Comments on the Draft Report NIST NCSTAR 1-9: "*Structural Fire Response and Probable Collapse Sequence of World Trade Center Building 7*", issued by NIST August 21st, 2008

(Revised and Extended Version of Comments Issued September 11th 2008)

By

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1.0 Introduction

A preliminary (draft) version of NIST's final report on the collapse of WTC 7 was issued on August 21st 2008 together with a call by NIST's Investigation Team for the submission of comments on the Draft Report from interested parties within the general public. First I wish to thank NIST for producing such a detailed technical report on the collapse of WTC 7 and secondly, I applaud NIST for allowing researchers from around the world to offer technical feedback that hopefully will be duly considered by NIST before a final version of the report is issued.

In reading the Draft WTC 7 Report a number of issues emerge that are crucial to the credibility of NIST's proposal as to how and why building 7 collapsed on September 11th, 2001. These key issues center on the narrative surrounding the ignition of the fires in WTC 7 and the spreading of these fires within the building prior to its collapse. The accuracy of NIST's account of what transpired within the confines of building 7 during 9/11, is vital to NIST's entire WTC 7 Report because it provides the basis for the computer modeling/simulation of the heating of structural elements on the fire-affected floors, which in turn, leads to NIST's proposed collapse initiation and propagation mechanism.

In the following comments I will attempt to address each of the key topics - fire ignition and spreading, fire intensities and durations, structural heating, collapse initiation and propagation, – and in so doing, highlight my concerns or objections to NIST's position on these topics as presented in its Draft WTC 7 Report.

2.0 The Ignition and Spreading of the Fires in WTC 7

In Chapter 9 of NIST NCSTAR 1-9 we encounter one of the most significant problems with attempts to unravel the mystery of why and how WTC 7 collapsed late in the afternoon of September 11th, 2001 – the question of where and how fires started in building 7. On page 376 of NCSTAR 1-9 we read:

"*… the ignition and early course of the fires (in WTC 7) were unknown because they were presumed to have occurred in the damaged and heavily smoke-shrouded southern portion of the building.*"

NIST's knowledge of the fires in WTC 7 is therefore based on images of the *exterior faces* of the buildings. Unfortunately however, as acknowledged by NIST, most of the burning of combustible materials at the WTC on 9/11 took place beyond the views available through exterior windows well *inside* the buildings.

NIST propose, and it appears to be a reasonable assumption, that the fires in WTC 7 started near the south face as a result of the collapse of WTC 1 at about 10:29 on the morning of 9/11. However, even this assumption is problematical because fires on the crucial 12^{th} and 13^{th} floors of WTC 7 were not in fact observed until after 2:00 p.m., and then only on the *east* face of the building.

Faced with the problem of modeling the spreading of the fires in WTC 7, NIST begins its computer simulation with a set of 2 MW fires, presumably one per floor, for floors 7, 8, 9, 11, 12 and 13. These hypothetical fires are stated to be "*roughly equivalent to small, single workstation fires*", but NIST is quite vague about *where* these fires were located other than "*near the southern face of the building*". What is more, for the fire to spread to NIST's satisfaction on floor 8, *two* fires were hypothesized to start at this level within the building.

Unfortunately NIST's fire simulation strategy is just as arbitrary for the modeling of the fires on other floors. Thus on page 382 of NCSTAR 1-9 we read that the fire on floor was modeled using the floor 12 fire delayed by 1 hour and the floor 13 fire was modeled using the floor 12 fire delayed by 1/2 an hour.

Other aspects of NIST's simulation of the fires on floors 11 - 13 appear to be quite unphysical. Thus the fire on floor 12 was prescribed to start "*near the center of the south face at an assigned time of 12:00 noon*." This is a strange choice of ignition time given that the WTC 7 fires were supposedly started by flaming debris from the collapse of WTC 1 at 10:29 a.m. It implies that some of the flaming material in the WTC 1 debris that settled near WTC 7 remained dormant for about an hour and a half before spontaneously igniting fires that were subsequently observed on floor 12.

3.0 Fire Intensities and Durations

The way the fires spread in WTC 7 during 9/11 was largely determined by the distribution of combustible materials throughout the building. In NIST's fire simulations this distribution was approximated by an average fuel load for each fire-affected floor of 20 - 32 kg/m^2 or 4.0 and 6.4 lb/ft^2, (See NIST NCSTAR 1-9 pages 59 – 60). As shown in Figures 10-15 and 10-16 of NCSTAR 1-9, this fuel loading is calculated by NIST to have been sufficient to sustain temperatures

above 400 °C for the floor beams and concrete slab on the east side of floors 12 and 13 for about 2 hours. According to NIST's fire simulations, floors 12 and 13 were the most severely heated floors in WTC 7; however, there are reasons to question the level of heating claimed by NIST.

Figure 9-13 in NIST's *Fire Simulation* chapter of NCSTAR 1-9 would have us believe that a very substantial heat release rate of 200 MW was sustained on floor 12 of WTC 7 for over 2 hours, starting at about 3:00 p.m. on 9/11. Figure 9-11 further indicates that fully developed fires were present over an area estimated to be about 750 m^2 on floor 12 between 3:00 p.m. and 5:00 p.m. But we need to ask: Is a 200 MW fire consistent with a fuel loading of 32 kg/m^2 - the value used by NIST for its floor 12 fire simulations? The answer appears to be no. Thus a 200 MW heat release rate for 2 hours implies a total energy release of 1,440 GJ. If the combustible material on the 12^{th} floor of WTC 7 is assumed to release 20 MJ/kg, we have to conclude that 72,000 kg of office material was combusted over an area of 750 m^2, or there was a fuel loading in WTC 7 of 96 kg/m^2 – a value *three times* NIST's assumed fuel loading.

That there is a problem with NIST's predicted fire intensities in WTC 7 compared to the assumed fuel loading is supported by comparisons to other studies of fires in steel framed buildings. For example, the well-known Cardington tests conducted in the U.K. in 1999 measured a maximum heat flux of about 200 kW/m^2 over a period of about 1 hour from the combustion of 6000 kg of cellulose-based fuel inside a 144 m^2 steel framed structure, giving a fuel loading of 42 kg/m^2. Thus we see that in the Cardington tests the total energy release is predicted to be 144 x 200 kW for one hour which equals 28.8 MW for 3600 seconds or 104 GJ. The heat of combustion of the fuel was 17 MJ/kg, so for 6000 kg we would expect a heat release of 102 GJ in good agreement with the predicted energy release.

The main problem with the NIST fire simulation appears to be the calculated *duration* of the fire on the 12^{th} and 13^{th} floors of WTC 7. For example, if we assume a more reasonable fire duration of 40 minutes, rather than NIST's excessive 2 hours, we may revise the energy release down from 1,440 GJ to a mere 480 GJ in which case the combustion of 20 MJ/kg fuel would have consumed 24,000 kg of material and the fuel loading would have been 32 kg/m^2 in agreement with NIST's assumed fuel load. That these are more realistic figures is also supported by some of NIST's own studies of the relationship between combustible loads in buildings and classifications of fire severity. Thus M G. Goode in NIST Report No. GCR-04-872, published in July 2004, provided a table showing that fire durations of 0.5 and 0.75 hours are to be expected for fuel loads of 20 kg/m^2 and 30 kg/m^2, respectively.

4.0 Structural Heating

In view of the fact that NIST appears to have overestimated the intensity and duration of the fires in WTC 7, particularly on floor 12, it follows that the heating of the structural steel is also overestimated in the WTC 7 *Draft Report*. This is fatal to the overall validity of NIST's collapse initiation hypothesis because NIST's hypothesis is predicated on the thermal expansion of long span beams and girders on floors 12/13 and their eventual loss of connectivity with column 79, (See Chapter 8 of NCSTAR 1-9).

NIST's computer simulation of the thermal response of floors 12/13 is described in Chapter 10 of NCSTAR 1-9 and estimates temperatures as high as 675 °C "*on much of the east side and the east portion of the south side of* (floor 12)". NIST also concludes that the temperatures of floor beams and girders on floors 12/13 were 600 °C or higher for 1 - 2 hours.

The temperature vs. time profile of a structural steel member exposed to a fire and protected by a layer of insulation of thickness d_i is given by the formula:

$$\Delta T_s / \Delta t = [k_i / (d_i c_s \rho_s)] (A_p / V) (T_g - T_s)$$

where,

$\Delta T_s / \Delta t$ is the rate of change of the temperature of the steel

k_i is the thermal conductivity of the insulation material

c_s is the heat capacity of the steel

ρ_s is the density of the steel

A_p / V is the section factor of the steel member

$T_g - T_s$ is the temperature difference between the steel and the combustion gases

Values for the quantities k_i , d_i , c_s , ρ_s and A_p / V appropriate for calculations of the heating of structural members in WTC 7 are as follows:

$k_i = 0.12$ W/m.°C (Monokote MK-5)

$d_i = 0.015$ m

$c_s = 660$ J/kg.°C

$\rho_s = 7800$ kg/m^3

$A_p / V = 100$ m^{-1} (W33x130 girder)

In order to use this formula to determine the temperature vs. time profile of a structural steel member in WTC 7 we need to estimate an upper layer gas temperature on the critical floors 11 - 13. However, as shown in Section 3.0 above, the duration and intensity of the fires on floor 12 of WTC 7 discussed by NIST in Chapter 10 of NCSTAR 1-9, appear to be inconsistent with the fuel loads used in NIST's simulations. It is also important to note that the floor heating simulations shown in Figures 10-13, 10-15 and 10-17 of NCSTAR 1-9 are inconsistent with the upper layer temperatures shown in Figure 9-11. Thus Figure 9-11 shows well-developed fires were present along the entire north and east walls of floor 12 between 3:00 and 5:00 p.m. during 9/11. By comparison the computed concrete slab temperatures on floors 11 – 13 show *no significant heating anywhere near the north face of building 7* throughout this time period.

However, based on data from A. Jowsey's thesis: *Fire Imposed Heat Fluxes for Structural Analysis*, (Edinburgh 2006), an upper layer gas temperature of 800 °C sustained for 40 minutes would appear to provide a realistic description of the fires at the east side of floors 12 and 13 prior to the collapse of WTC 7. This leads to a predicted heating rate of 7.46 °C/min and a maximum temperature for the floor framing beams and girders near the critical column 79 of about 300 °C, or barely *half* the temperatures estimated for these structural members in the NIST WTC 7 Draft Report.

5.0 Collapse Initiation and Propagation

NIST's computer simulation of the collapse of WTC 7, as presented in chapters 8 and 12 of NCSTAR 1-9, is remarkable for the low temperatures - as low as 100 °C – at which failures of connecting elements such as bolts and studs are predicted to have first occurred in WTC 7 after about 3:00 p.m. on 9/11. These failures were caused, so NIST asserts, by the thermal expansion of asymmetrical framing beams and girders on the east side of floors 12/13. Nevertheless, in NIST's model complete separation of column 79 from lateral restraints to buckling is predicted to occur only at temperatures well above 300 °C. Thus NIST's collapse initiation hypothesis *requires* that structural steel temperatures on floors 12/13 significantly exceeded 300 °C - a condition that could never have been realized with NIST's postulated 32 kg/m^2 fuel loading.

However, assume for a moment that collapse initiation in WTC 7 did in fact occur as NIST states: by a thermally induced buckling failure of column 79 on floors 12/13. It would then be appropriate to ask: Is the collapse propagation mechanism proposed by NIST consistent with the *observed* collapse of WTC 7? If the answer to this question is "Yes", it would add credibility to NIST's account of what happened to building 7 on 9/11 even if an inappropriate fuel loading was used to arrive at this conclusion. However, I would suggest that NIST's account of the last ½ minute of the life of WTC 7 not only lacks crucial physical detail, but is also at odds with what was observed in the collapse videos of WTC 7.

In NIST's WTC 7 collapse simulation the fires in the lower part of the building severely heated floors 12 and 13 near column 79 causing it to lose lateral support and buckle. Then, according to NIST, the entire section of column 79 above floor 14 began to descend and trigger a global "disproportionate" collapse of WTC 7. In NCSTAR 1-9, Chapter 12, page 57, it is claimed that the top of column 79 was moving downward within 0.2 seconds of its buckling between floor 5 and 14.

Let's consider this alleged motion of column 79 in more detail. Figure 12-43 in Chapter 12 of NCSTAR 1-9 shows column 79 buckling between floors 5 and 14 starting about 14.9 seconds into NIST's collapse initiation simulation. The lateral displacement of column 79 is shown to be about 5.5 meters to the east of its normal fully vertical position at 15.5 seconds into the simulation. A consideration of the geometry of a column buckling over a length of about 36 meters shows that a lateral displacement of 5.5 meters should lower the top of the column by about 0.8 meters. In the same collapse simulation timeframe, (14.9 – 15.5 seconds), NIST shows in Figure 12-45 that the vertical displacement of column 79 at the roof level was in fact 0.83 meters in 0.6 seconds. This implies that within 1 second of buckling column 79 was moving downwards with an acceleration of 4.6 m/s^2 or about ½ g which is a very dramatic motion for a column that was restrained by several framing beams and girders on all the undamaged and unheated floors above floor 14 just moments before collapse initiation. I would therefore ask NIST to explain how and why all lateral supports acting on column 79 from more than 30 upper floors, were simply ripped out or otherwise detached from their very secure connections in only 0.2 seconds?

To conclude this section I would like to comment on NIST's computer simulation of the final global collapse of WTC 7. Of course we are all very familiar with what actually transpired during the final moments in the life of WTC 7 because of the numerous videos of this dramatic event, as discussed in Chapter 5 of NCSTAR 1-9. These videos typically present an unobstructed view of at least the upper third of Building 7 and permit the collapse to be followed for 4 - 5 seconds. The videos show the upper section of WTC 7 descending very smoothly as an intact structure, with the roofline remaining essentially horizontal until it passes behind buildings in the foreground. The only significant distortion of the boxed-shaped Building 7 that is noticeable after the façade begins its downward motion is the formation of a kink on the eastern side of the north face - a kink that becomes more pronounced as the collapse proceeds.

NIST's measurement of the rate of descent of the roofline of WTC 7 shows a more or less constant acceleration of about 7 m/s^2 for the first 4 seconds of the collapse. This means that WTC 7 was falling at a speed of more that 15 m/s just 2 seconds into its collapse and had dropped over 50 meters (equivalent to about 12 stories) within 3.5 seconds. Nevertheless, as discussed above, the upper 12 stories showed very little evidence of trauma during this period of time apart from trails of smoke streaming from some broken windows as the building fell.

Now consider NIST's description of the final moments of WTC 7 as exemplified by the computer-generated simulacra of NCSTAR 1-9 and 1-9A. Computer images of the final collapse of WTC 7, such as Figure 12-69 of NCSTAR 1-9 and Figures 4-46 and E-4 of NCSTAR 1-9A, show very extensive buckling of the exterior columns over much of the building a few seconds into the collapse. While there may be some questions regarding the scaling of the maximum deflections shown in Figure 12-69, Figures 4-46 and E-4 use lateral and vertical displacement contours that span 2 meters, a level of building distortion that should have been visible in the WTC 7 collapse videos, but was in fact not seen. And consider also Figures 4-53 and 4-54 of NCSTAR 1-9A that show a localized cave-in of the top ten floors of WTC 7 at its northeast corner about the time of global collapse initiation – another behavior of Building 7 that was never observed. It is simply astounding that, although NIST's computer generated images of a crumpled and severely distorted Building 7 look nothing like the video images of the real thing, NIST nevertheless concludes: "*the global collapse analyses matched the observed behavior reasonably well*."

I would also like to draw attention to another problem with the global collapse analysis described in NCSTAR 1-9 and 1-9A of the *Draft Report* – a problem concerning NIST's collapse timescale. Although the precise instant of the collapse initiation of Building 7 is difficult to define, NIST states that significant downward motion of the entire roofline of WTC 7 started 23 seconds into its computer simulation of the collapse. NIST also states that 24.5 seconds into the simulation, the roof of WTC 7 was falling with a velocity of approximately 10 to 15 m/s. This claim is at least consistent with Figure E-4 of NCSTAR 1-9A which shows that the roofline of WTC 7 had descended about 3 stories at 24.6 seconds of the simulation, or 1.6 seconds into global collapse.

However, let's consider Figure 12-69 of NCSTAR 1-9 that purports to show the condition of WTC 7's exterior 26.8 seconds into NIST's collapse simulation, or 3.8 seconds after collapse initiation. Measurements of the depth, width and height of the images of WTC 7 depicted in Figure 12-69 show that NIST's simulation predicts that extensive column buckling at 3.8 seconds has dropped the roofline of WTC 7 about 5 stories or 20 meters. This is simply *not* consistent with observations of the actual collapse of WTC 7 which show that the roofline dropped by about 15 stories, or 60 meters, 3.8 seconds after collapse initiation.

6.0 Collapse Times

In Section 12.5.3 of its *Draft Report* NIST discusses the collapse time of Building 7. Now since the final stages of the collapse were shrouded in dust and debris, NIST wisely restricts its discussion of this topic to estimates of the time it took the building to fall a specific distance after the roofline began to move downwards. Thus, on page 595 of NCSTAR 1-9, we read: "*The time the roofline took to fall 18 stories was 5.4 s, with an uncertainty of no more than 0.1 s*." There are, however, several problems with this estimate:

(i) If Building 7 is assumed to have fallen with constant acceleration, application of the formula $s = \frac{1}{2} a.t^2$ to NIST's collapse data leads to the conclusion that the building fell with an acceleration ~ 5 m/s^2, or about ½ g. However, the formula also shows that with an acceleration of 5 m/s^2, the building fell a mere 2.5 cm in the first 0.1 seconds and just 62.5 cm after 0.5 seconds. Since NIST's estimate of the downward motion of Building 7 is based on a video taken at a distance of approximately 0.6 km, it would surely be impossible for NIST to detect a roofline movement of less than 50 cm. Thus there would be an uncertainty of about 0.5 seconds, (*not 0.1 seconds!*), in the determination of the time it took Building 7 to fall through the first few meters of its global collapse.

(ii) According to NIST, the global collapse of WTC 7 was initiated by the buckling of columns between floors 7 and 14. It is reasonable to assume that the gravitational force driving the collapse did not instantaneously exceed the reaction force holding up the building, but took a finite time to overcome the resistance offered by the columns. Indeed, according to NIST NCSTAR Chapter 12, pages 286 – 287, the stress unloading of exterior columns occurred over a period of about 2 seconds. However, NIST's FEA result that Building 7 was subject to such a slow collapse initiation is at odds with observations of the actual demise of WTC 7 that show there was no protracted collapse initiation over 2 seconds but a rapid, (less than 1 second), onset of downward motion.

(iii) If it is assumed that a net downward acceleration began to act on the upper block of floors at time t_o and increased in a linear fashion to a terminal acceleration of 5 m/s^2 at $(t_o + 2)$ seconds, WTC 7 would have dropped only about 3.4 meters 2 seconds into the collapse; this is less than 50 % of the drop distance estimated by NIST on page 276 of NCSTAR 1-9. However, as shown below, WTC 7 actually dropped more than 15 meters in the first 2 seconds of the collapse.

(iv) Based on many existing studies of the collapse of WTC 7, I believe NIST's estimate, (made on page 273 of NCSTAR 1-9), that "*global collapse started 6.9 s ± 0.1 s after the east penthouse began its descent into the building*" is significantly in error. I would suggest that a better estimate of the onset of global collapse would be 7.65 s after the east penthouse began its descent. By *delaying* the start of the downward motion of the upper section of WTC 7 by just 0.75 seconds the overall collapse becomes much faster.

NIST actually provides very little information on the rate of collapse of WTC 7 other than a few scattered numbers in Chapters 5 and 12 of NCSTAR 1-9. I believe this is a significant shortcoming of NIST's *Draft Report*. However, let's consider the drop distance vs. time data that *is* provided by NIST. We have already noted one example from page 595: "*The time the roofline took to fall 18*

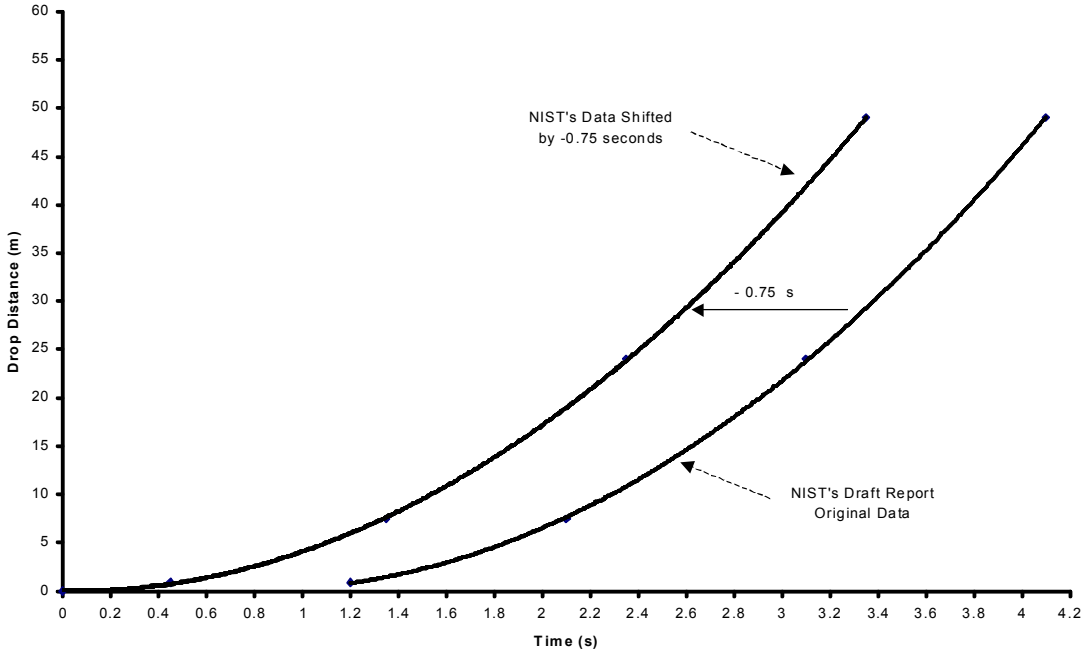
stories was 5.4 s…". Another example is on page 277 from which we may deduce that WTC 7 fell 10 stories in 3.2 s. While it is true there is no *a priori* reason for the acceleration of a collapsing building to be constant except under the condition of free fall, evidence presented below shows that the acceleration of WTC 7 during global collapse was relatively constant over the first 4 seconds of motion. Clearly then, "18 stories in 5.4 s" is inconsistent with "10 stories in 3.2 s" since the former implies an acceleration of 7.8 m/s^2, while the latter implies an acceleration of only 4.9 m/s^2.

In spite of NIST's apparent reluctance to provide detailed collapse rate data it *is* possible to derive useful drop distance vs. time data from Section 5.7.4 of NIST's *Draft Report* using measurements on the images of WTC 7 shown in Figures 5-199, 5-200, 5-202, 5-203, 5-208 and 5-211. From these images one may derive roofline descent data such as:

Time = 2.1 s, drop = 7.5 m; time = 3.1 s, drop = 24.0 m; time = 4.1 s drop = 49.0 m

When these, and additional data points are plotted on linear graph paper a smooth drop distance vs. time curve is obtained but the curve does not extrapolate well to t = 0. However, a simple subtraction of 0.75 seconds from NIST's times, equivalent to the global collapse commencing 7.65 seconds after the east penthouse collapsed, produces a curve that passes almost directly through the origin, (i.e. zero drop distance at t_o), as shown in Figure 1 below.

Figure 1: WTC 7 Drop Distance vs. Time Plots



It is important to note that the time-shifted collapse curve shown in Figure 1 is in good agreement with other data on the collapse rate of WTC 7 that have been published on a number of internet sites. In addition, an energy transfer calculation in which the crush-up of the upper 39 floors of WTC 7 is modeled with an energy to collapse each floor of 1 GJ, leads to an acceleration, **a**, given by:

$$\mathbf{a} = [\ 9.15 - 0.314\ t\ ]\ m/s^2$$

This result is also in good agreement with the studies I have noted above. Thus there appears to be a consistent trend among non-NIST researchers to find, (at least for the first 4 seconds of collapse of WTC 7), a roofline acceleration in the range 8.5 to 9.5 m/s^2, rather than the value of 5 - 8 m/s^2 favored by NIST. I would therefore ask NIST to reconsider the analysis presented in Section 12.5.3 of the *Draft Report*, and hopefully adjust its findings to be in better agreement with the vast majority of existing studies of the collapse time of WTC 7.

7.0 Conclusions

I believe there are many problems with the material presented in NIST's *Draft Report* on the collapse of WTC 7; most of these problems stem from the assumed fuel loading on the fire-affected floors but I would add that NIST's collapse hypothesis is not physically achievable and not supported by observations of the behavior of Building 7 during its collapse. In addition, NIST's global collapse time estimates appear to be in error by about 0.75 seconds which leads to a substantial under-estimation of the acceleration of the collapsing building.

I therefore believe that the National Institute of Standards and Technology, through its *Draft Report*, has fallen well short of substantiating its own collapse initiation hypothesis but could, on the contrary, be said to have provided evidence that a single column failure, brought on by thermal expansion of floor framing beams and girders, did *not* precipitate a global collapse of WTC 7 - the reason being that the NIST simulation predicts a *slow* collapse initiation which was *not* observed. Therefore I believe that an alternative collapse initiation and propagation hypothesis is called for - one that more accurately reflects the reality of what happened to WTC 7 on September 11th 2001.

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