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NIST WTC 7 BUILDING COLLAPSE INVESTIGATION REPORT: PRINCIPAL FINDINGS WITH COMMENTARY (CRYING WOLF?)

By Richard Schulte

As the ninth anniversary of September 11th approaches, some in the fire protection profession would like to move on. The recommendations for making buildings “safer” contained in the NIST investigations of the collapse of the World Trade Center (WTC) towers and the WTC 7 Building have, for the most part, been implemented.

Given that NIST appears to have won the debate over whether or not it is necessary that their recommendations be incorporated into the model building codes used in the United States, why is a continued discussion of the NIST investigation reports still of interest? There is a rather simple answer to that question—the state of the US economy. Many in the private sector blame the massive amount of new regulations being issued from Washington as one of the principal culprits for the stagnating economy, and, of course, the new code provisions for high rise buildings had their origins in Washington.

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Has the implementation of the NIST recommendations had a negative impact upon the building construction industry in the United States? In general, the answer to that question, at least at the present time, is no. The reason for this is that the building construction industry in the United States is presently in a state of depression. Given that few high rise buildings are being constructed, the effect of the new code provisions based upon the NIST recommendations is muted. There seems to be little doubt, however, that the effect of the new code provisions will be significant once the building construction industry does recover.

Given that few high rise buildings are being constructed, the effect of the new code provisions based upon the NIST recommendations is muted.

Given that the code provisions based upon the NIST recommendations eventually will have a significant impact on the building construction industry in the US, continuing the discussion on whether or not the NIST recommendations are rational and necessary still makes sense, particularly since NIST did such a poor job of justifying their recommendations. Perhaps NIST's "handiwork" can be undone before too much damage to the construction industry in the US occurs.

One could say that one of the upsides of the recession is that the recession presents an opportunity to re-open the discussion of the NIST recommendations.

Chapter 14 (Volume 2) of NIST's NCSTAR 1-9 report includes the following excerpts. These excerpts present an overview of the results of NIST's investigation into the collapse of the WTC 7 Building. Included with these excerpts is also a commentary on NIST's findings.

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"This chapter presents the findings of the NIST Technical Investigation, organized according to the first three of the four Investigation objectives for Building 7 of the New York World Trade Center (WTC). The fourth objective . . . is the subject of Section 14.5. . ." (Page 617)

"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 combustible building contents were consumed." (Page 617)

"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 combustible building contents were consumed."

Commentary: This statement by NIST demonstrates how unique of an event the collapse of the WTC 7 Building actually was. Would the WTC 7 Building have collapsed on any other day than on 9/11? The answer to that question seems obvious. Given that a major fire has never occurred in a high rise building protected by a sprinkler system in the United States, except on 9/11, it can be said with almost 100 percent confidence that the operation of the sprinkler system would have controlled a fire occurring in the building.

If we assume sprinkler system failure in a fire in the WTC 7 Building, there is no reason to believe that the FDNY would have been unable to control and eventually extinguish the fire with manual fire fighting operations. Hence, the probability of a failure of both sprinkler protection in a tall building and manual fire fighting operations by the FDNY was essentially zero. Given this, we can state with a great deal of confidence that the collapse of the WTC 7 Building was really just a freak occurrence.

Given the conclusion above, two questions arise. The first question is, can engineers address every and all freak occurrences, some which are beyond our imagination to conceive? The second question is, should engineers be expected to address every and all freak occurrences, even those which are beyond our imagination to conceive?

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In my mind, it is simply not possible for engineers to completely eliminate the probability of a structural collapse, regardless of the time and capital expended trying to do so. The best that we can do is to minimize the probability of a structural collapse.

The WTC 7 Building was provided with three separate systems designed to prevent a structural collapse caused by a fire-the sprinkler system, the standpipe system/FDNY and structural fire protection. If not for the events of 9/11, the combination of these three systems would have successfully prevented the collapse of the WTC 7 Building.

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The central question which needs to be answered by engineers is: how much building fire protection is enough? Even with the implementation of NIST's recommendations for making high rise buildings "safer", we have only reduced the probability of a structural collapse, but not eliminated this possibility entirely.

The improvement in the level of safety by implementing the NIST recommendations is so minuscule that the costs far outweighs the benefits. In other words, the implementation of the NIST recommendations is a waste of capital which could be better put to use addressing some other more pressing safety issue.

“WTC 7 collapsed due to uncontrolled fires with characteristics similar to previous fires in tall buildings. . . 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.” (Page 617)

“The probable collapse sequence that caused the global collapse of WTC 7 was initiated by the buckling of Column 79, which was unsupported over nine stories, after local fire-induced damage led to a cascade of floor failures. . .” (Page 617)

“The collapse of WTC 7 was a fire-induced progressive collapse. . . This is the first known instance where fire-induced local damage (i.e., buckling failure of Column 79; one of 82 columns in WTC 7) led to the collapse of an entire tall building.” (Page 618)

“The probable sequence that caused the global collapse of WTC 7 was initiated by the buckling of Column 79, which was unsupported over nine stories, after local fire-induced damage led to a cascade of floor failures. . .”

“There was no evidence to suggest that there was damage to the SFRM [sprayed fire resistive material] that was applied to the steel columns, girders, and beams, except in the vicinity of the structural damage from the collapse of WTC 1, which was near the west side of the south face of the building.” (Page 618)

Commentary: It seems highly improbable that the sprayed-fireproofing installation throughout the WTC 7 Building was 100 percent intact on 9/11. While there may not have been any evidence of damage to the fireproofing in the WTC 7 Building (in locations other than the portions of the building which were damaged by the collapse of the WTC 1 tower), there also was no evidence that proves that the sprayed-fireproofing installation was 100 percent intact. Could damaged fireproofing have been a factor in the collapse of the WTC 7 Building? It doesn't appear that there is actually any way of making such a determination with 100 percent certainty. Given that all of the evidence addressing this question was destroyed in the collapse of the building, it can be stated with 100 percent certainty that we will never know one way or the other with 100 percent certainty.

“The observed descent time of the upper 18 stories of the north face of WTC 7 (the floors clearly visible in the video evidence) was 40 percent greater than the computed free fall time. . . .” (Page 618)

“Diesel fuel fires did not play a role in the collapse of WTC 7. . .” (Page 619)

“Blast events did not play a role in the collapse of WTC 7. . .” (Page 619)

“There were no serious injuries or fatalities because the estimated 4,000 occupants of WTC 7 reacted to the airplane impacts on the two WTC towers and began evacuating before there was significant damage to WTC 7. Evacuation of the building took just over an hour.” (Page 619)

“Blast events did not play a role in the collapse of WTC 7. . .”

“The occupants were able to use both the elevators and the stairs, which were as yet not damaged, obstructed, or smoke-filled.” (Page 619)

“The decision not to continue evaluating and fighting the fires was made hours before the building collapsed, so no emergency responders were in or near the building when the collapse occurred.” (Page 619)

“Consistent with the NYCBC, there was no redundancy in the source of water supply for the sprinkler system in the lower 20 floors of WTC 7. . .” (Page 619)

“The passive fire resistance design of the WTC 7 structural system was based on catalogued ASTM E 119 test data. Practice today (and in the 1980s) for the fire resistance design of structures, based on the use of ASTM E 119 standard test method, is deficient since the method was not designed to include key fire effects that are critical to structural safety. . .” (Page 620)

Commentary: While the ASTM E119 standard may be considered to be deficient if the standard is considered by itself, the fire protection for a tall building consists of a combination of several systems. The fire protection for the structural systems for a tall building do not depend on only one feature. The primary protection provided for the structural system for a tall building is sprinkler protection. The second-

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ary means of providing fire protection for the structural system for a tall building is manual fire fighting operations. Only if both sprinkler protection and manual fire fighting operations fail does the structural fire protection provided for a tall building become of critical importance in collapse prevention in a fire. If you look at the fire protection of a tall building in this manner, a strong argument can be made that the ASTM E119 standard is more than adequate for the purpose for which it is used.

NIST's statement that "*the collapse of WTC 7 represents the first known instance of the total collapse of a tall building primarily due to fires*" appears to be a testament that the results produced by the ASTM E119 standard are conservative. Any lack of conservativeness of the results produced by the ASTM E119 standard are addressed by providing sprinkler protection and by manual fire fighting capabilities.

It would seem that concerns about ASTM E119 are being overblown by research scientists with an interest in structural engineering under fire conditions. Other than on 9/11, we can conclude that the use of ASTM E119 is "safe". Can we do better than ASTM E119? The answer to that question is most definitely yes, but it once again comes down to cost vs. benefit. We can probably save more lives investing

our time and resources in other areas of research than trying to develop and perfect structural fire engineering methodology.

It would seem that concerns about ASTM E119 are being overblown by research scientists with an interest in structural engineering under fire conditions.

Given the high level of building fire safety provided by the combination of sprinkler protection and manual fire fighting capabilities, it is probably safe to say that research on structural fire engineering should not be a high priority.

"Determination of the actual fire performance of the WTC 7 structural system was not the responsibility of any of the design professionals associated with the design, construction, or maintenance of WTC 7. . . Structural engineers are not required to consider fire as a load condition in structural design. Fire protection engineers may or may not be called upon to assist the architect in specifying the required passive fire protection. Thus, none of these professionals has been assigned the responsibility to ensure the adequate fire performance of the structural system." (Page 620)

Commentary: In my mind, NIST has failed to make a compelling argument for the need for structural fire engineering. The historical record on the safety of high rise buildings clearly shows that high rise buildings protected throughout by a sprinkler system are "safe" buildings and that sprinkler systems protecting high rise buildings are highly reliable.

The failures which occurred in Lower Manhattan on 9/11 were caused by a terrorist attack. All building systems which we construct are vulnerable in the event of an intentional attack on a building. The purpose of militaries around the world is to develop the means of destroying things and once a means of destruction is developed, it's difficult to "keep the genie in the bottle". That means that buildings will always be susceptible to weapon systems that will be developed in the future and there isn't much that we can do to address this problem.

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"The design of the WTC 7 did not include any specific analysis of how the structural system might perform in a real fire. There is a critical gap in knowledge about how structures perform in real fires," (Page 620)

Commentary: If there is indeed "*a critical gap in our knowledge about how structures perform in real fires*" then it would seem that it would have been impossible for NIST to have performed the analysis of the collapse of the WTC 7 Building presented in their report. Hence, it would seem that any recommendation that structural fire engineering should be a routine part of the design of tall buildings is premature. Given the safety record of high rise buildings protected by a sprinkler system, describing our lack of knowledge on this subject to be "*a critical gap*" seems to be an exaggeration of the problem. So far, mankind has managed to survive without this knowledge and it is likely that mankind will be able to survive even if we don't develop a structural fire engineering methodology. Given the financial bind that the United States finds itself in today, government-sponsored research on this subject is something of a luxury that we can't afford at present.

"There was no evidence that the fires spread from floor to floor, except, perhaps, just prior to the collapse of the building." (Page 622)

Commentary: Based upon experience, it is difficult to believe that all of the penetrations of the floor construction throughout the fire floors in the WTC 7 Building were properly firestopped. Given this, it seems highly improbable that floor-to-floor fire spread did not occur much earlier in the fire than indicated by NIST. Since the building collapsed, we'll never be able to say with 100 percent certainty whether or not fire spread between floors via floor penetrations.

"Simulations of the fires using the Fire Dynamics Simulator (FDS) generated air temperatures comparable to those in large-room fire tests of office workstations." (Page 622)

“Doubling the estimated combustible fuel load on the open-landscaped Floor 8 from 20 kg/m² (4 lb/ft²) to 40 kg/m² (8 lb/ft²) led to a predicted fire spread rate that was slower than actually observed. . .” (Page 622)

“Calculated fire-elevated temperatures in the interior columns, including Columns 79, 80, and 81, stayed below 200°C [392°F] on all of the floors. The exterior column temperatures were below 150°C (300°F), except on Floors 12 and 13, where the east and south exterior columns reached 300°C (570°F). At these temperatures, structural steel experiences relatively little loss of strength or stiffness. Thus, WTC 7 did not collapse due to fire-induced weakening of critical columns.” (Page 623)

“The simulated fires on Floors 7, 12, and 13 heated portions of the tops of the floor slabs to over 900°C (1650°F). . .” (Page 623)

Commentary: It should be noted that the ASTM E119 test for determining the fire resistance rating of floor construction only involves the exposure of a floor assembly from the underside. Obviously, the exposure of floor construction to heat simultaneously from both above and the below would be expected to significantly reduce the fire resistance of the floor construction.

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Increasing the required fire resistance rating of floor construction from two hours to three hours will have little impact on the capability of floor construction to resist fire if the floor construction is exposed to heat from both above and below (as was the case in the WTC 7 Building fire). Hence, the importance of applying water on the fire, either through automatic or manual means, in order to absorb some of the heat generated and to prevent the spread of fire to multiple floors.

The application of water on the fire via hose streams is an important element of structural fire resistance (in the improbable event of sprinkler system failure).

“Raising the fire-generated air temperatures by 10 percent, which was within the range of reasonable and realistic fires, raised the peak temperatures in the floor beams and slabs by about 70°C (170°F) [126°F]. Additionally, the areas over which the temperatures of the floor beams exceeded 600°C (1100°F) [1112°F] increased. A 10 percent increase in temperature resulted in a roughly 30 percent increase in the heat flux to structural members. Comparable changes in the opposite direction resulted from lowering the fire-generated air temperatures (Case A).” (Page 623)

Commentary: In other words, the structural fire engineering analysis is very sensitive to the temperatures predicted by the Fire Dynamics Simulator.

“The connection, beam, and girder failures in the floor systems, and the resulting structural responses, occurred primarily at temperatures below approximately 400°C (750°F), well below the temperatures at which structural steel loses significant strength and stiffness.” (Page 623)

Commentary: Manual fire fighting operations, specifically the application of hose streams on the fire, would have had a significant impact on the temperatures which developed on the fire floor. Given this, the application of hose streams on the fire would have a significant impact on the response of the structure to the fire. This seems to be an obvious conclusion, however, it is an important factor to consider when analyzing the statement above (and also the next excerpt). The application of hose streams on a fire provides significant protection against the type of structural responses that NIST indicates were responsible for the collapse of the WTC 7 Building.

It should be noted that the latent heat of vaporization for water is 8,095.3 Btu per gallon of water (970.4 Btu per pound). (The latent heat of vaporization is the amount of energy it takes to convert water at its boiling point, 212°F (100°C), to steam at 212°F (100°C).) In other words, the vaporization of one gallon of water is capable of absorbing all of the heat generated by the burning of a pound of wood (assumed to be 8,000 Btu/lb).

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The application of a single 100 gpm hose stream for an hour is capable of absorbing all of the heat generated by the burning of 6,000 pounds of wood, while the application of a single 250 gpm hose stream for an hour is capable of absorbing all of the heat generated by the burning of 15,000 pounds of wood. In other words, the application of just a single hose stream on a fire will have a significant impact on the temperatures which develop. Manual fire fighting, whether exterior or interior operations, is at least as good of a method of providing structural fire protection as sprayed-applied fireproofing for structural steel and, perhaps, even a superior method of providing structural fire protection.

. . .the application of a single 250 gpm hose stream for an hour is capable of absorbing all of the heat generated by the burning of 15,000 pounds of wood.

I guess we could say that NIST's statement above is theoretical in that it assumes the failure of fire department personnel to conduct fire fighting operations. While this occurred on 9/11, it would not have occurred on September 10th or any other day in recent history. The reliability of fire department personnel in major cities in the United States is as close to 100 percent as we can get.

"Thermal expansion was particularly significant in causing the connection, beam, and girder failures, since the floor beams had long spans on the north and east sides (approximately 15 m, 50 ft)." (Page 623)

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"The fires thermally weakened Floors 8 to 14. As Floor 13 fell onto the floor below, a cascade of floor failures continued until the damage reached the massive Floor 5 slab, leaving Column 79 without lateral support for nine floors. The long unsupported length of Column 79 led to its buckling failure." (Page 624)

Commentary: Would the floors in the building have failed if the FDNY had conducted manual fire fighting operations? That's a question that NIST failed to address in their report on the collapse of the WTC 7 Building. The answer to that question seems obvious-if the fire in the

Would the floors in the building have failed if the FDNY had conducted manual fire fighting operations?

WTC 7 Building had occurred on September 10, 2001 and the sprinkler system protecting the building had failed, it is my opinion that the building would still be standing.

The reason that the WTC 7 Building is *"the first known instance of the total collapse of a tall building primarily due to fires"* is the high degree of reliability of manual fire fighting. Combine this with the high degree of reliability of sprinkler protection and the probability of the total collapse of a tall building protected by a sprinkler system is very close to zero.

"Computer simulations of the fires, the thermal heating of the structure, the thermally induced damage to the structure, and the structural collapse can be used to predict a complex degradation and collapse of a building. The overall features and timing of the prediction were consistent with the videographic evidence." (Page 625)

“It was recognized that uncertainties existed in the fire simulations, thermal analyses, analyses of the structural response to fires, and the analyses of global collapse, including assumptions made where the data were not available. The propagation of uncertainties in the inter-dependent analyses was minimized by conducting sensitivity studies and multiple analyses with a range of values for critical parameters, and by determining the best fit between the analysis results and observed events from photographic and videographic evidence. The occurrence and timing of the analytical results closely matched the observed events (e.g., east penthouse descent, followed by global collapse), which demonstrates the effectiveness of this approach for the interdependent analyses.” (Page 625)

“These computational models comprise a set of research tools that can take months (eight months in this case) for a complete simulation. Their adaptation for engineering practice would forestall future disasters, while reducing the potential for structural overdesign.” (Page 626)

Commentary: If the computations took 8 months to complete in 2007/2008, it would appear that it would not have been possible to do these same calculations when the building was being designed in the 1980's. Hence, statements by NIST that the design team for the WTC 7 Building did not take into account the reaction of the structure to fire when the building was being designed appears to be a rather nonsensical statement.

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In fact, Version 1 of the Fire Dynamics Simulator (FDS), referred to as the Industrial Fire Simulator, was not developed until the mid-to-late 1990's. Even today, the “validation” of the FDS as used by NIST in the investigation into the collapse of the WTC towers and the WTC 7 Building is questionable.

“By the conventional measure of life safety, the evacuation of WTC 7 was successful, as NIST identified no life-threatening injuries or fatalities among the estimated 4,000 building occupants on September 11, 2001.” (Page 626)

Commentary: Most fire protection professionals would consider the number of injuries and fatalities which occurred as a result of the collapse of the WTC 7 Building to be a minor miracle. In fact, it is my opinion that the fewer than 3,000 fatalities which occurred in Lower Manhattan on 9/11 was a miracle. I would not have been surprised if the death toll had been in the range of 10 to 20 thousand. The unexpectedly low number of fatalities on 9/11 was due to the magnificent performance of the World Trade Center towers.

“Evacuation drills had been conducted every six months.” (Page 627)

“Due to the focus on rescuing people trapped in the debris field, providing aid to the injured, and the loss of water in the hydrant system, FDNY was not able to consider the possibility of fighting the fires in WTC 7 until approximately 1:00 p.m. At approximately 2:30 p.m., FDNY gave the order to forego firefighting activity and for personnel to withdraw to a safe distance from the building.” (Page 627)

“The structural design did not explicitly evaluate fire effects, which was typical for engineering practice at that time and continues to remain so today. Many of the shear connections in WTC 7 were not capable of resisting lateral loads resulting from thermal expansion effects in the steel floor framing when the floor beams were heated.” (Page 628)

“NIST simulations showed that, for the heaviest columns in WTC 7, when properly insulated, it would have taken an exposure of about 7 h at post-flashover upper layer gas temperatures to raise the steel temperature to 600°C (1100°F), the point at which the steel strength

would have been reduced by half. A similar calculation indicated it would have taken about 4 h to reach this temperature for an insulated lighter column. These times are both far longer than the time over which post-flashover gas temperatures were sustained in the computed WTC 7 fires. For comparison, this steel temperature would have been reached in under one-half hour if the insulation were not applied.” (Pages 628 and 629)

“The current fire resistance rating system, which does not include thermal expansion effects, is not conservative.”

“It is unlikely that the collapse of WTC 7 would have been prevented had the insulation thickness on the floor beams been increased by 50 percent, from 13 mm (½ in.) to 19 mm (¾ in.). NIST calculations indicated that the time to reach the steel temperature of 649°C (1200°F) would have increased by about 10 min to 20 min.” (Page 629)

“The ASTM E119 test does not capture critical behavior of structural systems, e.g., the effect of thermal expansion or sagging of floor beams on girders, connections, and/or columns. . . The current fire resistance rating system, which does not include thermal expansion effects, is not conservative.” (Page 629)

Commentary: If NIST’s statement that ASTM E119 *“is not conservative”* why is the collapse of the WTC 7 Building *“the first known instance of the total collapse of a tall building primarily due to fires”*? NIST’s statement that ASTM E119 *“is not conservative”* is simply incorrect. It would appear that NIST’s position on ASTM E119 stated above is intended to secure additional research funding for the NIST Building and Fire Research Laboratory.

“In the course of the Investigation, NIST and its contractors were aware that there were existing, emerging, or even anticipated capabilities that could have prevented the collapse of WTC 7, had they been in place on September 11, 2001. NIST did not conduct studies to evaluate the degree to which building performance could have been improved on September 11, 2001, had the capabilities been available. These include:

- *More robust connections and framing systems to better resist the effects of thermal expansion on the structural system, which is not currently considered in design practice.*
- *Structural systems expressly designed to prevent progressive collapse. . .*
- *Better thermal insulation (i.e., reduced conductivity and/or increased thickness) to limit heating of structural steel and to minimize both thermal expansion and weakening effects. Currently, insulation is used to protect steel strength, but it could also be used to maintain a lower temperature in the steel framing to limit thermal expansion.*
- *Automatic fire sprinkler systems with independent and reliable sources for the primary and secondary water supply.*
- *Improved compartmentation in tenant areas to limit the spread of fires.*
- *Thermally resistant window assemblies which limit breakage, reduce air supply, and retard fire growth.*

(Page 630)

Commentary: One other concept which could have prevented the collapse of both the World Trade Center towers and the WTC 7 Building which was not included in the list above is airline security. There were numerous opportunities to foil the terrorist activity which resulted in 9/11.

Perhaps one of the best means to counter the hi-jacking of commercial aircraft is the “hardening” of the separation between the passengers and the flight deck and providing the pilots of the aircraft with weapons which can be used to defend themselves against attack by hijackers. If the terrorists had not gained access to the aircraft controls, the events of 9/11 would never have happened.

Basically, there are two ways to look at the collapse of the WTC 7 Building. One way is to look at the glass as being “half full”, while the other way is to look at the glass as being “half empty”.

Rather than modify the way we design buildings, perhaps the most rational and economical approach to address the problem is through changes in security procedures. Of course, in many cases, little research will be necessary to tighten security. It would be too much to expect that a government agency and government employees, such as NIST, to recommend a solution which doesn’t involve further work by that agency.

Conclusion

Basically, there are two ways to look at the collapse of the WTC 7 Building. One way is to look at the glass as being “half full”, while the other way is to look at the glass as being “half empty”.

It seems reasonable to conclude that the WTC 7 Building would not have collapsed on any other day than on September 11th. Given that, if we take the “half full” approach, there is little or no justification for the NIST recommendations, however, if we take the “half empty” approach, then perhaps NIST’s recommendations can be considered to be justified.

The historical record appears to indicate that the “half full” approach to high rise building fire safety is the more appropriate approach than NIST’s “half empty” approach. Based upon that record, it seems that NIST is simply “crying wolf” with its recommendations.

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