NIST Technical Briefing on its Final Draft Report on WTC 7 for Public Comment

Shyam Sunder: [in progress] -welcome you this morning to our technical briefing on the release of our reports of the World Trade Center 7 investigation, which we started in right earnest three years ago after having completed our investigation of the World Trade Center Towers and had issued the final reports from that investigation. My name is Shyam Sunder. I'm the director of the Building and Fire Research Laboratory at the National Institute of Standards and Technology, and I'm also the lead investigator for the investigation. Today's briefing is for the technical community. It's a more detailed briefing than the briefing we provided to the media last week, and hopefully it'll provide you with more understanding of what we have actually accomplished and our findings and recommendations. At the beginning of the briefing, I'd like to point out a few protocols with regard to those who have actually signed up to ask questions. There are a very large number of people who are signed on to view the webcast but not ask questions. But a small subset have signed up to ask questions. The questions may be submitted at any time during the technical briefing. Questions must be technical and must focus on World Trade Center 7. And please make the questions as short as possible and asking just one question at a time. We have a number of individuals registered, and this will allow us to get to as many questions as possible in the available time. The briefing itself is in two parts. The first part will focus on the investigation objectives, the design features of World Trade Center 7, the probable collapse sequence. At the end of the first part, we will take a short break to ask questions. This is not a break from the transmission, but simply a pause from my presentation so that any questions that are raised until that point in time have a chance to be asked. After that short pause, we will start with the second phase of the presentation, which will focus on other possible hypotheses, the principal findings, factors that could have changed the outcome, and then our recommendations.

As a large number of you already know, we had four objectives when we started this investigation, the overall investigation, in August of 2002. One was to determine why and how the World Trade Center buildings collapsed. In the case of the Towers, it was after the initial impact of the aircraft, and in the case of World Trade Center 7, the building collapsed later that afternoon at 5:20. The second objective was to determine why the number of fatalities and injuries were low or high depending on location, and the focus here was on fire protection, occupant behavior, evacuation, and emergency response. The third objective was to determine the procedures and practices that were used in the design, construction, operation and maintenance of the World Trade Center Towers-buildings. And the main purpose of that was to establish the baseline performance from which to compare the actual performance on 9/11. And, finally, to identify as specifically as possible areas in national building and fire codes, standards, and practices that warrant revision.

So let me speak a little bit to the design of this particular building. It was a 47-story office building located to the north of the main WTC complex, about 370 feet to the north of Tower 1. And it was located on top of an existing Con Ed substation and on land owned by The Port Authority of New York and New Jersey. And you can see that in the slide at the very north, the trapezoidal-looking building on the north. On 9/11, these buildings-this building endured fires for almost seven hours, from the time of collapse of Tower 1 until 5:20 in the afternoon, or almost 5:21. The collapse of Building 7 was the first known instance of the total collapse of a tall building primarily due to fires. In the next slide, you see the location of the Con Ed substation viewed from the north of the building. It's at the very bottom. You can see the circled region where you see an extension from the footprint of the high-rise building above. The structural design of World Trade Center 7 consisted of approximately-was designed with four tiers, mainly to accommodate about 2 million square feet of floor area. The lowest four floors housed lobbies, two-story lobbies on each side on the center of the south side of the first and third floors. And then the north side of those first and second stories was the Con Ed substation. The mechanical spaces were on Floors 5 and 6, and between those two floors were transfer trusses and a series of eight cantilever transfer girders. Floors 7 through 45 were tenant floors, all structurally similar to each other. And then the 46th and 47th floors, while mainly tenant floors, were structurally reinforced to support special loads, such as the cooling towers and the water tanks that were used for fire suppression. The framing system was designed to distribute the weight of the building and resist lateral or wind loads in this particular case. The frame included columns, floors, spandrel beams, girders and transfer elements. The lateral loads, the wind loads, were resisted by the exterior moment frame of the building. And what you see on the top of this figure are the four exterior walls of the building. The gravity loads were supported by roughly 58 exterior columns-were supported roughly equally by the exterior columns and the interior columns. There were 58 exterior columns and there were 24 interior columns. You see here those 24 interior columns and the 58 exterior columns. The columns were numbered counterclockwise, starting in the northwest corner at 1 for the exterior and then ending at 57. The 58th column was adjacent to Column 15, and was numbered Column 14A. In the core of the building, or on the interior of the building, we had 24 columns, going from 58 through

81. In the northeast regions, Columns 79, 80 and 81 are shown in the figure. They were outside the core of the building, and the remainder 21 columns were actually within the core of the building. This was the core of the building where you have the elevators and the stairwells and the mechanical utility closets and so forth. Some of these columns were massive, in the sense that they were built-up columns, and some of them were non-built-up columns. As you can see here, the Column 79, which is shown in red, at the northeast corner, was a built-up column with a cover plate, and Columns 80 and 81, immediately to the south of Column 79, were built-up columns with web plates. And these plates were pretty thick, ranging from less than-from about two inches to more than six inches, and typically on the order of three inches in the case of Column 79, in the region of interest to us. The transfer trusses and girders between Floors 5 and 7 are shown here. We had essentially Truss 1 and Truss 2, as you can see here on the south end, or the lower end of the figure. Truss 1 really redistributed loads from Column 76. Truss 2 redistributed loads from Column 77. And then a girder that connected Column 77 to 78 helped transfer the load from Column 78 to Column 78A, down at the bottom. And you had a similar kind of a truss system on the west side, plus also some transfer girders on the west side. You see a large number of transfer girders on the right side of the figure. These are the overhanging cantilevers that help support the exterior columns 47 through 54 for the high-rise building and transfer that load down to the foundation. The floor slabs were reinforced concrete and resting on steel beams. In many cases, the concrete was poured on 3-inch corrugated metal deck. Floor 5 had a 14-inch concrete thickness. Floor 7, the south half, had an 8-inch concrete thickness and the north half an 8-inch concrete slab on a 3-inch metal deck. And on Floors 8 through 47, the concrete was 5 and a half inches thick. And you can see here in the core of the building, you'll see the locations of the stairs, one on the east and another on the west, and you see the elevator banks, as well, in the core. It's important to see what was on the roof. When you looked at the roof from the top you could see the cooling tower at the north side and the setback on the south side, but most importantly you see the east penthouse that is directly over Columns 79/80, and the edge of the east penthouse is near Columns 76/77, and then the screen wall is the next three rows of columns or three lines of columns, and then the west penthouse is the last three lines of columns. The building had active fire protection systems, the usual systems, and we will talk later about the building classification and the systems that were in place. But the most important thing is that the sprinkler system was divided into three zones. The top zone had Floors 40 and 47 and the mid zone had Floors 21 through 39. For both of those zones, the primary water supply was from overhead water storage tanks on the 46th floor. The secondary water supply was pumped from the city water main. At the lower zone, below Floor 21, the primary water supply was a direct connection to the city water mains, and the secondary water supply was also from the city water main,

but this time through an automatic fire pump. Insofar as the emergency power systems are concerned, there were a number of functions in the building that required backup electrical power, and as a result there was a number of diesel generators in those buildings. This chart shows the location of those different emergency power systems, and you will see that these are located, primarily the main fuel tanks or the diesel fuel tanks were at the bottom of the building, shown right here at the bottom, and the first four of them were below, underground, and one of them was on the first floor. They supplied-the generators themselves were located on Floors 5, 7, 8 and 9. And since there was already a day tank on Floor 5 and a further generator emergency power system was to be applied--was to be installed on that floor, there was a pressurized fuel line that sent diesel fuel up to the nine generators that connected that particular system. Those nine generators you can see here on the right side of the sketch. Four of the generators were on the northeast corner, near Column 79. Two were on the northwest corner, and then three were on the southwest corner. The green generators are those belonging to an independent generator system on that particular floor, with a 250-gallon day tank. This next chart simply tells you where the tanks were located and the day tanks were located, the primary supply tanks and the day tanks, as well as the floors where those were located. So among the specific questions we asked as we carried out this investigation was why did this building collapse after having withstood fires for seven hours? What role, if any, did the transfer elements play in the collapse of the building? What role, if any, did fuel oil systems for emergency power generators play in the collapse of the building? What role, if any, did hypothetical blast events play in the collapse of 7? And the primary reason we considered this scenario was simply because of questions that had been raised by a number of people in the public but not that we had any evidence at all that hypothetical blast events had any role to play on that day. But we did want to make sure that we left no stone unturned in understanding what, if any, role such hypothetical events might have played on 9/11.

The next question was how well did the construction, design, and maintenance practices conform to accepted practices? And, lastly, we wanted to know if WTC 7 would have collapsed even if there had been no structural damage caused by the collapse of the WTC Towers.

So at this moment, I will switch now to the probable collapse sequence, first speaking about the methodology we used to determine the probable collapse sequence and then talking about the specific sequence that we determined based on that analysis. We used a series of rigorous and comprehensive models to determine the probable collapse sequence for this building. There were basically five steps. We first estimated the initial damage to the building due to the collapse of World Trade Center 1. We modeled the growth and spread of fires that were generated by the collapse of World Trade Center 1. We determined the thermal response of the structural components. We then identified the thermally induced initial local failure that triggered collapse initiation. And then, finally, we modeled a collapse propagation that led to the global collapse of the building. In doing so, we combined physics-based mathematical modeling; analysis of visual evidence, particularly-mainly photos and videos; and analysis of the design, construction and inspection documents, which we had in great abundance. And we had the structural drawings. We had the architectural drawings. We had flow layouts, tenant layouts. And we did have detailed shop fabrication drawings for the connections that were used in this particular building. In summary, I will say that we significantly advanced the current state of the art and tested the limits of current computational capabilities in carrying out this analysis, as will become apparent pretty shortly. With regard to fire growth and spread, we used the Fire Dynamics Simulator in a manner that we had done for the WTC Towers. The aspect ratio for the floors in this particular building was similar to those in the Towers. So we felt very comfortable and felt that it was validated for the purpose that we were using it for. There were far fewer photographs and videos of WTC 7 than of the Towers. Thus, some of the details of the WTC 7 fires were not as precise as for the Towers. Now, keep in mind that in the case of the Towers we were able to generate minute-by-minute information on all of the windows, each window on the fire-affected floors, over the period from the time the airplane hit those buildings all the way to the time those buildings collapsed. We did not have that detail of information, but we had pretty robust information about where the fires were. The fire simulations were conducted for each floor individually. There were no obvious pathways for the flames and heat to pass from one floor to another, aside from debris-damaged area of the southwest corner of the building. The sustained or late fires were observed only on six floors-Floors 7 through 9 and 11 through 13. And the actual fires on these floors were most likely initiated at the time of the incidence of the debris from the collapsing Towers. A typical single-floor simulation took us up to two days on a Linux cluster with eight processors. And what you see in the left side of the slide is on the progression of fires on Floor 12. And you will see as a function of time how the fires actually grew. Floors 11 through 13, the fire went in an anti-clockwise direction, or counterclockwise direction. Floors 7 through 9 it was clockwise. So in the case of Floor 12, you see the fire starting in the south region, moving toward the east, moving again to the north and eventually going to the west. And this simulation will show you really what I just showed you in the previous slide. And you can see how the fire grows. And keep in mind, temperatures, everything that you see in green is in the range of 400 to 500 degrees Celsius, (Note everything you see in red is-or yellow is about 800 degrees, and red is about 900 to 1,000 and more. So, as we will come back later, it was more important for us to focus on what's in the green or blue rather than what was in red or yellow. (Note 579, 22:12)And, as you can see here, the fire is evolving, and you see that Column 79, which is in the northeast corner, is subjected to the heat from this fire on this particular floor for a pretty long time, as the combustibles are burned all around that particular floor system surrounding Column 79. The floor system had a span length of as much as 54 feet on one side. The area that was supported by the column was about 2,000 square feet. The next step in the analysis, basically what fire dynamics analysis gives us, is the heat release rate as the result of the fires on those particular floors. That becomes input to our thermal analysis. And, as you can see in the next slide, you see the view from the southwest-southeast of the building as a whole, the bottom half of the building, or the bottom stories of the building, as well as Floor 13. Remember that fire on Floor 12 would actually heat up the beams on Floor 13. And, as you see, the temperatures are well-you see a lot of temperatures in the 200, 300, 400, 500 and even going up to 600 and 700 degrees.

But the primary initial effects that caused damage, as we will show later, were really happening at much lower temperatures, on the order of less than 400. What the ANSYS thermal analysis provides us is the temperature on the steel through the fireproofing. The fireproofing is intact throughout the building except in the immediate vicinity where Tower 1 hit it. And the fireproofing thickness was used as was specified in the documents that we had. The ANSYS structural model is the next step. Basically we take the temperatures from the ANSYS thermal analysis and put them as input to the ANSYS structural model. And what that will do is then try and predict where you have local fire-induced damage to the connections themselves, which are bolted connections for the most part, as well as failures of beams through buckling and girders through possibly buckling and of course connection failures. We had a 16-story detailed ANSYS model. This is the bottom 16 stories of the building. The top stories beyond 16 all the way to 47 was also modeled, but in a simplified fashion, accounting for the loads that were transmitted to the bottom of the building. And the reason to focus on the bottom of the building here was simply because the fires themselves were seen on Floors 7 through 9 and 11 through 13, and those floors, you can see them in blue. The floors above that are represented through a superelement, and the floors below that are also represented by a superelement. We used ANSYS 11.0 double precision software, again, on the order of 100,000 nodes and elements, on a pretty sophisticated computer workstation. And the analysis time for one run was about six months on this particular system. Keep in mind that as the analysis progressed we had to keep track of the damage that-fire-induced damage to the connections and members. The last step in the analysis was to then take the local fire-induced damage from the ANSYS in our structural model and input them to an LS-DYNA structural response model to actually predict the sequence of events that led to collapse propagation and ultimately global collapse. So the prior model got us to the point of collapse initiation and this model gets us from collapse initiation all the way through global collapse. Again, we used a double precision version of the software. In this particular case, we had 3 million nodes and 3.5-I'm sorry, 3 million elements and about 3.6 million nodes. Again, high-speed Linux clusters, and our analysis time in this particular case was about eight weeks in total. So if you look at the total analysis time, it's roughly eight months to do a single run. Now, in comparison, a single run for the WTC Towers was about two months. So this is about four times as sophisticated and as demanding as what we did for the Towers, and it's mainly because of the details of the model. Every connection was properly modeled, both in the LS-DYNA model and the ANSYS model, and the details of that are well documented in our reports. So at this point I'm now going to take a few minutes to describe for you the probable collapse sequence. And at the end of that we'll take a break and take some questions.

The first step in the probable collapse sequence was associated with the collapse of the WTC Towers. The collapse of World Trade Center 2 did not cause any structural damage or start any fires in WTC 7. Collapse of World Trade Center 1, which was the second tower to collapse, at 10:28 that morning, damaged seven exterior columns on the lower floors of the south and west faces and initiated fires on 10 floors between Floors 7 and 30. What you see is a photograph that shows you the degree impact from the collapse of Tower 1. And the arrows point, actually, to pretty significant pieces of the structural steel from the Towers that are actually going to directly impact Building 7. And this photograph was taken approximately 14 seconds after that Tower began to collapse. To get closer to the damage, you see here a photograph of the southwest corner of the building. So Tower 1 really was diagonally across from this particular corner. You see here-what you see, actually, is the west face, but it's the southwest corner. And you can see that several columns have been severed between-on the lower floors, below about Floor 18 down to Floor 11 and below. In terms of those seven columns that were severed, six columns were on the south face and one column was on the west face. But, of course, one of those columns on the south face was exactly on the corner of the southwest. We then carried out, through analysis of photographs, estimated where the damage was on the building. And this picture kind of captures our estimate of where the damage was. And, remember, the photographs for this particular building on the south face were more infrequent than on other sides, because the Towers had collapsed, and folks were not there on the south side of this building to take pictures from close up. What you see is really the region in red is where we have exterior visible damage to the structural steel. You see this on the lower floors, but you also see it at the very top of the building, where probably a structural element from the Tower really went right through top to bottom of the building. You also see in yellow where the window glass is broken. And, as you look on the south face on the lower floors, in the region where the structural damage does not happen, the bulk of that region has window glass broken on the south face. On the west face, you see window glass breakage, as well, but less extensive and more concentrated on the southwest corner on the lower floors.

The second step of the collapse sequence is the growth and spread of fires. As I previously mentioned, the fires on the lower floors grew and spread, since they were not extinguished either by the automatic sprinkler system or by FDNY through manual suppression because water was not available. The collapse of the Towers pretty much cut off water supply to this particular building. Second, we observed that fires were generally concentrated on the east and north sides of the northeast region, beginning at about 3:00 to 4:00 p.m. So if you look at this particular slide, you can see on-you are seeing, actually, the building in the northeast corner. You see some broken windows on the 12th floor. But if you look across the corner on the east face, you see fire in the east face extending over much of the length of the east face on that particular floor, Floor 12. Now, this picture was taken somewhere between 3:20 and 3:40 that afternoon. And we also did not observe any fires on the upper floors-19, 22, 29 and 30-roughly after about 1 o'clock. And we know, as I've said before, Floors 21 through 47, the sprinkler system was supplied by the water tank at the top, and it's possible that the sprinklers were functioning and helped put those fires out.

Floor 19 fires have also been put out, simply because they didn't have enough combustibles and they just-they were local and burnt out.

Here is just another set of pictures of the fires on the north face of Building 7, one taken somewhere between 3:11 and 3:16 or 3:17 that afternoon and the second one taken at about 4:40 or 4:39 that afternoon. And you'll see that we have uncertainty bounds from the time assigned. That's the degree of confidence we have in the timing of those photos. So in this particular case we have a two-minute uncertainty in identifying the time. In the picture on the left, you see the fires on Floor 12, and on the picture on the right you see fires on Floor 11. Again, the picture on the right is in the northeast region. You also see some fires on Floors 8 and 9 and a dying fire probably in Floor 7, at least in this particular photo. We can take all of that information and summarize it much like we did for the Towers. Here is just the windows that were either broken or fire was observed somewhere between 3 o'clock until about 5:20. And you will see here that Floor 12 has extensive fires. Floor 13 has fires. Floor 11 has some fires. And, again, Floor 8 has extensive-extensive in the sense of the coverage of the floor of fires, as well as Floor 7. And there's also fires on Floor 9. The window breakage indicated to us that those are places where fires did go or will go, because usually the windows break when the temperature increases, causing them to break, and then eventually they provide the oxygen or air to fuel the fires.

The next step, step three, is really the summary of the probable collapse sequence. We're starting now with the initial local failure for collapse initiation. The fire-induced thermal expansion of the floor system surrounding Column 79 led to collapse of Floor 13. That in turn triggered a cascade of floor failures. In fact, there were a cascade of floor failures that led to loss of lateral support to Column 79 over nine stories, resulting, then, in the failure of Column 79 through buckling. What you see on the left side of the diagram is Column 79. The red circles indicate the floors-and this is just before buckling, after the floors had failed-you see no support where the red circles are. You see yellow, which suggests partial support. But even in those red circled regions you see that some of the floors-8, 9, 10, 11 and 12-have some restraint in the north direction. So Column 79 was really free to move in the east-west direction. And what you see in the photograph on the right side is actually Column 79 buckling. This is a photo taken a little bit from the southeast, so you see Columns 79, 80 and 81, and you see that Column 79 has actually buckled in the east-west direction. And very shortly thereafter, then, Columns 80 and 81 will buckle, which is the next step of the collapse sequence. But before I get to the next step, let me show you some more details of Column 79 and the floor framing system surrounding Column 79. What you see in this figure is a photograph of Column 79. You see the floor framing system, and the floor framing system has beams going really from east to west. And this is a view looking from the northwest-northeast region, so you see-everything that you see going into the depth of the photograph is really moving toward the south face of the building. All of the beams are going the east-west direction. You also see a girder that's connected to Column 79 going to the north face of the building, and if you look on the other side of the girder, you will see that the beams on that floor system are not in the same direction as the beams on the left side of the floor system. And this is a key factor, because as the floor expands, the beams expand, the beams are pushing this girder from east to west, and there's nothing to oppose it on the other side of the girder from west to east. So, in short, the girder can either buckle or it can lose the connection with Column 79. And what actually happens is that the connection is lost. Now, it's also important to keep in mind that the interior connections in these buildings were simple shear connections. They were not moment-resisting connections. The exterior connections were all moment-resisting connections. And, particularly with Column 79, these were seated connections, so there was a seat that you can see at the bottom, and they were held together with two bolts. The seats were connected to the bottom flange of the girder with two bolts. And, of course, on the top flange on the girder you had also two bolts that connected the column to the girder. The next picture actually shows you what we're talking about. You see the northeast floor system. When that northeast floor system is heated, a few things happen, as you can see in this particular chart. The exterior columns have a pretty rigid frame, and the composite floor system, the steel-concrete floor system, wants to expand. And, as you all know, steel expands much more than concrete. And so there's differential thermal expansion that occurs. As a result of the differential thermal expansion, the studs that connect the steel to the concrete, the steel beam to the concrete slab, fail, and therefore you have a situation where the girders, the beams are free to expand in an unrestrained fashion. At the same time, you see that in those cases where there is in fact restraint or where in fact the girder prevents or the columns prevent the beams from expanding, you can have buckling of that particular floor system. And of course a third thing that can happen is that when you have expansion of the floor system it can push on the girders that are around, and the girders can either buckle or the girders can lose their connection to the columns, as you see in this particular illustration. Why is all the expansion taking place in the east toward the west? It's because of the dense grid of columns on the east, which actually prevents them from expanding-allowing expansion on the east side. And the main reason the girder can be pushed off to the west is there is no opposing beam on this side trying to push it back to the east, because of the arrangement of the floor framing system. And, as you see in the sketch on your slides, you will see that once the bolts break, then you have essentially the girder moves off the seat and eventually falls. So I'll show you now a simulation that demonstrates this process. Column 79-you're looking at the building here now from the south side. Column 79 is to the extreme right, followed by 80 and 81. And then you have a number of other interior columns, as well. And you'll see a floor failing, and eventually the cascading floor failures leading to the buckling collapse or buckling failure of Column 79 and subsequently the buckling of 80 and 81. So the next step, once Column 79 buckles, you have what's called vertical progression of failure. That buckling triggers a vertical progression all the way up to the east penthouse and subsequent cascading failure of the adjacent interior columns, that's Columns 80 and 81. And once you have this vertical progression of failure-floor system failure all the way to the ceiling, or to the roof, you have this encompass the entire east region, all the way to the top of the building. Once you have the vertical progression, the next step is really horizontal progression of the failure.

The interior columns buckle in quick succession from east to west on the lower floors. And basically three conditions have to happen for this to occur. One, there has to be a loss of lateral support from the floor system failures, so you suddenly have interior columns now with long unsupported lengths. There are forces exerted on those columns by the falling debris. And, thirdly, you have some load redistribution from the other buckled interior columns. So what you see in this particular picture are two photographs. One, the first one on the left, shows you the failure progression all the way to the third line of interior columns from the east. And then the next one shows you the situation when all of the interior columns have buckled, which happens about 6 and a half seconds after collapse initiation.

And the final step is global collapse. And now we have the interior core of the building has started to move downward. All the columns have buckled. Then the next step is where the exterior columns buckle at the lower floors between Floors 7 and 14 due to this load redistribution to the exterior from the downward movement of the building core. And at that point the entire building above the buckled-column region moves downward in a single unit, as was observed in the videos, and completing the overall global collapse sequence. And this, the figures on the bottom basically show you a view from the west and a view from the south of the buckling that takes place in those members.

So at this point I want to move now to looking at some of the videos, some of the observations and comparing our model with that and to draw some-eventually to draw some findings. So the next one is now-this is a very good video that was shot by CBS News from the northwest perspective or view of the building collapse. So what you see here is the north face of the building. At the very top in black rectangle is the east penthouse. Toward the right of that, at a lower height, is the screen wall. And on the west side, a dark, slightly darker roof feature is the west penthouse. The dark band on the floors just below the roof line have to do with the utility space, where you have the cooling towers in that region. So as I play this video, watch for what happens first on the east side. You'll see a kink forming on the east penthouse, followed by windows breaking just below that on some of the upper floors. And eventually you'll see the screen wall start to go inside and followed by the west penthouse. Remember, these are located in the interior of the building, and once they disappear it's after that that you see the exterior fa?ade of the building, the north face of the building, start to move down. And when that happens, you'll see some other features, as well. So watch for the kink, the east penthouse collapses, the windows break. Now you see very soon the screening wall and the west penthouse, and followed by the global collapse that happens. Compare that with the visualization of our physics-based model. And what you are seeing here is really that same model, showing you the same view from the northwest perspective. And you'll start seeing here the floors failing, eventually the buckling of the lower columns, followed by failures all the way to the top. The kink, the roof, east penthouse disappears, and eventually you have progression from east to west and overall global collapse. To show you a different view of that simulation, let's look at a view from the south. And you pretty much see the same response. You see the floors failing on the east side and also a few on the west side, followed by failures all the way to the rooftop. The east penthouse collapses, and then you have the overall progression horizontally and global collapse. Now, it's important to keep in mind that this model does include the original structural damage. And so some of those initial failures you saw on the west side of the floors, the floor failures on the west side, was due to the-on the lower floors-were due to the structural damage. And we'll come back to that topic shortly. If you look at the exterior, the photo here of the observations, in the next slide you will see a photo, shows you the east penthouse, the window breakage. You see the vertical progression and the column buckles. And you see the screen walls and the west penthouse are still intact, but the east penthouse does have a kink. In the next photograph, taken somewhat later, when the global collapse has started, you see that the fa?ade on the north has started to move down, away from the black rigid frame of the original shape of the building. You now see much more extensive window breakage on the east side, some window breakage in the middle and some window breakage on the west side. And you have a kink that forms in the north fa?ade, where there's a vertical red line, solid red line, pretty bold, that you see. We can take all of that information and look at it from the top of the building, and you'll see that the kink in the east penthouse forms in the-you can see that through the red line that you see in the top here, and it's actually well aligned with Columns 79, 80 and 81. So the kink that forms is directly below, or directly above, Columns 79, 80 and 81, and of course the penthouse itself has a column support, P17. You also see the kink that forms in the north fa?ade of the building, the second red line that's going top to bottom. It happens at the western edge of the east penthouse, or at the interface between the east penthouse and the screening wall. This is where the penthouse, the east penthouse, actually rotated around as it collapsed, as you can see at the bottom of this figure. We were able to do a pretty detailed vibration analysis of that video that we showed, and based on the vibration analysis, we could do a signature analysis. What you see in this particular slide shows you at different times different things that happened. And the zero time in this particular graph is when the east penthouse begins to collapse, and you observe it at the roof level. And we can trace back the times from our model as to when the Column 79 buckled, when the floors were collapsing, and then when you had horizontal progression and beginning of global collapse itself. And then we have overlaid that on this vibration analysis. And the vibration analysis really was a horizontal east-to-west motion off the north fa?ade in the very corner of the building, the northwest corner of the building. And you can see it's a pretty good comparison between the key events that were taking place and the nature of the vibrations that were observed. In the next slide, we actually bring all of this information together. So you will see the video playing. You will see the model working itself. And then you will see how the events took place in the graph on the bottom right of your screen. The computer model will start first, because it's modeling events all the way from the fire and the initial floor failures before the east penthouse fails. Soon, the CBS News video will start playing. And, of course, also at the time this vertical red bar on the graph will start moving from east to west. So at this point we can see floors collapsing, buckling of 79, east penthouse collapses, horizontal progression taking place, video is playing and of course you have beginning of global collapse. And these times are well synchronized, and so it gives us a pretty good confidence in also the timing of the model, not just the overall physical process. We compared the accuracy of the models by comparing them to the observations. And, of course, we looked at a number of things-starting of the cascading floor failures from the vibration analysis, and then a huge number of features, five or six that you see on the next slide. And it may be not very clear to you from the broadcast, but if you have downloaded the slide in hard copy you can see it very clearly. What you see is the observed time followed by a second column that shows you the time from the analysis with the debris damage included.

And, as you can see this, the observation and the simulations matches reasonably good. And you'll see that there are some discrepancies, particularly the order of the east screen wall-the east end of the screen wall actually falls after the west penthouse collapses, unlike what happened in the video. So we wanted to test-and, of course, one of the key things here is our estimate of the initial structural damage. That was an estimate from photographs, plus we estimated the extent of the depth and the extent of inner damage associated with what was visible exterior. So we did an another analysis, one with no structural damage, assuming the fires were the same, but there was no structural damage from the collapse of World Trade Center 1. When we did that analysis, you see the third column of numbers. And if you compare the third column of numbers with the observations, they are on the higher side in general, compared with the analysis with damage, which is on the lower side. So in reality what you see is the observations are somewhere in between the with damage case and the without damage case in general, and that's pretty good. We are able to bound the solution. And beyond that we actually find that overall observations match better with the case which has the debris damage. When you look at the two simulations, you see them much more close together-the simulation with the observation, they are much more closer together. So just to show you what the simulation looks like when you don't have structural damage, I'm going to play that particular simulation right now, and it's probably going to have the same kind of features, with some important differences overall. Again, now you're seeing vertical progression, east penthouse, progression from east to west. And eventually the building collapses. But if you look at the shape of that collapsed region, it's a little bit different from what you saw when we included the damage. And it's also different from what you saw in the video. The video and the initial simulation with the damage better match each other when you look at this particular endpoint in the simulation. And that shows that the damage, the structural damage did play a role, but it was not crucial for this building to collapse. So at this point I'll take a break. We have been at this for about 55 minutes. We can take a short break to answer any questions that might be on what you have heard right now.

Male Speaker: We have received several questions over the webcast. Let me begin with the first one. This comes from Jake Pauls, of Jake Pauls Consulting Services. This question, "Did NIST use interviews with occupants to learn what they saw of the damage to WTC 7 when the Towers fell, when and how they evacuated from WTC 7, and if you did not seek such information, why not?"

Shyam Sunder: Well, I want to hold that question till we actually come to the findings, where we talk about the evacuation process. As you know, we have not yet talked about the evacuation process. We did speak to several people, first responders, specifically, about what happened in Building 7. We also found out sufficient information to determine the amount of time it took to evacuate Building 7 and whether or not instructions were provided for that evacuation. As you will see later, the evacuation was completed in less than an hour after the first airplane hit, so 8:46, or 8:40, soon after the first airplane hit on 9/11, the building evacuation did start, and by-within an hour's time, all of the estimated 4,000 occupants of the building were evacuated safely and without any serious injury at all. There were a number of positive measures that were taken, and there were some challenges, as well. One of the challenges was that there was some crowding in the bottom of the building since the people from the Towers, the rest of the complex, were walking to the lobby level of Building 7, and they were being there for-being helped sometimes for injuries and so forth. It was a triage center. Secondly, some of the people were held back a little bit because there was still debris falling from the Towers. And the wise decision, the positive decision that was made was to actually evacuate the building or exit the building from the west side of the building, where there was some scaffolding due to ongoing construction which protected the occupants from any debris falling on them and helped really achieve a successful outcome.

Male Speaker: Second question comes from Craig Beyler, of Hughes Associates. His question, "Was fa?ade damage and window losses on the south face included in the FDS modeling initial conditions?" Shyam Sunder: I will defer that question to Dick Gann. Dick, do you want to answer that? Dick Gann: The window breakage was included. The fa?ade damage would have only contributed to a very small change in heat absorption in a region that really didn't matter too much, so it was not accurately conveyed there. Shyam Sunder: Thank you.

Male Speaker: A second question also from Craig Beyler, "Was an analysis performed to evaluate if a fire affecting only Floor 13 would have been able to cause the collapse, i.e., would the failure of the floors below 13 failed without fire effects on those floors? Shyam Sunder: Well, what I have presented to you so far does not show that result. What we have shown you is the two cases, both which have the fires similar to those on 9/11, one with the structural damage and one without it. We are obviously interested in studying the issue of whether or not the building may have had this kind of a collapse even if you did not have fires in the lower floors. And one of the kinds of analysis we are trying to do or are doing is to not have any fires at all, but just assume that Column 79 had buckled, and would this building collapse? So in fact it's a little bit more severe condition than the condition that Craig Beyler is asking, which is to allow fires on Floor 13 and not on the other floors. So when we have those results we will present them to the community.

Male Speaker: Our next question comes from David Chandler, of the American Association of Physics Teachers. "Any number of competent measurements using a variety of methods indicate the northwest corner of WTC 7 fell with an acceleration within a few percent of the acceleration of gravity. Yet your report contradicts this, claiming 40 percent slower than free fall, based on a single data point. How can such a publicly visible, easily measurable quantity be set aside?"

Shyam Sunder: Can you repeat the question, please? Male Speaker: Sure. "Any number of measurements using a variety of methods indicate the northwest corner of WTC 7 fell with an acceleration within a few percent of the acceleration of gravity. Yet your report contradicts this, claiming 40 percent slower than free fall, based on a single data point."

Shyam Sunder: Well, the-first of all, gravity is the loading function that applies to the structure-applies to all bodies on this particular-on this planet, not just in Ground Zero. The analysis showed there is a difference in time between a free fall time-a free fall time would be an object that has no structural components below it. And if you look at the analysis of the video, it shows that the time it takes for the 17-for the roof line of the video to collapse down the 17 floors that you can actually see in the video, below which you can't see anything in the video, is about 3.9 seconds. What the analysis shows, and the structural analysis shows, or the collapse analysis shows, is that same that it took for the structural model to come down from the roof line all the way for those 17 floors to disappear is 5.4 seconds. It's about 1.5 seconds, or roughly 40 percent, more time for that free fall to happen. And that is not at all unusual, because there was structural resistance that was provided in this particular case. And you had a sequence of structural failures that had to take place. Everything was not instantaneous.

Male Speaker: The final question comes from James Gourley, with Carstens & Cahoon, LLP. The question is, "Did NIST test any WTC 7 debris for explosive or incendiary chemical residues?" Shyam Sunder: That's-I'm going to hold that discussion because other hypotheses are going to be discussed in the next phase of this presentation, so we'll hold that question till that phase is completed.

Male Speaker: And that concludes the questions for now. Shyam Sunder: Okay. At this point, we will move on to the second phase of this presentation, where we talk about the other hypotheses and the principal findings and eventually to recommendations.

Okay, the first thing we looked at was, of course, the role of fuel oil fires. As many of you have read about this particular building, what was a feature that stood out was the number of emergency generators that were in this building because of the types of functions that were ongoing in that building-an emergency command center, a large number of trading floors or organizations that do trading that require heavy computing and reliable computing. And so among the scenarios we looked at is the role of these fuel fires. And these were diesel fuel fires. We looked at hypothetical diesel fuel fires on the 7th, 8th and 9th floors and concluded that those did not contribute to the collapse of World Trade Center 7. The generators on the 8th and 9th floors were supplied by the two 12,000-gallon tanks under the building. Nearly all the fuel in these tanks was recovered months after the building collapsed. Our estimate was that at most 1,000 gallons of fuel was unaccounted from these tanks, which was equivalent to about 5 percent of the office combustibles on a single floor. The day tanks that supplied fuel to the emergency generators on these floors did not contain enough fuel to be a significant contributor to the combustible load, as well. It is unlikely that the tanks would have been resupplied, because of multiple safeguards in the fuel delivery system, and none of the day tanks were located near critical Column 79. Fire did not reach the northeast region of the 8th or 9th floors until about 4:00 p.m. The second hypothesis that we looked at was the 5th floor was the only floor with a pressurized fuel line supplying nine of the emergency generators on that floor. There were two 6,000-gallon underground tanks that supplied these nine generators, and which were always kept full for emergencies and were full on 9/11. Both of these tanks were found to be damaged and empty in the rubble pile several months after the collapse. So there was only two possibilities-one, that this fuel might have contributed to a fire on Floor 5, or, secondly, all of that fuel was actually burnt in the rubble pile after the building collapsed. We decided to assume the worst case, which is assume that all of the fuel actually was used up in a fire on Floor 5. And particularly what we considered is a severe pool fire that might have resulted from the ignition of spillage of the diesel fuel on that floor or that might have been pumped to that particular floor. We considered five scenarios for this case. Two of them were overventilated fires near Column 79. And in the first case, we assumed that the fuel burning was sustained for seven hours. In the second case, we assumed that the fuel burning rate was twice that of the first case. So it's a higher intensity fire with substantial duration, but less than seven hours. The second two scenarios were underventilated fires near Column 79. And in this particular case, we assumed that the air handling system was turned off. In one case, we assumed the louvers were closed. In the other case, we assumed the louvers were open. And, of course, the initial burning rate was fit to the availability of air, the amount of air that was available for it. And the last scenario we considered was an overventilated fire near the breach in the south wall. Our findings from these five scenarios were that hypothetical pool fires on the 5th and 6th floors did not contribute to the collapse of World

Trade Center 7. These worst case scenarios could not be sustained long enough or could not have generated sufficient heat to raise the temperature of Column 79 or another critical column to the point of significant loss of strength or stiffness. So here is a scenario where the column itself was seeing the full effects of the pool fire. Such a fire would also have produced a large amount of smoke that would have been visible and would have come out from the exhaust louvers on those floors, and no such smoke discharge was actually observed. And the last point, and probably a very critical point, is that the gas temperatures would have very quickly exceeded the boiling point of the coolant for these nine generators, which is on the order of the water temperature, the boiling point of water, which is close to 100 degrees Celsius. Once all of these nine generators were down, there would have been no power to operate the fuel pumps, and the fires would have burned out well before columns in the region of Column 79 experienced significant loss of strength. So there were very good reasons that we could rule out this particular scenario. With regard to the role of fuel oil fires, we also looked at a day tank on Floor 5 supplying the remaining two emergency generators on that floor. And we decided-we concluded that it did not contain enough fuel for a fire that could threaten Column 79. And, of course, none of these day tanks were located near Column 79. We also looked at the-in addition to the pool fire that we looked at, we also looked at a diesel fuel spray on Floor 5, and we concluded that that would have been less damaging than a pool fire. Finally, the FDNY personnel that we spoke to did not see any indication of burning liquid fuels before the building collapsed.

A second hypothesis that we considered, possible hypothesis we considered, was the role of blast events. We looked at the size-location, size and timing of these events. And basically we did this analysis in three phases. In Phase 1, we identified the hypothetical blast scenarios to initiate structural collapse. And we identified a scenario with a minimum amount of required explosive, which turned out to be nine pounds of linear-shaped charge of RDX, and which was appropriate for the columns on the east side of the building. The recommended column preparation for this particular shaped charge required at least 30 minutes for cutting and placing. And additional preparation time was required to clear the column for cutting, such as removing the walls or other coverings that might have restricted access to the bare steel-to bare steel at a column section. The second phase of our analysis was to assess the blast wave propagation inside the building and the corresponding response of the windows. We used blast propagation calculations for this minimum explosive case from Phase I, the nine pounds. We also did a second calculation for a much smaller charge, two pounds, to see if that would actually break windows. And that was not sufficient to fail the column, but we wanted to just see how small we needed to get before windows would fail. And we carried out four blast analyses in total for these two charge sizes and of course two floor layouts. And it's important for me to discuss a little bit about these two differing floor layouts in the tenant areas. In the lower floors, 7 through 9, we had essentially workstations, modules, office modules, cubicles around the entire building-around the entire floor. On Floors-on the upper floors, 11 through 13, we had more instances where we saw offices, enclosed offices with partition walls running all the way to the ceiling, across the entire outer fa?ade of the building and the interior fa?ade. So this particular situation provided a lot more combustible fuel for the fire analysis, but it also helped dampen the propagation of the blast wave. What you see in the next slide is the peak over pressures for the nine-pound shaped charge on the left and the two-pound charge on the right. And, as you can see here, the region in the vicinity of Column 79, the pressures are pretty significant. And, of course, you see considerable window breakage in that region. Even with the two-pound charge, you have considerable over pressures and some amount of window breakage. The third thing we did in our calculations was to assess the approximate distance from the building the blast would have been audible in an urban setting. Adjacent buildings and their effects on the sound propagation was not considered in the initial analysis, but however sound from a blast in the urban setting would be reflected and channeled down streets with minimum attenuation-that's well known in the blast analysis field-due to the hard building exteriors. So for all four scenarios, significant audible sound was predicted from all the building faces. And if the propagation was unobstructed, the sound level from all the building perimeter openings at 1 kilometer-that's about roughly six-tenths of a mile-would be approximately 130 to 140 decibels. Our findings from this was hypothetical blast events did not cause the collapse of World Trade Center 7. NIST concluded that blast events did not occur and found no evidence of any blast events. The minimum explosive charge, the nine pounds, required to fail critical column, i.e., 79, would have produced a pressure wave that would have broken windows in the north and east, resulted in a sound level of 130 to 140 decibels, which is the equivalent sound to a gunshot blast, standing right next to a jet plane engine, and more than 10 times louder than being in front of speakers at a rock concert at least half a mile away. And it would have generated a sound that would be reflected and channeled with minimum attenuation down streets, urban streets, with hard building exteriors. Although such a blast could be heard a mile away, there were no witness reports of such a loud noise, nor was such a noise heard on audio tracks or videotapes that recorded WTC 7.

I think the next side is pretty explanatory, and it simply says that time required for preparing a column for intentional demolition would have to be-there's a lot of process that would've had to happen before it could actually have been done. And this is very hard to be able to do without being detected by others. And if you wanted to do this without any prior preparation, then you would have to have a much larger charge. Keep in mind that we knew how the buildings were designed. We knew how much charge was required. But in general, people would not know how much charge would be required and how much-and where to place them to bring a building down. Intentional demolition usually prepares most, if not all, interior columns in a building with explosive charges, not just one column. If you look at photographs of intentional demolition or videos of intentional demolition, you actually have a wave that progresses from one side of the building to the other side, and you can see it in the manner in which the building actually collapses. You have a sequence of charges going off, and that's not what we saw on 9/11.

The third hypothesis, the third issue we looked at was the role of the Con Ed substation, or the electric substation, and we concluded that the Con Ed substation played no role in 1:18:20 to 1:18:25 the fires that caused the collapse of World Trade Center 7. Electronic communication into and out of the Con Ed substation show that the substation operated until it was intentionally shut down at 4:33 p.m. Additionally, there was no evidence of a fire in the Con Ed substation. Even though utility power to the rest of WTC 7 was lost at 9:59 a.m., when Tower 2 collapsed, auxiliary unit power, utility power, to the Con Ed station from transmission switching feeders allowed internal operations to be maintained in the Con Ed station. The fire detector signals from this electric substation were monitored offsite throughout the day. One fire detector within the station gave an alarm when WTC 1 collapsed and stayed in that mode, alarm mode, until the substation was isolated from incoming feeders at 4:33 in the afternoon. There were no other indications-for example, no high-temperature alarms from the transformers, no visible smoke emanating from the Con Ed substation-that a fire occurred within the substation during that time period. Likely causes of the fire alarm were the smoke and dust dispersed in the area of the substation from the collapse of World Trade Center 1.

I think at this point it's probably worth saying a little bit about the role of fire resistance ratings. Based on the New York City Building Code, a sprinkler high-rise office building 1-C, which would be Class 1-C in the code, would have required a one-and-a-half-hour rating for the floor system, and an unsprinklered high-rise building, Class 1-B, would have required a two-hour rating for the floor system. So given the fact that this building had sprinklers, the floor system should have had at least a one-and-a-half-hour rating. But the floor system in this building was actually specified to have a two-hour rating in the bid documents, consistent with the Class 1-B unsprinklered building. The Underwriters Laboratory listing for this particular-for the floor beams of this particular type of composite floor show that half an inch of the fireproofing product used in WTC 7 will provide a two-hour fire resistance rating. And we had a set of inspection reports of the fireproofing which indicated that the target thickness that they were trying to apply was half an inch to achieve the two-hour BEAMS, while the applied thickness had an average value of a little bit more than half an inch. Therefore, the SFRM thickness that was applied to the framing of the composite floor system was consistent with a two-hour fire resistance rating, higher than the one and a half hours that it would be needed since this building had sprinklers. Based on thermal calculation, we concluded that it is unlikely that the collapse of World Trade Center 7 could have been prevented had the insulation thickness on the floor beams been increased by 50 percent. That is, if we had gone from half an inch to three quarters of an inch, our calculations show that the time to reach the steel temperature of 649 degrees Celsius would have increased by about 10 to 20 minutes. Now, this is the temperature at which steel loses substantial strength and stiffness. More than 75 percent of its strength and stiffness are lost. But remember that the probable collapse sequence was based on thermal expansion effects, which happen at temperatures below 400 degrees. So the 10 to 20 minutes is when you have to reach all the way to 650. The time to reach less than 400 would be substantially smaller. The ASTM E119 test does not capture critical behavior of structural systems-the effect of thermal expansion, the sagging of floor beams and the effect of the floor beam sagging on girders, connections and columns. In short, what we see is that the thermal expansion of WTC 7 initiated the probable collapse sequence at temperatures below approximately 400 degrees Celsius, and thus, to the extent that thermal expansion, rather than loss of structural strength, precipitates an unsafe condition, the current fire resistance ratings system is not conservative.

I'll now get to our principal findings. We have these findings organized by the objective of the investigation. The first one is the probable collapse sequence. WTC 7 withstood debris impact damage that resulted in seven exterior columns being severed and subsequently withstood conventional fires on several floors for almost seven hours, in particular six floors. The collapse of WTC 7 represents the first known instance of the total collapse of a tall building primarily due to fires. The collapse could not have been prevented without controlling the fires before most of the combustibles in the building were consumed. 1:23:41 – 1:23:48 And WTC 7 collapsed due to uncontrolled fires with characteristics that are similar to previous fires in tall buildings. Specifically, the fires in 7 were similar to those that have occurred in buildings such as One New York Plaza in 1970, the First Interstate Bank in 1988 and One Meridian Plaza in 1991, where the automatic sprinklers did not function or were not present. These three buildings, however, did not collapse because of differences between their structural designs and that of WTC 7. Fires for the range of combustible contents in World Trade Center 7 persisted in any given location for approximately 20 to 30 minutes. And, as I said, the Floors 7 through 9 had lesser combustibles, about four pounds per square feet, and Floors 11 through 13 had about 6.4 pounds per square feet. They were more heavily loaded. And had a water supply for the automatic sprinkler system been available and had the sprinkler system operated as designed, it is likely that fires in WTC 7 would have been controlled and the collapse prevented. (Note 541, 1:24:55)Our observations support a single point of fire ignition on any given floor in World Trade Center 7. In most instances, the fire on any given floor likely initiated near the damaged southwest region. The collapse did not occur until nearly seven hours later in the northeast region. Unlike the towers, there was no dispersion of jet fuel causing simultaneous fire initiation over extensive areas on multiple floors-on consecutive floors. I will not repeat the finding with regard to the collapse sequence itself. We have already gone through that in great detail. (Note 479, 1:25:34) I will say that the collapse of World Trade Center 7 was a progressive collapse, a new kind of progressive collapse which I would call a fire-induced progressive collapse. And progressive collapse is defined as the spread of local damage from an initiating event from structural component to structural component, eventually resulting in the collapse of an entire structure or a disproportionately large part of it. So this is the first known instance where fire-induced local damage led to the collapse of an entire tall building. The transfer elements-trusses, girders and cantilever overhangs-did not play a significant role in the collapse of World Trade Center 7. Likewise, the Con Ed substation did not play a significant role in the collapse of World Trade Center 7. We also concluded that without the initial structural damage caused by debris impact from the collapse of Tower 1, WTC 7 would have collapsed from the fires having the same characteristics as those experienced on 9/11. And I think those items that we have gone through in detail are now repeated. And those are-you can see them on your slide.

So I'm now going to the principal findings for Objective 2, which deals with evacuation and emergency response. As I said to Jake Pauls' question, there were no serious injuries or fatalities, because the estimated 4,000 occupants of 7, WTC 7, did react to the airplane impacts on the two Towers and began evacuating before there was significant damage to World Trade Center 7. Evacuation drills had been conducted every six months, and that likely contributed to speed and overall success of the evacuation. Building officials held the occupants in the lobby until they identified an exit path that was safe from the debris falling from Building 1 across the street. As I previously said, the evacuation took just over an hour, which is about 30 minutes longer than the estimated minimum time if the elevators and stairs had been used to maximum advantage. And, of course, since the building itself was not directly affected in this first hour-there was no structural damage to it or fires in it-the use of elevators would have been appropriate. Occupants were able to use both elevators and stairs, and some of the additional evacuation time was due to the considerable crowding in the lobby that I had previously discussed. The decision not to continue evaluating and fighting the fires was made hours before the building collapsed, so no emergency responders in or near the building-were in or near the building when the collapse occurred. I think it's important to recognize that there was technical advice that was being provided, or an assessment being done, as to the structural integrity or stability of the building over that period of time by the city agencies, and they decided to, at around midafternoon, somewhere round 2:30, they decided that it's possible that the building could collapse, and that they gave up any further activities related to that particular building. Evacuation management at every level did not provide timely evacuation instructions to building occupants during the event. It was not clear whether specific guidance was delivered to the occupants via the public address system. And that's, of course, information we determined from studying the issue of evacuations.

Getting to the findings on Objective 3, which are the procedures and practices, it's important to recognize that WTC 7 was designed and constructed as a "tenant alteration project" of the Port Authority, and its design and construction followed the requirements of the 1984 edition of the Tenant Construction Review Manual of the Port Authority. Although the Port Authority was not subject to the New York City Building Code, the 1968 New York City Building Code, including amendments through January 1, 1985, appears to have been used for the design and construction provisions of World Trade Center 7, based on citations in the construction documents. As we have previously discussed, the type of building-there was some lack of clarity on the type of building classification used, in the sense that, consistent with a Class 1-B building, the fireproofing was consistent with it. But a Class 1-B building did not require a sprinkler system, but the building actually had a sprinkler system installed, so it could be argued that if this building had been designed to a Class 1-C, less fireproofing could have been applied to the system-to the building. Our conclusion was that the design of WTC 7 was generally consistent with the New York City Building Code. Again, consistent with the New York City Building

Code there was no redundancy in the source of water supply for the sprinkler system in the lower 20 floors of WTC 7. Since there was no gravity-fed overhead tank supplying these floors, the sprinkler system could not function when the only source of water, which was from the street mains, was not available. Current practice for fire resistant design of structures, which is based on the use of ASTM E119, is deficient, since the method was not designed to include key fire effects that are critical to structural safety. Specifically, current practice does not capture four things: thermally induced interactions between structural subsystems, or subassemblies, elements and connections, especially the effect of restraint conditions; system-level interactions, especially due to thermal expansion, since columns, girders and floor subassemblies are tested separately, and therefore the interactions are never understood; the performance of connections under both gravity and thermal effects-connections are designed primarily for gravity loads and not for thermal effects; and last, but not least, the scale effects in buildings with long span floor systems. As our results for the Towers showed, most of the furnaces in this country are less than 20 feet in dimension, critical dimension, so everything that's been tested typically has been tested at scales less than 20 feet. We actually did a test on a floor system that was twice as large as the standard-size assembly that would be tested in the U.S. and found that the larger span length actually has a lower fire rating. It does not-so if a smaller test provides you the appropriate fire rating and acceptable fire rating, it's possible that if the actual building has a much longer span, then that may not be an acceptable fire rating. Current practice also does not require design professionals to possess the qualifications necessary to ensure adequate passive fire resistance of the structural system. In short, none of the key professionals is assigned the responsibility to ensure the adequate fire performance of the structural system. And, of course, we all know what the roles, different roles of the architects, structural engineers and fire protection engineers are. Architects typically rely on catalogued E119 data to specify the passive fire protection. They are not required to explicitly evaluate the fire performance of the structure as a system. Structural engineers are not required to consider fire as a load condition in structural design. All they are required to do is design for gravity loads and for earthquake and wind loads and other kind of environmental loads. And fire protection engineers may or may not be called upon to assist the architect in specifying the required passive fire protection. So we have a huge gap in practice where something like this can happen. There is also a critical gap in knowledge about how structures perform in real fires, particularly considering the effects of the fire on the entire structural system; the interactions between the different subsystems, elements, and connections; and the scaling of those fire test results to full-scale structures, particularly in structures that have long span floor systems. So as we looked at these findings, our question was, what factors could have changed the outcome on 9/11 in terms of the collapse of this building and the evacuation process that was used? And so some of these ideas, as I present them, you must keep in mind that these are-some of these are existing capabilities, some of these are emerging capabilities, and some of these are actually future anticipated capabilities that we hope will get developed. But we have not done a systematic evaluation of whether doing one or more of these actions would have actually resulted in preventing the collapse. So it's something we're putting out there so that these would provide options for folks to consider in terms of developing acceptable solutions. And of course we start off with more robust connections and framing systems-floor framing systems, in this particular case-to better resist the effects of thermal expansion on the structural system. As we said, we had simple connections in the interior, and we had irregular, or asymmetric, floor systems.

Second is structural systems expressly designed to prevent progressive collapse. The current model building code does not require that buildings be designed to resist progressive collapse. And, of course, designing a building to resist progressive collapse may involve a number of factors, or a number of ways of doing-providing redundancy to the structural system, but there are simpler ways of doing it, as well, such as introducing braces between columns.

Third is better insulation, or better fireproofing. Currently, insulation is used to protect the steel strength, but we could use it to maintain a lower temperature in the steel to limit thermal expansion. Automatic fire sprinkler systems with independent and reliable sources for the primary and secondary water supply. Improved compartmentation in areas to limit the spread of fires. And thermally resistant window assemblies which will limit breakage, reduce air supply, and therefore retard fire growth.

In terms of human performance, there were factors that contributed to the outcome of no loss of life on this building. The number of people in WTC 7 was much smaller than designed, and of course they were able to evacuate much quickly. We had about 4,000 people in the building. Normally, the building has about 8,000 people on an average day. Participation of the building occupants in recent fire drills. Shortness of delay in starting to evacuate. Evacuation assistance provided by emergency responders. And the decision not to continue reconnaissance of the building and not to fight the fires within, of course, led to saving further loss of firefighter lives on that day. There were also some factors that did not play a life safety role on 9/11 but could have been important had the fires been more widespread and the building damage more severe, or the building occupancy at full capacity. And that may have been-that includes the accuracy and reliability of communication among emergency responders and building occupants and the efficiency of the management of large-scale emergency incidents, keeping in mind that the Mayor's Office of Emergency Management, which was located in the building, became inoperable pretty quickly in the day, and that management system was lost. So at this point I'm going to move to our recommendations. Based on our findings, we have identified one new recommendation, and we are reiterating 12 recommendations from our investigation of the Towers. The urgency of these prior recommendations is significantly reinforced by their pertinence to the collapse of a tall building with a structural system that is in widespread use. And this is just showing you the grouping of the recommendations. There's one set of recommendations, one grouping that does not apply to this particular building is improved building evacuation. We have no recommendations that we are reasserting from this particular building. We have several recommendations related to improving building evacuation from our investigation of the Towers, including the need to have the capability for fully evacuating the buildings in an emergency, to make the stairwell enclosures a lot more robust, to have a separation between exits, stairwells, and to ensure that the signs and so forth are intuitive and understood so people can evacuate efficiently. Comparison-I think it's important to compare Building 7 with the Towers. I think first of all it's very important to note that WTC 7 was unlike the WTC Towers in many respects. It was a more typical office building, tall building in the design of its structural system. It was not struck by aircraft. The fires in WTC 7 were quite different from those in the Towers. In 7, we did not have thousands of gallons of jet fuel, setting large areas of any floor igniting-setting them on fire simultaneously. Instead, 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. And, of course, as I said before, these other buildings did not collapse due to differences in structural design while WTC 7 succumbed to its fires. The key premise behind our recommendations is that the partial or total collapse of a building due to fires is, first of all, an infrequent event. This is particularly true for buildings with a reliably operating active fire protection system such as an automatic fire sprinkler system. A properly designed and operating sprinkler system will contain the fires while they are small and, in most instances, prevent them from growing and spreading to threaten structural integrity. The intent of current practice, based on prescriptive standards and codes, is actually to achieve life safety, not collapse prevention. And in this particular case, as we've said, all of the lives were saved. There were no known fatalities. It is our key premise, though, that buildings, however, should not collapse in infrequent fires that may occur when active fire protection systems are rendered ineffective, i.e., when sprinklers do not function, are not-do not exist or are overwhelmed by the fire. And, of course, the manual suppression systems are not in force, either. Fire scenarios for structural design based on single-compartment or single-floor fires are not appropriate representations of these infrequent fire events. Such events occurred in several tall buildings, resulting in unexpected substantial loss. And I should point, again, reemphasize that single-compartment or single-floor fires are often used in fire protection engineering, but we feel that those are not appropriate representations, as if you look at photos from these recent fires, the First Interstate Bank in 1988 and the One Meridian Plaza in 1991, you will see that you have multiple-floor fires engulfing entire floors and are pretty significant. So what are the characteristics of these infrequent fire events for structural design based on historical data? And this is kind of-what we're trying to tell you is these are the features that you see in these other fires. One, these are ordinary combustibles and ordinary combustible load levels. There's local fire origin on any given floor. There's no widespread use of accelerants. That means you don't have arsonists using accelerants throughout the floor and so forth. There's consecutive fire spread from combustible to combustible on any given floor. The fire-induced window breakage provides ventilation for continuing the fire spread and accelerated fire growth. There's concurrent fires on multiple floors. And the active fire protection systems are rendered ineffective. And that is what we believe is an appropriate set of infrequent fires to consider in structural design. So I'll quickly flip through the prior recommendations as well as the new recommendation, with calling out the relevance to Building 7. The first recommendation was with progressive collapse should be prevented in buildings through the development and nationwide adoption of consensus standards and code provisions. And with regard to WTC 7, our statement is that had WTC 7 been expressly designed for prevention of fire-induced progressive collapse, it would have been sufficiently robust to withstand local failure due to the fires without suffering total collapse. One new recommendation is that buildings be explicitly evaluated to ensure the adequate performance of the structural system under worst-case design fires or infrequent design fires with any active fire protection system rendered ineffective. This is the kind of fire I just described. Of particular concern are the effects of thermal expansion in buildings with one or more of the following features. And these are the four or five features that are important to recognize that contributed to the collapse of World Trade Center 7: long-span floor systems, which experience significant thermal expansion and sagging; connection designs, especially shear connections, that cannot accommodate thermal effects; floor framing that induces asymmetrically induced forces on girders, or net lateral forces on girders due to the thermal effects; shear studs that could fail due to differential thermal expansion in composite floor systems; and the lack of shear studs on girders. We feel that careful consideration should also be given to the possibility of other design features that may adversely affect the fire performance of the structural system. The relevance to Building 7 is that the effects of restraint of free thermal expansion on steel framing systems, especially the long spans on the east side of WTC 7, were not considered in the structural design and led to the initiation of a building collapse. A little bit more on the details of this particular recommendation. Typical floor span length in tall office buildings is in the range of 40 to 50 feet. This range is considered to represent what we call long-span floor systems. Thermal effects-for example, thermal expansion-and, of course, thermal effects could include loss of strength, loss of stiffness, creep and so on, including 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. Building owners, operators and designers are strongly urged to act upon this recommendation. So that's one of our key messages today. We feel that engineers should be able to design cost-effective fixes to address any areas of concern identified by the evaluations using the existing, emerging or even anticipated future capabilities, and I gave you some examples a little bit earlier. We feel that industry should also partner with the research community to fill critical gaps in knowledge about how structures perform in fires, particularly considering the effects of fire on the entire structural system; the interactions between subsystems, elements, and connections; and the scaling of these fire test results to full-scale structures. Now, the next few recommendations are also focused on reiterating our prior recommendations. The first one is focused on the technical basis for determining the appropriate construction classification and fire rating requirements, especially for tall buildings, and making related code changes now as much as possible. And in the case of Building 7, the floor systems failed at shorter fire exposure times than the specified fire rating-two hours-and at lower temperatures, because thermal effects within the structural system, especially thermal expansion, were not considered in setting the fire rating requirements in the construction classification. And these are determined using the ASTM E119 and equivalent testing methods, or testing standard. The next one says that the technical basis for the century-old standard for fire resistance rating of components, assemblies and systems should be improved through a national effort. And a key step in fulfilling this recommendation is to establish the capability for studying and testing the components, assemblies and systems under realistic fire and load conditions. As far as relevance to 7 is concerned, it's almost identical to the statement I just read, so I won't repeat it. The structural breakdowns that led to the initiating event and the eventual collapse of this building occurred at temperatures that were hundreds of degrees below the criteria that determines structural fire resistance ratings. The United States currently does not have the capability for studying and testing these important fire-induced phenomena critical to structural integrity. The next recommendation has to do with the structural frame approach to fire resistance ratings. And we feel that the definition of the primary structural frame should be expanded to include bracing members that are essential to the vertical stability of the primary structural frame under gravity loading-for example, girders, diagonal bracing, composite floor systems that provide lateral bracing to the girders-whether or not the bracing members carry gravity loads. (Note 1:49:51) So with regard to Building 7, thermally induced breakdown of the floor system was the determining step in causing collapse initiation and progression. Therefore, the floor system should be considered an integral part of the primary structural frame. There already have been some improvements to the definition of the primary structural frame in the building code through the 2007 edition, but we are going one step further to say that even the floor system is an integral part of the primary structural frame. The next one deals with the fire resistance of structures, that the fire resistance of structures be enhanced by requiring a performance objective that uncontrolled building fires result in burnout without partial or total collapse. Current methods for determining the fire resistance rating of structural assemblies do not explicitly specify a performance objective. With regard to Building 7, we found that large, uncontrolled fires led to failure of a critical column and consequently the collapse of the building. In the region of initiation, collapse initiation, on the east side of Floor 13, the fire had consumed virtually all of the combustible building contents, yet collapse was not prevented. So had this performance objective been in place that we would prevent collapse without-achieve burnout without collapse, we might have not had the collapse on 9/11. We also are very strongly behind a recommendation to develop performance-based standards and codes as an alternative to current prescriptive design methods, to enable the design and retrofit of structures to resist fires. And we feel that a performance-based assessment of the effects of fire on Building 7, had it considered all of the relevant thermal effects, including thermal expansion, which occurs at lower temperatures, would have identified the vulnerability of the building to fire-induced collapse and allowed alternative designs for the structural system. With regard to the active fire protection systems, we believe that the performance and the redundancy should be enhanced to accommodate the greater risks associated with building height and population. And specifically, with regard to this particular building, no water was available, as I said, for the automatic suppression system on the lower 20 stories of Building 7 once the water-street-level mains were disrupted. This lack of reliability in the source of the primary and secondary water supply allowed the growth and spread of fires that ultimately resulted in the collapse of the building. So, as we have said, you need reliability of the water supply, and it's important that among them we have redundancy in the water supply, as well. The next recommendation deals with improved emergency response, and we feel that we need to ensure effective and uninterrupted operation of the command and control system for large-scale building emergencies. And, of course, with regard to Building 7, we had the Mayor's Office of Emergency Management in this building, and where the robust interagency command and control system was not available on 9/11 because of the conditions in Building 7. And there's also the finding that the site leadership changed during the day, primarily because we had a lot of loss of firefighter fatalities and fire service facilities with the collapse of the Towers. The next one deals with retention of documents by building owners. And with regard to Building 7, I should point out that the efforts that were required in locating and acquiring drawings, specifications, tenant layouts, material certifications, and, especially, shop fabrication drawings, significantly lengthened the investigation into the collapse of this particular building. With regard to the role of the "design professional in responsible charge," that needs to be clarified. As I said before, following typical practice, none of the design professionals in charge of WTC 7 was assigned the responsibility to explicitly evaluate the fire performance of the structural system. And that is something that needs to happen as we go forward. And, finally, with regard to education and training, there's a lot of information that needs to be developed, and the next two recommendations deal with that. First of all, the fire-structure interactions that led to the collapse of Building 7 required research professionals with expertise in both disciplines, and that's fire protection engineers, or fire science and engineering, and structural engineering. Assuring the safety of future buildings will require that participants in the design and review process possess a combined knowledge of fire science, materials science, heat transfer and structural engineering and design. Also, with regard to the state-of-the-art computational tools, we stretched the state of the art in the kind of tools we used in the analysis of the collapse of Building 7. And, of course, making these expanded tools and derivative, validated and simplified modeling approaches for use by practitioners could help in preventing future disasters, and that was the focus of our ongoing research going forward. But that is research that needs to happen in partnership with industry. We believe our recommendations are realistic, appropriate, and achievable. These need to be given, we believe, immediate and serious consideration by the building and fire safety communities. And implementation of these recommendations will achieve improvements in-appropriate improvements in the way buildings are designed, constructed, maintained and operated, with the goal of making buildings safer in future emergencies. We have assigned top priority to work with the building and fire safety communities, particularly the codes organizations and the standards organizations, to translate our recommendations into practice. And the first comprehensive set of model building code changes have been adopted in the International Building Code last year, and several others are being considered as we speak in the next code cycle. Our recommendations are also having an impact on the construction of iconic high-rise buildings worldwide, including some of the reconstruction going on on Ground Zero. And so at this point I'd like to conclude by saying that we welcome comments from the public on the draft investigation reports. These were draft reports that were issued on August 21, last Thursday. We had a total of about 1,000 pages, although a summary report is about 75 pages long.

And we will consider all of the comments that we receive from the public before they are issued in final form. In order for comments to be considered by us, they have to be very specific. There has to be a short reason for any suggested change, language in terms of what change is requested, and, of course, we need specific citation as to where in the-which report and where in the report we are talking about. So that-instructions for all of that is available on our Web site and in the slide that you'll see in front of you right now. We will accept comments through 12 noon Monday, September 15, 2008. And comments may be submitted through a link on the WTC Investigation Web site, via email to wtc@nist.gov, by fax or by mail. And you have the address, mailing address, provided in the slide and also on the Web site. And, finally, I want to simply say that we will continue to vigorously promote implementation of our recommendations from our investigation of both the Towers and Building 7 and provide necessary technical support to standards and codes organizations as they consider our recommendations. Thank you very much. I'd be happy to take more questions.

Male Speaker: Let me first come back to Jake Pauls' question that we deferred in the earlier session. "Did NIST use interviews with occupants to learn what they saw of the damage to WTC 7 when the Towers fell, when and how they evacuated from WTC 7? And if you did not seek such information, why not?" Shyam Sunder: Well, the most important situation that we looked at in terms of evacuation was really the WTC Towers 1 and 2. That's a building in which we lost over 2,000 people on 9/11. And evacuation was time critical. We had 56 minutes in Building-Tower 2, and we had 102 minutes in Tower 1. And it was very crucial-it was critical for us to find out in the constrained time what could have been done to improve evacuation in that particular case. So it was a great priority for us to study evacuation in that-in those buildings. And we did that through more than 1,000 interviews, which included 800 interviews that were done in a statistically robust fashion and then the remaining 200 or so interviews that were done on a face-to-face basis to generate valuable information as to what really happened on 9/11. And that has actually helped us formulate our findings and therefore come up with robust recommendations for building evacuation. With regard to Building 7, while it was important for us to-first of all, there was no loss of life. The buildings themselves stood for seven hours. Evacuation was completed in less than one hour, before the Towers began collapsing. And so none of the obvious concerns that we had with regard to learning lessons, or learning-developing findings and so forth, which were very significant in the case of Towers, really applied to Building 7 in any significant fashion. And so we did not do such an extensive analysis of the evacuation in Building 7. But some of the interviews that we did with occupants did touch on Building 7, and some of the interviews that we did with first responders, or emergency responders, also touched on the evacuation in Building 7. So we did get sufficient information to be able to document the successful evacuation of Building 7 on 9/11. If Dick Gann has any additional comments to add, I would defer to him.

Dick Gann: Note Note 376 2:02:30 Recall that virtually the entire population of the building that morning was out of the building before the Towers collapsed. So people used the elevators. They were in perfectly good working order. The paths that they took to the elevators or through the stairwells were at that point undamaged. So the evacuating people didn't have very much to say about damage to the building that occurred later in the day. We did talk with the people who either were-did stay in the building or who went back into the building later and were able to get a limited amount of information on interior damage.

Male Speaker: Okay. This next question is from Lorie van Auken, of the September 11 Advocates. "Why did the occupants of WTC 7 get evacuated on 9/11 while the occupants of WTC 2 were told to stay or to go back to their desks?" Shyam Sunder: Thank you very much for that question, and of course I can appreciate very much that that's an important question, and we did our very best to thoroughly investigate those questions when we released our report of the Towers. And as our findings from the Towers indicated, that the overall evacuation of the people below the floors of impact was quite successful. Most of the loss of life in Building 1 was focused-was, in fact, concentrated on people who were above the floors of impact, who had no way of coming down through the damaged impacted region, the fire region, because the stairwells had all been closed off after the airplane impact and the fires. With regard to Building 2, we found that the most important thing is in those 16 minutes before Building 2 was hit but after Building 1 was hit, roughly 3,000 people self-evacuated, even though their building had not been hit and they had not been given an instruction to evacuate yet. They used elevators that were still functioning during those 16 minutes to evacuate the building. So the loss of life above the floors of impact after Tower 2 was hit was substantially smaller, I would say almost half what was the case, or a little bit less. And the exact numbers are all documented in our reports, and it's been a while, so I don't have them right off the top of my head. But, so they were-so the number of people above the floors of impact in Tower 2 was less than half those in Tower 1 who lost their lives on 9/11. In this particular building, Tower 2, at least one of the stairs of the three was marginally passable for a while, and about, I believe, 16 or 18 people were actually-were able to find that particular stairwell and were able to make their way down and eventually survive or evacuate the building. We did document the problems or the issues with regard to conflicting advice that was provided to evacuate or not evacuate in the Towers, and we also sourced the-where those conflicting pieces of information came about. And there was differences between the guidance being provided by the folks who were calling the fire department control center and the instructions being provided, or guidance being provided, by the local emergency responders from the Port Authority in the building. It is also important to note that the standard practice in fires is to defend in place in tall buildings. So the normal instructions would be you stay put in the floors where you are supposed to be until somebody can come and get you. And, of course, 9/11 had many things that were not related to standard fires, and, as we have indicated, the training both in terms of fire service operations and in terms of the communications and command and control were not sufficient for an emergency of the scale that we saw on 9/11, and that was one of our recommendations for improvements in the future. Anybody else wants to add any comments to that? Okay.

Male Speaker: Let me come back to James Gourley's question from earlier in the briefing. His question was, "Did NIST test any WTC 7 debris for explosives or incendiary chemical residues?" Shyam Sunder: Well, with regard to alternative hypotheses, I think I need to point out very clearly that when we started the investigation we considered a whole range of possible hypotheses. And from that, based on our technical judgment, we decided what were credible hypotheses that we should pursue further. Among them, of course, was the fuel oil fire, diesel fuel fire, the transfer girders, the role of the transfer girders, and, of course, the most obvious, which is the normal building fires, or the building fires, conventional building fires or the fires that we talked about this morning. In addition to that, because of the concern expressed by several people about blasts and blast-oriented sounds, we decided to include that as a hypothetical scenario to also evaluate. We judged that other hypotheses that were-possible hypotheses that were suggested really didn't-were not credible enough to justify a careful investigation. With regard to the issue of the residue,(Note 195) there is reference often made to a piece of steel from Building 7 that is documented in the earlier FEMA report that deals with some kind of a residue that was found, sulfur-oriented residue. And in fact that was found by a professor who was then at the Worcester Polytechnic Institute, Professor Jonathan Barnett. But that piece of steel has been subsequently analyzed by Professor Barnett and by Professor Rick Sisson, who is also from the Worcester Polytechnic Institute, and they reported in a BBC interview that aired on July 6 that there was no evidence that any of the residue in that steel-in that piece of steel had any relationship to an undue fire event in the building or any other kind of incendiary device in the building.

Male Speaker: The next question comes from Dr. Steven Jones. "Did NIST have available to it samples of dust from the WTC catastrophe? And if so, did NIST examine the dust for red or gray chips?" Shyam Sunder: (2:10:35 Note 255) As I said just a moment ago, we went through a pretty rigorous screening process to figure out which were the credible hypotheses that we would pursue and how we went about pursuing them, and we did not believe that the possible hypothesis that you just mentioned fell into the realm of a credible hypothesis. And, of course, with any of these alternative theories that we did not consider, the most important factor was none of them had a coherent theory as to what actually happened on 9/11. They are just isolated anecdotes, pieces of information, that really don't stand together in some kind of a meaningful fashion.

Male Speaker: The next question comes, again, from Lorie van Auken, of the September 11 Advocates. The question is, "If building materials typically supply fuel to a fire for 20 minutes, and insulation used on the columns, including Column 79, lasts for two to three hours, how did Column 79 fail? What fueled the fire for that long?" Shyam Sunder: That's a good question. And of course keep in mind that the-20 to 30 minutes is the time it takes for a combustible in a particular location to start igniting and then complete the process of completely burning out. But that combustible may be a table. It may be a filing cabinet. It may be a computer workstation. It can be furniture, chairs, and so on. So this is not as though the entire space is all burning concurrently. It is each combustible burns for 20 to 30 minutes. And of course when you look at Column 79 and the 2,000 square feet of floor area around Column 79, you can have fires moving from combustible to combustible in that vicinity for a long time. So it moves around, and, as you saw the simulation show it, it does take a long time. It's just that each combustible takes 20 to 30 minutes to burn, not the entire floor. The other thing to keep in mind is that when you have the full combustible burning, temperatures can actually go to much higher temperatures in the steel. And, of course, the phenomenon that we saw on 9/11 that brought this particular building down was really thermal expansion, which occurs at lower temperatures. So we had lower-you had lower temperatures, gas that was still coming, that was heating up, so you had temperatures rising even before the combustibles started burning a lot in a location. And once the combustibles are already burned, the room doesn't go to room temperature instantaneously. It takes a long time for the heat and the temperature to actually dissipate. So there's a lot of heat that's in the room, and the 20 to 30 minutes is just for each combustible.

Male Speaker: The next question comes from Mindy Kleinberg, also of the September 11 Advocates. "If Column 79 collapsed and then 80 and 81, all of which are on the same side, why wasn't the collapse asymmetrical?"

Shyam Sunder: Well, keep in mind that what you-the only view you had of the building, video view you had that was any clear and visible where you could actually make out what was happening were from the north of the building. So what was happening behind the north fa?ade was not visible to you-to anyone from the north view. And what you would see happening is that when Columns 79, 80 and 81 collapsed in sequence, that you would have internal failures that were asymmetrical, internal to the building, which would not be visible from outside the building. And then when you had the progression of failures from east to west, you again would have a progression internal to the building. Keep in mind that the interior of the building had columns that were-had the connections that were not moment-resisting. They were simple connections. These columns were kind of what they are called leaning columns or standalone columns, where the floor is kind of holding them in place. The exterior wall, on the other hand, was a moment-resisting frame. So it's a much more stable structure, and it's not going to fail easily. So when you see what you see from the outside, it really is the exterior of the building, which you don't see anything happening. But if you look through the videos very carefully, and we have done them in many, many-for over many, many hours, you do see hollowing out of materials behind the windows. You see air gaps show up and so forth as the collapse starts to start from the north-from the top to the bottom.

Male Speaker: The next question is also from Mindy Kleinberg, and that is, "What exactly was the fire protection engineer's job description if not to evaluate the fire performance of the structural system?"
Shyam Sunder: Well, it turns out that in normal building practice the architect is the primary person who is in charge of-there are two kinds of architects, but the main job of the architects is to design the building in terms of how it looks and how the spaces fit together and what the functionality of the different spaces are and so forth. But it's also the architect's job to specify fireproofing. Every project-any significant project has an architect, and it's that individual's stamp or signature on the drawings that

really prescribes what the fireproofing will be in the building. Now, the job of the structural engineer is really to design the structural skeleton that supports what the architect wants to do in terms of the spaces in that building. And it's a skeleton that the structural engineer designs. And, of course, he is designing it under gravity, wind, earthquakes and other-snow loads and so on, but not due to fire. It turns out that you can actually have a building being designed without a fire protection engineer. But fire protection engineers are really brought in most often for the active fire protection systems in a building. So they would be involved in any major building-I'm talking about simple buildings where they may not be involved, but in a major building they'll be involved in installing the fire alarms, the sprinkler systems, the standpipes, the hoses, the communication systems that will be required for fire department to communicate within the building or for the building operators, building owners and the fire safety directors in a building to communicate with occupants in the building. So that would be the primary job of a fire protection engineer. They also sometimes can guide architects in the way you should partition floors and the way you can have compartmentation on the floors to prevent spread of fire from location to location. But very rarely are they called in, in current practice, to actually specify a fireproofing.

Male Speaker: The next question is a follow-up question from Jake Pauls, of Jake Pauls Consulting Services. His question is, following up on his earlier question about occupant evacuation, and using the term "occupants" broadly to include emergency responders, "What interior direct observation reports of WTC 7 damage were available for your analysis for the post-Tower collapse period, and where in WTC 7 were those interior observations made?"

Shyam Sunder: Terry, do you want to take that? Therese McAllister: (Note 377, 2:29:10) We interviewed a number of emergency responders that were in and around WTC 7 after the collapse of the Towers. They generally were walking up and down the building on the lower floors up to about Floor 10. And they did report the conditions that they saw from walking around the core and the floor areas on the lower floors. And we did use that information as part of our assessment of the interior damage.

Male Speaker: Okay, the next question is also from Lorie van Auken, and this is a follow-up question, or follow-up comment. "Why didn't the-or why did the occupants of WTC 7 get a different set of instructions from the occupants in World Trade Center 2?" Shyam Sunder: I'm not sure I said that explicitly, that they got a different set of instructions. I think what we said in our findings, if you go back to some of the slides I presented-let me see if I can find it-but the basic thing is that the-let me-one second-give me a second here. We actually said evacuation management at every level did not provide timely evacuation instructions to building occupants during the event. That is in Building 7. So we are not saying that they gave proper guidance or timely guidance. What is important is that people just evacuated Building-there was a lot of self-once the Tower 1 had been hit, many of the people in the other buildings started self-evacuating, recognizing that something serious had happened. And so they really didn't wait a whole lot for people to instruct them. And that really was the example I gave you of 3,000 people

who evacuated in Tower 2 before that building was struck by airplanes, by an airplane. And the same is true for Building 7. People decided to evacuate once they knew-they heard about the fact that Building 1 had been hit by an airplane.

Male Speaker: And the next question is from Lorie van Auken. Note 403, 2:19:50 "Did NIST interview Larry Silverstein to find out why he said, 'There was so much loss of life we decided to pull it,' regarding WTC 7?" Shyam Sunder: No, we did not interview Larry Silverstein. (Note 404, 2:22:05) And let me kind of explain why we do that-why we did not do that. We are a technical scientific investigation. So what we place the most importance on, credence on, are the scientific facts, to the extent that we can get them. And of course what helps us most in this complex reconstruction are the things I just mentioned this morning. One is, we want to get documents, documentary evidence-that is, plans, specifications, structural plans, architectural plans, connection-framing-detailed fabrication drawings and so on. We then look for visual information-again, information from photographs and videos that actually tell us what actually happened on 9/11. We then try and go in depth and talk to people who actually were in charge of emergency response on the site. And we go and talk to people who may-in the case of the Towers, who were actually occupants of the building. So, again, we do that not by just anecdotal conversation. We actually do it in a very structured format, where the information we obtain from that analysis can be useful to make robust findings and then conclusions and recommendations. So that's how we approached this investigation. What people say, what they said on TV, why they say it, when they say it, for us is really the least important from the point of view of trying to carry out a scientific investigation. I will point out that the term "pull it" is an expression that is often used in the fire service community when you decide not to do any further work in a building which is subjected to an emergency. So it's not an unusual term. But, again, what was said doesn't really matter. What happened really matters. And we have the science behind our findings and recommendations, and that's important.

Male Speaker: This next question comes from Dr. Steven Jones. "NIST discusses the fall time for WTC 7 on page 40 of the summary report, where it's stated, 'assuming that the descent speed was approximately constant.' However, observations by others of the descent speed show that the building is accelerating rather than being at constant speed. So the question is, why did NIST assume that the descent speed was approximately constant?"

Shyam Sunder: Well, the-I'm going to have John Gross answer that question as soon as he is ready. But the most important thing is this was a gravitational force, so gravitation is a force of acceleration. So I will have John clarify what he said.

John Gross: Yes, the force of gravity obviously is-the acceleration of gravity is what's at-the driving force, and our calculation was based on the amount of time from the top of the parapet to fall till it disappeared from view between the two buildings seen in the video. That time was established from the video by a single-frame search of the time, so that was down to 1/30th of a second. And then we did the same thing for when the top of the parapet disappeared. We found that time to be 5.4 seconds. Shyam Sunder: So, Steve, can you repeat that question? What is it that is being asked here?

Male Speaker: The question was, "Why did we report descent speed rather than acceleration?" The statement in the report has to do with assuming that the descent speed is constant. John Gross: Well, the descent speed is not constant. Obviously, it goes from zero at the initial to a later speed. We didn't-we computed the time that it takes to drop the roughly 18 stories that were in view. And we also provided the calculation based on the distance from the top of the parapet to the lowest point visible to compare that with the free-fall speed.

Shyam Sunder: So I guess is there a sentence there that [inaudible]? What does the sentence mean?

Fahim, can you clarify that?

Fahim Sadek: I think it's something that we need to clarify and correct in the final version of the report.

Shyam Sunder: Okay. Thank you for pointing that out to us, because that probably needs fixing.

Male Speaker: And the next question is again from Lorie van Auken. "Many people who were near WTC 7 on 9/11 did hear explosions. Some even heard a countdown on police radio. Did you speak with these people?"

Shyam Sunder: (2:27:50) No, we did not speak with those people, again for the same reason I just mentioned, so I won't repeat the whole argument, which is that the science speaks for itself and it's pretty robust. (Note 436, 2:28:00) Now, with regard-I do have some comments with regard to sounds that relate to booms or explosive sounds and so forth. There are many things that can cause sounds in a building, particularly in a situation that we were on 9/11. We can have pieces of the building facade collapse, fail. We can have interior connections because of fire damage and cause a sound that is pretty sudden in nature, which may sound like an explosion, and so forth. And of course there are heavy mechanical equipment, as we heard about diesel generators and fuel tanks and so forth on these different floors, and they can, of course, have a partial settlement, collapse and so forth that can cause sounds that appear to sound like explosions. It is important to note that if any one of those people who were in the building when they heard explosive sounds, it's likely that they would not have survived if in fact it was an explosion that actually brought the building down, because if in fact it was an explosion that brought the building down, the entire building would come down on them, and they wouldn't be survived to really tell the tale that they did on 9/11. So clearly the sounds they heard, the fact that they were able to escape, and then later on report on the sounds they heard suggests that they were events, but they were not the ones that actually brought the building down at 5:20 that afternoon. We have exactly 15 seconds left. And I think based on the fact we have now 10 seconds left, that will be all the questions we can really take for this morning. I really appreciate all of you for participating. NIST wants you to know that the public comment period is open through the 15th of September at noon, so, again, you can submit that. The instructions are available on our Web site. Thank you very much.