, no efforts were made to fight the fires.

The differences in the fires were not meaningful for the following reasons. By the time that WTC 7 collapsed, the fires in WTC 7 had advanced well beyond the likely points of origin on multiple floors (i.e., south and west faces) and originating points of fire origin had no bearing on the fire conditions when the building collapsed (i.e., in the northeast quadrant). Additionally, in each of the other referenced buildings, the fires burned out several floors, even with available water and fire fighting activities (except for WTC 5). Thus, whether the fire fighters fought the WTC 7 fires or not is not a meaningful point of dissimilarity from the other cited fires.

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1 WTC 5 was a nine-story building with uncontrolled fires that had complete burnout on a number of floors and partial collapse on four floors.

Some people have said that a failure at one column should not have produced a symmetrical fall like this one. What's your answer to those assertions?

WTC 7's collapse, viewed from the exterior (most videos were taken from the north), did appear to fall almost uniformly as a single unit. This occurred because the interior failures that took place did not cause the exterior framing to fail until the final stages of the building collapse. The interior floor framing and columns collapsed downward and pulled away from the exterior frame. There were clues that internal damage was taking place, prior to the downward movement of the exterior frame, such as when the east penthouse fell downward into the building and windows broke out on the north face at the ends of the building core. The symmetric appearance of the downward fall of the WTC 7 was primarily due to the greater stiffness and strength of its exterior frame relative to the interior framing.

In a video, it appears that WTC 7 is descending in free fall, something that would not occur in the structural collapse that you describe. How can you ignore basic laws of physics?

In the draft WTC 7 report (released Aug. 21, 2008; available at http://wtc.nist.gov/media/NIST_NCSTAR_1A_for_public_comment.pdf), NIST stated that the north face of the building descended 18 stories (the portion of the collapse visible in the video) in 5.4 seconds, based on video analysis of the building collapse. This time period is 40 percent longer than the 3.9 seconds this process would have taken if the north face of the building had descended solely under free fall conditions. During the public comment period on the draft report, NIST was asked to confirm this time difference and define the reasons for it in greater detail.

To further clarify the descent of the north face, NIST recorded the downward displacement of a point near the center of the roofline from first movement until the north face was no longer visible in the video. Numerical analyses were conducted to calculate the velocity and acceleration of the roofline point from the time-dependent displacement data. The instant at which vertical motion of the roofline first occurred was determined by tracking the numerical value of the brightness of a pixel (a single element in the video image) at the roofline. This pixel became brighter as the roofline began to descend because the color of the pixel started to change from that of the building façade to the lighter color of the sky.

The approach taken by NIST is summarized in Section 3.6 of the final summary report, NCSTAR 1A (released Nov. 20, 2008; available at http://wtc.nist.gov/NCSTAR1/PDF/NCSTAR%201A.pdf) and detailed in Section 12.5.3 of NIST NCSTAR 1-9 (available at http://wtc.nist.gov/NCSTAR1/PDF/NCSTAR%201-9%20Vol%202.pdf).

The analyses of the video (both the estimation of the instant the roofline began to descend and the calculated velocity and acceleration of a point on the roofline) revealed three distinct stages characterizing the 5.4 seconds of collapse:

- Stage 1 (0 to 1.75 seconds): acceleration less than that of gravity (i.e., slower than free fall).
- Stage 2 (1.75 to 4.0 seconds): gravitational acceleration (free fall)
- Stage 3 (4.0 to 5.4 seconds): decreased acceleration, again less than that of gravity

This analysis showed that the 40 percent longer descent time—compared to the 3.9 second free fall time—was due primarily to Stage 1, which corresponded to the buckling of the exterior columns in the lower stories of the north face. During Stage 2, the north face descended essentially in free fall, indicating negligible support from the structure below. This is consistent with the structural analysis model which showed the exterior columns buckling and losing their capacity to support the loads from the structure above. In Stage 3, the acceleration decreased as the upper portion of the north face encountered increased resistance from the collapsed structure and the debris pile below.

Does this mean there are hundreds or thousands of unsafe tall buildings with long span supports that must be retrofitted in some way? How would you retrofit a building to prevent this problem?

While the partial or total collapse of a tall building due to fires is a rare event, NIST strongly urges building owners, operators, and designers to evaluate buildings to ensure the adequate fire performance of structural systems. Of particular concern are the effects of thermal expansion in buildings with one or more of the following characteristics: long-span floor systems, connections that cannot accommodate thermal effects, floor framing that induces asymmetric forces on girders, and composite floor systems, whose shear studs could fail due to differential thermal expansion (i.e., heat-induced expansion of material at different rates). Engineers should be able to design cost-effective fixes to address any areas of concern identified by such evaluations.

Several existing, emerging, or even anticipated capabilities could have helped prevent the collapse of WTC 7. The degree to which these capabilities improve performance remains to be evaluated. Possible options for developing cost-effective fixes include:

- More robust connections and framing systems to better resist effects of thermal expansion on the structural system.
- Structural systems expressly designed to prevent progressive collapse. Current model building codes do not require that buildings be designed to resist progressive collapse.
- Better thermal insulation (i.e., reduced conductivity and/or increased thickness) to limit heating of structural steel and minimize both thermal expansion and weakening effects. Insulation has been used to protect steel strength, but it could be used to maintain a lower temperature in the steel framing to limit thermal expansion.
- Improved compartmentation in tenant areas to limit the spread of fires.
- Thermally resistant window assemblies to limit breakage, reduce air supply and retard fire growth.

NIST is recommending that building standards and codes be strengthened beyond their current intent to achieve life safety to prevent structural collapse even during infrequent building fires like those in WTC 7 when sprinklers do not function, do not exist, or are overwhelmed by fire.

Did investigators consider the possibility that an explosion caused or contributed to the collapse of WTC 7?

Yes, this possibility was investigated carefully. NIST concluded that blast events inside the building did not occur and found no evidence supporting the existence of a blast event.

In addition, no blast sounds were heard on the audio tracks of video recordings during the collapse of WTC 7 or reported by witnesses. According to calculations by the investigation team, the smallest blast capable of failing the building's critical column would have resulted in a sound level of 130 decibels (dB) to 140 dB at a distance of at least half a mile, if unobstructed by surrounding buildings. This sound level is consistent with a gunshot blast, standing next to a jet plane engine, and more than 10 times louder than being in front of the speakers at a rock concert.

For the building to have been prepared for intentional demolition, walls and/or column enclosures and fireproofing would have to be removed and replaced without being detected. Preparing a column includes steps such as cutting sections with torches, which produces noxious and odorous fumes. Intentional demolition usually requires applying explosive charges to most, if not all, interior columns, not just one or a limited set of columns in a building.

Is it possible that thermite or thermate contributed to the collapse of WTC 7?

NIST has looked at the application and use of thermite and has determined that its use to sever columns in WTC 7 on 9/11/01 was unlikely.

Thermite is a combination of aluminum powder and a metal oxide that releases a tremendous amount of heat when ignited. It is typically used to weld railroad rails together by melting a small quantity of steel and pouring the melted steel into a form between the two rails.

To apply thermite to a large steel column, approximately 0.13 lb of thermite would be needed to heat and melt each pound of steel. For a steel column that weighs approximately 1,000 lbs. per foot, at least 100 lbs. of thermite would need to be placed around the column, ignited, and remain in contact with the vertical steel surface as the thermite reaction took place. This is for one column . presumably, more than one column would have been prepared with thermite, if this approach were to be used.

It is unlikely that 100 lbs. of thermite, or more, could have been carried into WTC 7 and placed around columns without being detected, either prior to Sept. 11 or during that day.

Given the fires that were observed that day, and the demonstrated structural response to the fires, NIST does not believe that thermite was used to fail any columns in WTC 7.

Analysis of the WTC steel for the elements in thermite/thermate would not necessarily have been conclusive. The metal compounds also would have been present in the construction materials making up the WTC buildings, and sulfur is present in the gypsum wallboard used for interior partitions.

An emergency responder caught in the building between the 6th and 8th floors says he heard two loud booms. Isn't that evidence that there was an explosion?

The sound levels reported by all witnesses do not match the sound level of an explosion that would have been required to cause the collapse of the building. If the two loud booms were due to explosions that were responsible for the collapse of WTC 7, the emergency responder-located somewhere between the 6th and 8th floors in WTC 7-would not have been able to survive the near immediate collapse and provide this witness account.

Did fuel oil systems in WTC 7 contribute to its collapse?

No. The building had three separate emergency power systems, all of which ran on diesel fuel. The worst-case scenarios associated with fires being fed by ruptured fuel lines-or from fuel stored in day tanks on the lower floors-could not have been sustained long enough, could not have generated sufficient heat to weaken critical interior columns, and/or would have produced large amounts of visible smoke from the lower floors, which were not observed.

As background information, the three systems contained two 12,000 gallon fuel tanks, and two 6,000 gallon tanks beneath the building's loading docks, and a single 6,000 gallon tank on the 1st floor. In addition one system used a 275 gallon tank on the 5th floor, a 275 gallon tank on the 8th floor, and a 50 gallon tank on the 9th floor. Another system used a 275 gallon day tank on the 7th floor.

Several months after the WTC 7 collapse, a contractor recovered an estimated 23,000 gallons of fuel from these tanks. NIST estimated that the unaccounted fuel totaled 1,000 ±1,000 gallons of fuel (in other words, somewhere between 0 and 2,000 gallons, with 1,000 gallons the most likely figure). The fate of the fuel in the day tanks was unknown, so NIST assumed the worst-case scenario, namely that they were full on Sept. 11, 2001. The fate of the fuel of two 6,000 gallon tanks was also unknown. Therefore, NIST also assumed the worst-case scenario for these tanks, namely that all of the fuel would have been available to feed fires either at ground level or on the 5th floor.

Why did NIST model the sprayed fire resistive material (SFRM, also referred to as fireproofing) on the WTC 7 beams and columns as a "perfect" installation (i.e., without any gaps or damage in the SFRM coating), when realistically most buildings have some gaps or damage in the SFRM coating, either due to improper installation or deterioration over time?

NIST carefully considered the condition of the SFRM installation in WTC 7, including the applied thickness and evidence of gaps or damage in the SFRM. The SFRM in WTC 7 was modeled as undamaged except in the southwest region of the building where there was debris impact damage2. A uniform thickness equal to the specified SFRM thickness was used for the finite element thermal analyses of WTC 7 because 1) the variability in the SFRM thickness was small, 2) no evidence of significant damage to the SFRM was found, and 3) small areas of SFRM damage would not have affected the thermal or structural response of the structural framing system.

A number of factors were considered when determining the condition of the SFRM application to the WTC 7 beams and columns:

- Available measurements of SFRM thickness from inspections made during the SFRM application showed that the SFRM as applied was consistent with the required thickness and that the variability in the applied SFRM thickness was small. (NIST NCSTAR 1-9, Table 2-2)
- Review of photographs of WTC 7 beams and columns taken during renovations showed that the SFRM appeared uniform, and there was no evidence of spalling or gaps. (NIST NCSTAR 1-9, Figures 2-27 to 2-29.)
- Inspection of the building at 130 Liberty Street (formerly Bankers Trust or Deutsche Bank building) found no damage to the SFRM after impact by debris from the collapse of WTC 2, except in the immediate vicinity of the debris impact. (NIST NCSTAR1-9, Section 2.5.3)
- An analysis of the SFRM thickness for trusses in the WTC towers showed that the average measured

thickness exceeded the specified thickness and that use of the specified uniform thickness in the thermal analyses accounted for the effect of variability in the SFRM thickness. (NIST NCSTAR 1-6A, Chapter 5)

A thermal analysis of a steel plate (e.g., modeling a beam flange) with gaps in the SFRM showed that occasional gaps in the SFRM did not significantly alter the thermal response of the structural member. (NIST NCSTAR 1-6, Chapter 2)

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2 A different set of analyses for WTC 1 and WTC 2 led to a similar approach for modeling the SFRM, i.e., the SFRM was modeled as undamaged, except for areas subjected to direct debris damage from the aircraft impact.)

Why did the investigation take so long to complete?

The overall NIST investigation began on Aug. 21, 2002. Early in the investigation, a decision was made to complete studies of the two tower collapses (WTC 1 and WTC 2) before fully proceeding on the WTC 7 investigation. A major technical conference on the draft reports on WTC 1 and WTC 2 occurred on Sept. 13-15, 2005. The time between the technical conference on the WTC towers report and the issuance of this draft WTC 7 report is approximately three years, comparable to the length of a typical investigation of an aircraft crash.

The WTC 7 investigation was an extensive, state-of-the-art reconstruction of the events that affected WTC 7 and eventually led to its collapse. Numerous facts and data were obtained, then combined with validated computer modeling that is believed to be close to what actually occurred. A single computer simulation of the structural response to fires took about eight months to complete on powerful computing workstations and clusters.

Did debris from the collapse of WTC 1 cause damage to WTC 7's structure in a way that contributed to the building's collapse?

The debris caused structural damage to the southwest region of the building-severing seven exterior columns-but this structural damage did not initiate the collapse. The fires initiated by the debris, rather than the structural damage that resulted from the impacts, initiated the building's collapse after the fires grew and spread to the northeast region after several hours. The debris impact caused no damage to the spray-applied fire resistive material that was applied to the steel columns, girders, and beams except in the immediate vicinity of the severed columns. The debris impact damage did play a secondary role in the last stages of the collapse sequence, where the exterior façade buckled at the lower floors where the impact damage was located. A separate analysis showed that even without the structural damage due to debris impact, WTC 7 would have collapsed in fires similar to those that occurred on Sept. 11, 2001. None of the large pieces of debris from WTC 2 (the south tower) hit WTC 7 because of the large distance between the two buildings.

Would WTC 7 have collapsed even if there had been no structural damage induced by the collapse of the WTC towers?

Yes. Even without the structural damage, WTC 7 would have collapsed from the fires that the debris initiated. The growth and spread of the lower-floor fires due to the loss of water supply to the sprinklers from the city mains was enough to initiate the collapse of the entire building due to buckling of a critical column in the northeast region of the building.

Why did WTC 7's sprinkler systems fail during the fires?

The sprinkler systems did not fail. The collapse of WTC 1 and WTC 2 damaged the city water main. The water main served as both the primary and backup source of water for the sprinkler system in the lower 20 floors. Therefore, the sprinkler system could not function. In contrast, the sprinklers and standpipes on the building's middle levels (21st floor through 39th floor) and upper levels (40th floor through 47th floor) received water from two large overhead storage tanks on the 46th floor, and used the city's water mains as a backup.

How hot did WTC 7's steel columns and floor beams get?

Due to the effectiveness of the spray-applied fire-resistive material (SFRM) or fireproofing, the highest steel column temperatures in WTC 7 only reached an estimated 300 degrees C (570 degrees F), and only on the east side of the building did the steel floor beams exceed 600 degrees C (1,100 degrees F). However, fire-induced buckling of floor beams and damage to connections-that caused buckling of a critical column initiating collapse-occurred at temperatures below approximately 400 degrees C where thermal expansion dominates. Above 600 degrees C (1,100 degrees F), there is significant loss of steel strength and stiffness. In the WTC 7 collapse, the loss of steel strength or stiffness was not as important as the thermal expansion of steel structures caused by heat.

Did the electrical substation next to WTC 7 play a role in the fires or collapse?

No. There is no evidence that the electric substation contributed to the fires in WTC 7. The electrical substation continued working until 4:33 p.m. on Sept. 11, 2001. Alarms at the substation were monitored, and there were no signals except for one event early in the day. No smoke was observed emanating from the substation.

Special elements of the building's construction-namely trusses, girders, and cantilever overhangs, which were used to transfer loads from the building superstructure to the columns of the electric substation (over which WTC 7 was constructed) and foundation below-also did not play a significant role in the collapse.

Why were there no fatalities from the collapse of WTC 7?

Several factors contributed to the outcome of no loss of life-or serious injuries-in WTC 7. The building had only half the number of occupants on a typical day-with approximately 4,000 occupants-at the times the airplanes struck the towers. Occupants had recently participated in fire drills. The occupants, alerted by the attacks on WTC 1, WTC 2, and the Pentagon, began evacuating promptly. Evacuation of the building took just over an hour, and the process was complete before the collapse of the first WTC tower (WTC 2). Emergency responders provided evacuation assistance to occupants. No emergency responders were harmed in the collapse of WTC 7 because the decision to abandon all efforts to save WTC 7 was made nearly three hours before the building fell.

Why didn't the investigators look at actual steel samples from WTC 7?

Steel samples were removed from the site before the NIST investigation began. In the immediate aftermath of Sept. 11, debris was removed rapidly from the site to aid in recovery efforts and facilitate emergency responders' efforts to work around the site. Once it was removed from the scene, the steel from WTC 7 could not be clearly identified. Unlike the pieces of steel from WTC 1 and WTC 2, which were painted red and contained distinguishing markings, WTC 7 steel did not contain such identifying characteristics.

Your entire investigation included no physical evidence. How can you be so sure you know what happened?

In general, much less evidence existed for WTC 7 than for the two WTC towers. The steel for WTC 1 and WTC 2 contained distinguishing characteristics that enabled it to be identified once removed from the site during recovery efforts. However, the same was not true for the WTC 7 steel. Certainly, there is a lot less visual and audio evidence of the WTC 7 collapse compared to the collapses of the WTC 1 and WTC 2 towers, which were much more widely photographed.

Nonetheless, the NIST investigation of WTC 7 is based on a huge amount of data. These data come from extensive research, interviews, and studies of the building, including audio and video recordings of the collapse. Rigorous, state-of-the-art computer methods were designed to study and model the building's collapse. These validated computer models produced a collapse sequence that was confirmed by observations of what actually occurred. In addition to using its in-house expertise, NIST relied upon private sector technical experts; accumulated copious documents, photographs and videos of this disaster; conducted first-person interviews of building occupants and emergency responders; analyzed the evacuation and emergency response operations in and around WTC 7; performed computer simulations of the behavior of WTC 7 on Sept. 11, 2001, and combined the knowledge gained into a probable collapse sequence.

Did WTC 7 conform to building and fire codes?

The team found that the design of WTC 7 in the 1980s was generally consistent with the New York

City building code in effect at that time.

WTC 7's designers intended its stairwells to evacuate nearly 14,000 occupants, anticipated at the time to be the maximum occupancy of the building. Though the stairwell's capacity was overestimated, it was adequate for evacuating the building's actual maximum occupancy of 8,000, and more than adequate to evacuate the approximately 4,000 occupants who were in the building on Sept. 11.

What improvements to building safety have been recommended as a result of the WTC 7 investigation?

NIST has made one new recommendation and reiterated 12 recommendations from the investigation of the WTC towers.

The new recommendation involves explicitly evaluating buildings to ensure the adequate fire safety performance of the structural system. Of particular concern are the effects of thermal expansion in buildings with one or more of the following characteristics:

- long-span floor systems
- connections not designed for thermal effects
- floor framing that induces asymmetric forces on girders, and
- composite floor systems whose shear studs could fail due to differential thermal expansion (i.e., heat-induced expansion of material at different rates in different directions).

Typical floor span lengths in tall office buildings are in the range of 40 ft. to 50 ft. This range is considered to represent long span floor systems. Thermal effects (e.g., thermal expansion) that may be significant in long-span buildings may also be present in buildings with shorter span lengths depending on the design of the structural system.

The earlier recommendations encompass increasing structural integrity of buildings, enhancing structures' endurance when exposed to fire, creating new methods for increasing fire resistance in structures, improving active fire protection, improving some aspects of emergency response, and increasing education and training.

What are some of the firsts in this investigation?

This investigation is the first to show how fire can cause progressive collapse in a building. It is also the first to show that under certain conditions thermal expansion effects-rather than loss of strength and stiffness due to fire-can lead to structural collapse. It is the first to analyze a building's response behavior and determine its collapse sequence by integrating detailed models/simulations of debris impact damage, fire growth and spread, thermal analysis, collapse initiation, and collapse propagation-up to global collapse. This was an analysis of unprecedented complexity-an end-to-end computer run for the WTC towers on some powerful computers took about two months while a similar run for WTC 7 took about eight months, or about four times as long. NIST expects that the tools developed from this investigation, as well as the knowledge obtained from it, will aid in the development of more robust building design practice and in studies of future building collapse processes. These expanded tools and derived, validated, and simplified analysis approaches can guide practitioners and prevent future disasters.

Why did NIST study the collapse of WTC 7?

The NIST investigation of WTC 7 was conducted under the National Construction Safety Team (NCST) Act, as part of its overall building and fire safety investigation of the World Trade Center disaster. The act gives NIST the responsibility for conducting fact-finding investigations of building failures that resulted in substantial loss of life or that posed significant potential of substantial loss of life. NIST has no regulatory authority under the NCST Act.

How does the final report on WTC 7 issued on Nov. 23, 2008, differ from the draft report that was released for public comment on Aug. 21, 2008?

The final report is strengthened by clarifications and supplemental text suggested by organizations and individuals worldwide in response to the draft WTC 7 report, but the revisions did not alter the investigation team's major findings and recommendations, which include identification of fire as the primary cause for the building's failure.

The extensive three-year scientific and technical building and fire safety investigation found that the fires on multiple floors in WTC 7, which were uncontrolled but otherwise similar to fires experienced in other tall buildings, caused an extraordinary event. Heating of floor beams and girders caused a critical support column to fail, initiating a fire-induced progressive collapse that brought the building down.

In response to comments from the building community, NIST conducted an additional computer analysis. The goal was to see if the loss of WTC 7's Column 79—the structural component identified as the one whose failure on 9/11 started the progressive collapse—would still have led to a complete loss of the building if fire or damage from the falling debris of the nearby WTC 1 tower were not factors. The investigation team concluded that the column's failure under any circumstance would have initiated the destructive sequence of events.

Other revisions to the final WTC 7 report included:

- Expanding the discussion of firestopping, the material placed between floors to prevent floor-to-floor fire spread;
- Clarifying the description of thermal expansion as it related to WTC 7's shear studs and floor beams; and
- Explaining in greater detail the computer modeling approach used to define where and when the fire in WTC 7 started and the extent of window breakage as a result of fire.

Have the recommendations from NIST's investigation of the WTC towers led to any changes in building codes, standards, and

practices?

The first comprehensive set of eight model building code changes based on recommendations from NIST's investigation of the WTC towers were adopted by the International Building Code in 2007.

A second set of eight model building code changes based on NIST's recommendations from its investigation of the WTC towers were approved by technical committees and are awaiting approval, along with potential appeals on several other code changes, at the Final Action Hearing for the 2009 edition of the International Building Code.

NIST's recommendations from its investigation of the WTC towers also have spurred actions to develop new provisions/guidelines within other standards, codes, and industry organizations, such as: the National Fire Protection Association, the American Society of Mechanical Engineers, ASTM International, the American Society of Civil Engineers, and the Council on Tall Buildings and Urban Habitat.

What specific code changes based on recommendations from NIST's investigation of the WTC towers have been approved for inclusion in the International Building Code?

The eight specific code changes adopted in the International Building Code based on recommendations from NIST's investigation of the WTC towers include:

1. An additional exit stairway for buildings more than 420 feet in height.
2. A minimum of one fire service access elevator for buildings more than 120 feet in height.
3. Increased bond strength for fireproofing (nearly three times greater than currently required for buildings 75-420 feet in height and seven times greater for buildings more than 420 feet in height).
4. Field installation requirements for fireproofing to ensure that:
   - installation complies with the manufacturer's instructions;
   - the substrates (surfaces being fireproofed) are clean and free of any condition that prevents adhesion;
   - testing is conducted to demonstrate that required adhesion is maintained for primed, painted or encapsulated steel surfaces; and
   - the finished condition of the installed fireproofing, upon complete drying or curing, does not exhibit cracks, voids, spalls, delamination or any exposure of the substrate.
5. Special field inspections of fireproofing to ensure that its as-installed thickness, density and bond strength meet specified requirements, and that a bonding agent is applied when the bond strength is less than required due to the effect of a primed, painted or encapsulated steel surface. The inspections are to be performed after the rough installation of mechanical, electrical, plumbing, sprinkler and ceiling systems.
6. Increasing by one hour the fire-resistance rating of structural components and assemblies in buildings 420 feet and higher. (This change was approved in a prior edition of the code.)
7. Explicit adoption of the "structural frame" approach to fire resistance ratings that requires all

members of the primary structural frame to have the higher fire resistance rating commonly required for columns. The primary structural frame includes the columns, other structural members including the girders, beams, trusses, and spandrels having direct connections to the columns, and bracing members designed to carry gravity loads.

8. Luminous markings delineating the exit path (including vertical exit enclosures and passageways) in buildings more than 75 feet in height to facilitate rapid egress and full building evacuation.
