Report to the
California State Fire Marshal

on
Exit Access Travel Distance of 400 Feet

by
Task Group 400

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Executive Summary

Task Group 400 took on a task that blossomed into a much larger challenge than was expected. The goal was to provide mitigation measures which would allow the re-instatement of an exit access travel distance of 400 feet in Group F-1 and S-1 occupancies.

Task Group 400 developed a strategy to justify exit access travel distances of 400 feet based on the combination of fire sprinklers and tall ceiling heights. The concept was simple ï the sprinklers slowed the spread of fire and consequently the development of smoke, while the tall ceiling allowed for smoke to bank, or collect, at the upper levels and therefore not impact the occupants during escape.

In order to justify the increased exit access travel distance, Aon Fire Protection Engineering was engaged to perform fire modeling. The design parameters for the fire modeling were specific. The design building used was a warehouse occupancy with a ceiling height of 24 feet and protected with a control mode sprinkler system. The design fire was based on rack storage of Group A plastics which is a conservative approach. The fire modeling report, attached as Appendix A, shows conclusively that this type of building, with these levels of protection, can provide for safe egress when occupants need to travel up to 400 feet.

During this project, Task Group 400 identified two distinct issues. While developing a plan to address the ability to safely evacuate warehouses and factories it became apparent that allowing these larger travel distances resulted in larger buildings; larger buildings resulted in additional firefighting difficulties. It was felt that one issue could not be addressed without including the other.

Therefore, Task Group 400 produced code changes that address the mitigation required to allow an exit access travel distance of 400 feet, and also produced code changes to mitigate the increased difficulty created when fighting fire in these large buildings which utilize the increased travel distance allowance.

The resulting code changes have the following affect as compared to current code:

- The exit access travel distance increase to 400 feet is based on the ceiling height and fire sprinklers rather than smoke/heat vents and fire sprinklers.
- Smoke/heat vents will be required with ESFR sprinkler systems when the exit access travel distance exceeds 250 feet.
- Minimum temperatures are specified for the thermal element in smoke/heat vents.
- Group F-1 aircraft manufacturing hangars will be exempt from the requirement for smoke/heat vents, just as Group S-1 aircraft repair hangars are exempt in the current code.

Overview

The 2010 California Building Code and California Fire Code will become effective on January 1, 2011. Both of those codes have revised the allowable exit travel distance for large warehouse and large factory facilities. In the 2010 California Codes, warehouses and factories with non-combustible products are allowed an exit access travel distance of 400 feet; however, when those same buildings contain combustible materials, the exit access travel distance is being reduced to 250 feet.

The allowance of an exit travel distance of 400 feet has existed in the California Codes for warehouses and factories with non-combustible products since the early 1960ôs. The allowance of an exit travel distance of 400 feet for all warehouses and factories has existed in the California Codes for over a decade. This report is an evaluation of the potential of re-inserting the allowance of 400 feet.

Task Group 400 recognized that the item was deleted from the 2009 International Building Code, which is the model code used as the foundation for the California Building Code. The ultimate goal is to revise the International Building Code, however a revision processed through the International Code Council Code change process will not appear in the code until the 2015 Edition. The immediate goal of Task Group 400 is to submit a code change in the 2011 California Code Change process.

Task Group 400

Task Group 400 was formed to include stakeholders from all aspects of the issue. There were a total of 20 Stakeholders involved with Task Group 400. The Task Group 400 roster can be found on the next page. These stakeholders represented the following groups:

- Building Code Officials
- Fire Code Officials
- Fire Department Operations
- Facility owners
- Industry Consultants
- Fire sprinkler designers/installers

The specific Organizations represented are as follows:

- American Institute of Architects ï California Council
- Business and Property Owners Association
- California Building Officials
- California Fire Chiefs Association ï Operations Section
- National Association of Industrial and Office Properties
- Northern California Fire Preventions Association
- Southern California Fire Preventions Association

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Background

In the 1994 Uniform Building Code and 1995 California Building Code, the exit access travel distance in a building protected with a fire sprinkler system was typically 200 feet. The 1994 Uniform Building Code and 1995 California Building Code allowed the exit access travel distance to be increased to 400 feet when a warehouse for storage of noncombustible products or a factory for manufacturing of noncombustible products was provided with smoke/heat vents in addition to the fire sprinkler system.

In the 1997 Uniform Building Code and the 1998 California Building Code this section was revised to allow this increase to apply to all warehouses and factories provided the occupancies were protected with a fire sprinkler system and smoke/heat vents. This allowed increase in the exit access travel distance resulted in larger buildings with open, undivided areas. A typical warehouse building would range from 600 feet to 700 feet across. As buildings continued to grow, the dimension of 600 feet in a warehouse became the narrow dimension, with many buildings exceeding 1,000 feet in the other dimension. An example of this design is shown in Figure 1.

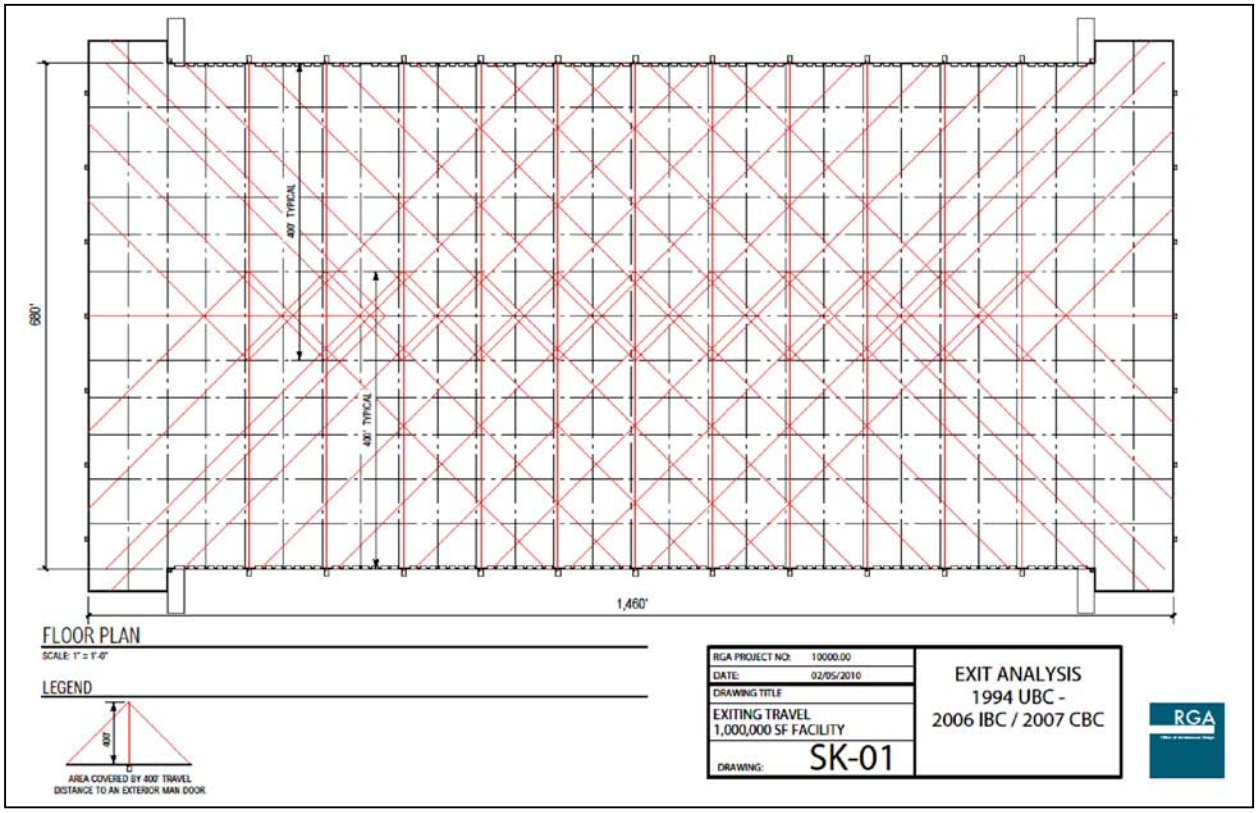

Figure 1 – Warehouse/Factory Occupancy with an Exit Access Travel Distance of 400 Feet

A change in the 2009 International Building Code and 2010 California Building Code has resulted in the elimination of the allowed exit access travel distance of 400 feet in large warehouses and factories. Previously, the installation of a fire sprinkler system and smoke/heat vents would result in an increased travel distance from 250 feet to 400 feet to the nearest exit.

Code Change E114-07/08 was approved in the International Code Council process to eliminate the increase in exit access travel distance based on the installation of smoke/heat vents. Excerpts from the Reason Statement for the code change are as follows:

> ñWhile smoke and heat (roof) vents by themselves will automatically vent smoke and heat generated by a fire in an unsprinklered one story building, there is serious doubt whether or not smoke and heat (roof) vents actually perform their intended function in buildings protected throughout by a sprinkler system.
>
> ñFire tests utilizing a combination of standard spray sprinklers and fusible link-activated smoke and heat (roof) vents conducted at Underwriters Laboratories (UL) in 1997 and 1998 clearly demonstrated that operating sprinklers interfere with the opening of roof vents. The following are quotes from the report of the tests at UL, ñSprinkler, Smoke & Heat Vent, Draft Curtain Interaction -- Large Scale Experiments and Model Developmentò, dated September 1998. (The report is referred to as NISTIR 6196-1.)
>
>> ñIt had become clear by this time in the project that the vents were unlikely to open when the fire was ignited more than about 4.6 m (15 ft) away.ò (Page 54, NISTIR 6196-1)
>>
>> ñ. . . .it appears from the data below that the sprinkler spray influenced the thermal response characteristics of this particular vent, and it is believed that sprinklers could have a similar influence on similar vent designs.ò (Page 64, NISTIR 6196-1)
>>
>> ñSix other tests were performed with the fire at this distance from the vent when the vent was equipped with a fusible link, and in none of these tests did the vent open. Examination of the near-ceiling temperatures from all the tests indicates that sprinklers of this type [standard spray sprinklers] have a significant cooling effect, and this will certainly have an effect on thermally-responsive, independently controlled vents.ò (Page 64, NISTIR 6196-1)
>>
>> ñThe significant cooling effect of sprinkler sprays on the near-ceiling gas flow often prevented the automatic operation of vents. This conclusion is based on thermocouple measurements within the vent cavity, the presence of drips of solder on the fusible links recovered from unopened vents, and several tests where vents remote from the fire and the sprinkler spray activated. In one cartoned plastic commodity experiment, a vent did not open when the fire was ignited directly beneath it.ò (Page 101, NISTIR 6196-1)ò
>
> ñThe following are quotes from Dr. Craig Beyler, Hughes Associates, Inc. regarding the operation of smoke and heat (roof) vents in buildings protected by a sprinkler system:
>
>> ñThe experimental studies have shown that . . . . .current design practices are likely to limit the number of vents operated to one and vents may in fact not operate at all in very successful sprinkler operations.ò (Page 1, ñInteraction of Sprinklers with Smoke and Heat Ventsò)
>>
>> ñNot only is the fear of early operation not founded, current design practice will likely lead to 0-1 vents operatingò (ñPage 61,ò ñSprinkler/Vent Interactions-What people think, what we know, and what we donôt.ò)

ñGiven the above, it can be concluded that smoke and heat (roof) vents do not actually operate as expected in buildings protected by a sprinkler system. Based upon this, it can be concluded that there is no technical basis for permitting an increase in travel distance of 150 feet beyond the travel distance permitted for Group F-1 and S-1 occupancies protected by a sprinkler system when smoke and heat (roof) vents are provided.ò[1]

The reasoning for code change was logicalé ie. the smoke/heat vents will most likely not operate in a sprinklered building, therefore allowing an increase in exit access travel distance based on smoke/heat vents does not make sense. The code change was approved, which resulted in limiting the exit access travel distance to 250 feet.

In 2010, Senate Bill 7 was introduced in California. This bill would have reinstated the previous language that was in the 2007 California Building Code allowing the exit access travel distance of 400 feet. This bill was not successful. Since the bill failed, it has given Task Group 400 the opportunity to approach this issue through the regulatory process rather than through the legislative process.

Task Group 400 Proceedings

While the reasoning for approving the Code Change E114-07/08 was logical, the result was the loss of the ability to utilize an exit access travel distance of 400 feet. California has successfully applied this allowance since 1998 in hundreds of buildings across the state. The application of the 400 feet allowance has not resulted in life loss in these buildings.

The fact that the smoke/heat vents will not operate as expected in a sprinklered building is a valid reason to separate the issue of allowing an increased travel distance based on the installation of smoke/heat vents. However, the reality is that the exit access travel distance of 400 has not in itself presented an undue life hazard in these buildings. Typically, only employees will be found in the areas where the exit access travel distance of 400 feet is allowed. As a result, those occupants are fully aware of the building and their surroundings. The employees are knowledgeable of the available exit routes in the building.

When the public enters a building, they will typically exit the same way they entered. This phenomenon has tragically been observed again and again where lives have been lost at the main entrance, or enroute to the main entrance. This tragic loss has occurred when other exits are closer than the main entrance, but the occupants were unaware of their existence. The employees are familiar with their environment and can decide which route is the most appropriate and most expedient.

The loss of the exit access travel distance of 400 feet has a significant negative impact on new warehouse and factory facilities. The fact that the original reasoning which provided the allowance of 400 feet was faulty, did not justify eliminating the requirement in its entirety. Therefore, Task Group 400 brought stakeholders together to evaluate and determine what mitigation measures are necessary to justify exit access travel distances of 400 feet.

[1] ñE114-07/08 Code Change Proposalò, Richard Schulte, Schulte & Associates, International Code Council, Code Change Cycle 2007/2008.

Over a period of 10 weeks, Task Group 400 held nine separate meetings. The process during these meetings was to start with where the code requirements are now, and determine adequate mitigation measures to safely allow an exit travel distance of 400 feet in warehouses and factories. Task Group 400 started with the following information and documentation:

- The 2010 California Building Code no longer allowed an exit access travel distance of 400 feet in warehouses and factories.

- Fire modeling studies by Boeing Corporation which indicated that ceiling heights of 25 feet and 50 feet combined with fire sprinklers provided adequate escape time to accommodate an exit access distance of 400 feet.[2] This study was conducted as part of the justification for ICC Code Change E109-09/10.

- Report by Arup USA which provided a peer review of the Boeing Corporation fire modeling studies.[3]

- Fire modeling studies sponsored by National Association of Industrial and Office Properties which indicated that a ceiling height of 30 feet combined with early suppression fast-response (ESFR) sprinklers provided adequate escape time to accommodate an exit access distance of 400 feet.[4]

Evaluation of Possible Options

Task Group 400 discussed and evaluated a number of options as mitigation measures to allow an exit access travel distance of 400 feet. Several options were considered in the process of developing a solution and ultimately writing a code change. Each of the options is listed below with rationale as to why the option was selected or not.

1. Reinsert the requirement for smoke/heat vents as is currently found in the 2007 CBC and CFC.

   Pros: This would be a simple solution. The language is available in the 2007 code, and creates a ñno changeò from the 2007 code.

   Cons: As was shown in the ICC code development process, the reasoning which allowed the increased exit access travel distance when smoke/heat vents are installed was invalid. To simply reinsert the language after it has been shown to be invalid would not be sound engineering practice.

   Action: This option was eliminated because lacked sound engineering justification.

2. Require Smoke/heat vents to all open at once with activation based on water flow from the fire sprinkler system. This is commonly referred to as ñganged releaseò.

[2] ñLarge Building Fire & Smoke CFD Analysisò, Ted Wu, Boeing Commercial Airplanes, June 23, 2009, updated March 17, 2010.
[3] ñPeer Review of FDS Modeling in Support of Code Change E109-09/10ò, Arup USA, May 9, 2010.
[4] ñFire Modeling Analysis ï Final Report for NAIOP the Commercial Real Estate Development Associationò, Aon Fire Protection Engineering, August 20, 2010.

Pros: This solution would ensure that the smoke/heat vents would open. It would also ensure that the smoke/heat vents opened after the initial fire sprinkler operation.

Cons: There was a possibility that firefighting operations could be negatively affected when all of the smoke/heat vents opened automatically. When all the smoke/heat vents open and provide maximum open area in the roof, it is possible that the actual air velocity in any given area would be so low that it would impede the ability to exhaust the smoke using fire department power fans.

Action: This option was eliminated, and it was decided to let the fire sprinklers do their job.

3. Develop a set of parameters where the vast volume of the large building could be utilized as a containment area for the smoke before the building fills the building down to a point where egress is affected.

Pros: The Boeing Company conducted fire modeling to evaluate an aircraft manufacturing hangar with a ceiling height of 50 feet and provided with a fire sprinkler system. This report demonstrated that the ceiling height of 50 feet captured enough smoke and heat to provide adequate egress time for a travel distance of 400 feet.

The Boeing Company conducted additional fire modeling to evaluate an aircraft manufacturing hangar with a ceiling height of 25 feet and provided with a fire sprinkler system. This report demonstrated that the ceiling height of 25 feet would also capture enough smoke and heat to provide adequate egress time for a travel distance of 400 feet.

Aon Fire Protection Engineering had completed a fire modeling study for a warehouse building with a ceiling height of 30 feet. This fire modeling was based on the use of early suppression fire-response sprinklers.

Cons: The studies were specific to buildings that did not represent the vast majority of buildings where a travel distance of 400 feet is applied. Common warehouses are frequently constructed with different design parameters. Many warehouses have a ceiling height of 24 feet, and use control-mode sprinklers rather than ESFR. This would rule out the application of the fire modeling to many new buildings.

Action: It was decided to further explore this concept and have additional fire modeling completed to determine if a warehouse building with a ceiling height of 24 feet and a control-mode fire sprinkler system would provide favorable results.

4. Install a standpipe system for fire department use.

Pros: This standpipe system would consist of 2½ò hose connections for firefighting operations. The hose connections could be spaced out around the perimeter of the building and at interior openings through fire walls or fire barriers. The

hose connections would assist in firefighter access to the fire and reduce the need to drag water-filled hose.

Cons: This solution is not a mitigation which addresses increased travel distance. This solution would be a benefit for firefighting operations.

On these large buildings, fire department operations vary from department to department. It may be difficult establish a fit-all design option.

Action: This option was eliminated because it was determined to not be a benefit for occupant egress. However, it was reconsidered when Task Group 400 evaluated mitigation measures for firefighting operations.

5. Require mechanical ventilation rather than smoke/heat vents.

Pros: Mechanical ventilation is currently an option allowed in the code to be used in lieu of smoke/heat vents.

The ability for the fire department to control the mechanical ventilation is a definite benefit during the fire and overhaul operations.

Cons: In order for the mechanical ventilation to be effective for occupant egress, it needs to be activated automatically. There is a possibility that the automatic operation may cause ventilation to occur when it is not necessary which could affect the fire spread.

The volume of air currently required in the code appears to be excessive. There is a discussion occurring in the ICC Code Technology Committee and the NFPA 204 committee with regard to the volume of air changes needed. Until that issue is settled, it was decided not to make mechanical ventilation mandatory.

Action: This option was left as option to the designer rather than a solution to allow increased travel distance.

6. Increase the Actual Delivered Density (ADD) of the fire sprinkler system.

Pros: Fire modeling has indicated that ESFR sprinklers can provide for an adequate egress time. ESFR sprinklers deliver significantly more water than typical control mode sprinklers.

Many studies have been successful with control mode sprinklers. Limiting the increased travel distance to only when ESFR sprinkler systems are installed is not the desired result. However, if fire modeling with control mode sprinklers is not effective, then the ESFR sprinkler system would be an alternative.

Many sprinkler systems in existing buildings do not have an ESFR system, but have still taken advantage of the 400ô travel distance. If the control mode sprinklers have not been a problem during actual fires there may be a method to use an increased sprinkler water density to improve success in the fire modeling.

Cons: The determination as to what the actual increase in sprinkler density is a not immediately known. There are many jurisdictions which use a 10% increase, however, there is no documentation to justify this percentage.

Fire testing would need to be completed to determine whether an actual increase of 10% produced the desired results.

It seems quite possible that the percentage of sprinkler water increase may also need to fluctuate as the level of hazard increases from Class I commodity to High Hazard commodity.

Action: This option was held in abeyance pending the outcome of the fire modeling with the control mode sprinklers. When the fire modeling report was received and showed a successful result, Task Group 400 eliminated this option.

7. Increase the type of construction to a higher level of fire resistivity.

Pros: This would provide for increased structural stability of the main structure.

Cons: Typical egress provisions are not dependent on type of construction.

The typical building using increased travel distance is a large open space, quite often with just four exterior walls. There are no interior walls where the increased fire resistive construction would slow the fire spread.

This is probably not a practical issue, since the egress will occur long before the type of construction, or increased fire resistance rating, would make a difference.

Action: This option was eliminated since it does not seem to impact egress time.

8. Install a fire alarm system consisting of audible and visual signaling devices throughout the area with the increased exit access travel distance.

Pros: A fire alarm system would provide earlier warning for the occupants in the event of fire. This earlier notification time would provide additional time for egress, and enable evacuation before conditions become untenable.

Cons: The fire modeling reports reviewed were all based on buildings where no fire alarm was present for early notification of the occupants.

High-piled storage may potentially obscure visibility, where early notification would be very beneficial. However, because of the racking and storage configurations a multitude of visual signaling devices is needed. This becomes a significant cost during installation, and moreover creates more of a maintenance problem throughout the life of the building.

With a large open space, the occupant may not be aware of a fire on the other end of the building. However, if the fire is at the other end of the building, the

occupants will be closer to other exits, so there will be time to escape even without the alarm.

Action: This option was held in abeyance pending the outcome of the fire modeling with the control mode sprinklers. When the fire modeling report was received and showed a successful result, Task Group 400 eliminated this option.

9. Base the allowable exit access travel distance on the commodity classification in the storage area.

Pros: Smoke/heat venting requirements are based on commodity classification. This would be a similar approach. As the level of hazard increased, the allowable exit access travel distance would be reduced. This would be an engineering approach and would be tailored specific to the hazard.

Cons: This requirement would be very difficult to maintain and enforce throughout the life of the building. In most buildings, the stored product can change based on season, clientele, or just change in manufacturing methods. This changing storage could result in a different exit access travel distance that the building is not designed for.

There are many variables which are used to determine the level of hazard. The combustibility of the product, the combustibility of the packaging, the combustibility of the pallet, the width of aisles, the height of storage, the configuration of the storage are all factors in determining the level of fire hazard. A simple application to commodity classification will not capture all of the variables. This may be an engineered solution but could quickly become quite complicated in its application.

Action: This option was eliminated because it is not as simple as it first appeared, and would create enforcement difficulties throughout the life of the building.

10. Create different set of allowable travel distances for Group S-1 occupancies and for Group F-1 occupancies.

Pros: There are differences in the fireloading between a storage warehouse and a manufacturing facility. The fire load is typically higher in the warehouse; however, the likelihood for fire to occur is greater in a manufacturing process.

When you assume that a fire will occur in both types of occupancies, then you just compare the fire load in each type facility. With the higher fire load in storage areas, you can expect a higher heat release rate, which would necessitate a shorter exit access travel distance.

Cons: There are many facilities which include both an F-1 portion and an S-1 portion in an undivided building. When looking at allowable area, construction type and other construction requirements, the F-1 and S-1 are considered equal. So if a different egress requirement is suddenly applied to one and not the other, it will create confusion and misapplication.

Action: This option was eliminated because it would create new problems in facilities containing both a Group F-1 and a Group S-1.

11. Require emergency lighting of the egress path.

Pros: Emergency lighting would provide a lit egress path. This would increase visibility to allow for safer egress.

Cons: Normal lighting is required during building operation, and emergency lighting is only needed when the electric power supply is lost. If the thought is to allow the fire to continue to burn until it damages the wiring supply power to the normal lighting, then typically all of the occupants will already be out of the building. Therefore, this would provide no improvement over the current use of normal lighting.

Action: This option was eliminated since the code already adequately addresses both normal lighting and emergency lighting.

12. Leave the code as isé do not propose a code change.

Pros: Leaving the code as is will mean that the maximum travel distance can be 250 feet.

Buildings can still be constructed with +/-1,000,000 square feet and still be able to comply with a travel distance of 250 feet. New buildings can comply by constructing exit passageways leading from the center of the building to the exterior. This is demonstrated in Figure 2.

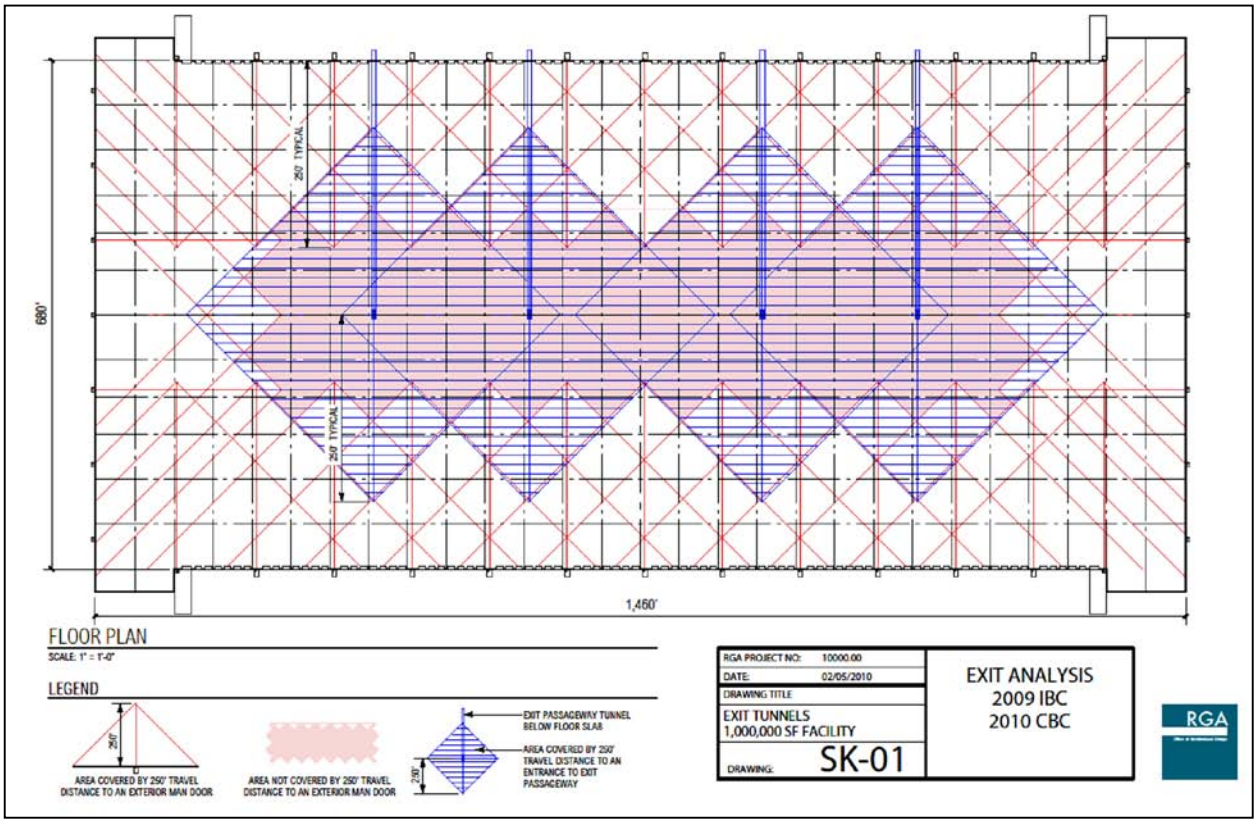

Figure 2 – Warehouse/Factory Occupancy with an Exit Access Travel Distance of 250 Feet

Cons: Exit passageways constructed in these large buildings are constructed as tunnels beneath the floor of the warehouse. This allows for minimal loss of floor space, which in turn allows for more storage.

The allowed exit access travel distance of 400 feet has not resulted in any known life loss since its first application in the 1998 California Building Code.

Even before the allowance of the exit access travel distance of 400 feet went into the code, fire modeling was used to justify the increased travel distance. Rather than construct the tunnels, fire modeling would be repeated for each specific building. If it can be shown through fire modeling in a generic building that the travel distance of 400 feet is acceptable, then it will eliminate the need to have each project repeat the process.

Even though the tunnels provide compliance with the code, they are not a practical solution to the problem for the following reasons:

- The typical occupant in these areas will be employees. The employees know where the exits are located.
- Tunnels are expensive, and not routinely maintained.

- The employees also know about the tunnels. And they probably also know the last time they were cleanedé who knows what is down there. So there will be a reluctance to use the tunnels.

- Fire departments typically will not utilize the tunnels for firefighting operations. From a firefighting standpoint, it is safer to enter from the exterior of the building and head towards the fire, rather than pop out of a tunnel possibly in the middle of the fire.

- It is nearly impossible to comply with ADAAG provisions in a tunnel.

- Even though this solution meets the code requirement, it is an expensive construction that results in little or no benefit.

Action: This option was eliminated since it did not provide a practical solution to the situation.

Task Group 400 decided that the most viable solution was to develop a set of parameters which considered the vast volume of the large building could be utilized to contain the smoke before it fills the space down to a point where egress is affected.

The Boeing Company conducted fire modeling to evaluate an aircraft manufacturing hangar with a ceiling height of 50 feet and provided with a fire sprinkler system. This report demonstrated that the ceiling height of 50 feet captured enough smoke and heat to provide adequate egress time for a travel distance of 400 feet.

The Boeing Company conducted additional fire modeling to evaluate an aircraft manufacturing hangar with a ceiling height of 25 feet and provided with a fire sprinkler system. This report demonstrated that the ceiling height of 25 feet would also capture enough smoke and heat to provide adequate egress time for a travel distance of 400 feet.

Aon Fire Protection Engineering had completed a fire modeling study for a warehouse building with a ceiling height of 30 feet. This fire modeling was based on the use of early suppression fire-response sprinklers.

The fire modeling reports showed successful results, however, common warehouses are frequently constructed with different design parameters. Many warehouses have a ceiling height of 24 feet, and use control-mode sprinklers rather than ESFR. This would rule out the application of the fire modeling to many new buildings.

It was decided to further explore this concept and have additional fire modeling completed to determine if a warehouse building with a ceiling height of 24 feet and a control-mode fire sprinkler system would provide favorable results.

ñThe early suppression fast-response (ESFR) sprinkler technology is specifically designed for the high-challenge storage occupancies. The ESFR technology is designed to operate earlier and provide an adequate flow of water to suppress the fire. Control Mode Density Area (CMDA) sprinklers are designed to control the spread of fire. While the CMDA sprinklers may also extinguish a fire, a satisfactory result from CMDA is to just stop the continued spread of the fire. The CMDA sprinkler was chosen as the more conservative approach rather than ESFR

technology. If the control mode sprinkler design provides adequate results, the ESFR sprinkler design will provide for improved results.ò[5]

In order to justify the increased exit access travel distance, Aon Fire Protection Engineering was engaged to perform fire modeling. The design parameters for the fire modeling were specific. The design building was a warehouse occupancy; the design fire consisted of rack storage of Group A plastic commodities. This fire was selected with the expectation that if this design was successful, all lesser hazards would also be successful. The Aon FPE report states ñAs a conservative approach, high-pile rack storage of Group A plastics was selected as the primary fuel. This commodity is recognized to represent the most severe fire hazard of the high density plastics tested.ò[6] The fire modeling performed by Aon Fire Protection Engineering demonstrates that with control mode sprinklers and a ceiling, or underside of roof, height of 24 feet, an exit access travel distance of 400 is acceptable. The complete report is attached as Appendix A.

Effect on Firefighting Operations

In the discussions of determining a solution for to allow the exit access travel distance of 400 feet, Task Group 400 recognized that the allowed increase would have an impact on firefighting operations. When a building is designed utilizing the travel distance of 400 feet, it results in larger buildings. Utilizing exit access travel distances of 400 feet to the closest exit, buildings can easily be designed with a narrow dimension of 600 to 700 feet. This results in firefighting operations where fire hose needs to be dragged into the building that same distance of 400 feet.

Whereas previously allowed construction was based on the installation of smoke/heat vents, the proposed solution was to allow the increased travel distance based on the volume of the building. The smoke/heat vents proved to be a benefit in the firefighting operations even though they were installed to allow the increased exit access travel distance. The concern with the impact on firefighting operations led Task Group 400 to consider mitigation measures to relieve some of the firefighting impact that the increased exit access travel distance was going to create.

Mitigation measures were considered using the guidance found in CFC Table 2306.2 Footnote g which reads:

> ñSpecial fire protection provisions including, but not limited to, fire protection of exposed steel columns; increased sprinkler density; additional in-rack sprinklers, without associated reductions in ceiling sprinkler density; or additional fire department hose connections shall be provided when required by the fire code official.ò[7]

Even though the footnote is applied when allowing larger fire areas than those listed in the table, it was felt that it also had appropriate application to this situation. The following mitigation measures were evaluated:

1. Provide additional fire protection for exposed steel columns supporting the roof.

[5] ñFire Modeling Analysis Reportò, Aon Fire Protection Engineering, November 29, 2010, Page 4.
[6] ñFire Modeling Analysis Reportò, Aon Fire Protection Engineering, November 29, 2010, Page 5.
[7] ñ2010 California Fire Codeò, California Building Standards Commission, Page 326.

Pros: This will increase the fire resistivity of the supporting columns and provide for a longer time before the columns are affected by fire.

This would allow more protection for the supporting structure and inhibit roof collapse so that the occupants will have additional time to exit the building.

Cons: In a fire situation, the steel columns directly impinged by the flames could be affected. These would be the columns within the perimeter of the fire itself. This effect on the steel columns will not occur immediately.

There are requirements in NFPA 13 that adequately require protection of steel columns when the columns are located within a storage array.

Action: This option was eliminated. It does provide protection for the firefighting operation, however it is already required by NFPA 13 and therefore would not result in any additional mitigation.

2. Increase the Actual Delivered Density (ADD) of the fire sprinkler system.

Pros: Providing an increase in the quantity of sprinkler water delivered onto the fire would assist in reducing the size and spread of the fire, thereby reducing the fire size when the fire department arrived.

Cons: The determination as to what the actual increase in sprinkler density is a not immediately known. There are many jurisdictions which use a 10% increase, however, there is no documentation to justify this percentage.

Fire testing would need to be completed to determine whether an actual increase of 10% produced the desired results.

It seems quite possible that the percentage of increase could also need to change as the level of hazard increased from Class I commodity to High Hazard commodity.

Action: This option was eliminated since without fire testing it would just be a ñbest guessò solution.

3. Installing in-rack sprinklers, without associated reductions in ceiling sprinkler density.

Pros: This concept would provide additional sprinkler water right onto the fire. The additional water would assist in reducing the size and spread of the fire, thereby reducing the fire size when the fire department arrived.

Cons: This solution would place sprinklers directly within the rack. Sprinklers located within racks become damaged during normal pallet-loading operations.

Storage in racks is not required in warehouse occupancies. Storage can be arranged as solid-pile storage or pallet storage and in those configurations in-rack sprinklers is not an option. This is not a workable solution in a warehouse which is not using racks for storage.

Sprinklers located within racks restrict flexibility in rack locations and adjustment for future tenants.

Many sprinkler fire tests have been conducted with the goal of eliminating sprinklers in racks.

Action: This option was eliminated since it does not fit all storage configurations and would have no application in some buildings.

4. Install a standpipe system for fire department use.

Pros: This standpipe system would consist of 2½ò hose connections for firefighting operations. The hose connections could be spaced out around the perimeter of the building and at interior openings through fire walls or fire barriers. The hose connections would assist in firefighter access to the fire and reduce the need to drag water-filled hose.

Cons: In many firefighting operations, fire apparatus can typically be located 50 to 75 feet from the building access doors. Therefore, this would only reduce a minimal distance of hose.

Concerns were discussed as to whether the hose connections should be located on the exterior so that they are outside of the fire area, or whether they should be located on the interior so that they are not subject to freezing.

On these large buildings, fire department operations vary from department to department. It may be difficult establish a fit-all design option.

Action: This option was eliminated since the realized benefit did not rise to the level of mitigation of the increased building size.

5. Require smoke/heat vents with all ESFR sprinkler systems.

Pros: Smoke/heat vents can be a tremendous asset during firefighting operations. Assuming that the smoke/heat vents donôt open as a result of the fire, they are still on the roof and available for manual operation.

The current California Building Code and California Fire Code require a method of manual activation. During a fire, firefighters could access the roof, travel to the appropriated smoke/heat vents, operate the manual release, and retreat quickly from the roof. Anytime firefighters are on the roof, they are in a dangerous situation. The less time spent on the roof, the less time firefighters are at risk.

California is an area where seismic activity can disable water supply and damage water supply piping and fire sprinkler piping. The requirement for smoke/heat vents in buildings protected with ESFR sprinklers provides a backup for this event. If the sprinkler system is disabled for any reason, the smoke/heat vents will prove invaluable. They will operate automatically and

provide a release for the smoke and heat allowing occupants to egress. The release of smoke and heat will also benefit the firefighting operation.

Cons: This would be a change to the concept now in the code where smoke/heat vents are not required when ESFR sprinkler systems are utilized. Smoke/heat vents are not required in the current code when ESFR sprinkler systems are installed. The requirement for smoke/heat vents with ESFR was removed as a result of fire testing which indicated that if all of the smoke/heat vents were open prior the start of a fire, it could delay the operation of the first fire sprinkler.

Action: This option was considered to be an appropriate mitigation measure for firefighting operations in these large buildings. The sprinkler operation is more critical than the smoke/heat vent operation. Criteria would need to be included to restrict the vent operation from impacting the sprinkler operation.

NFPA standards and Factory Mutual standards were used to determine criteria which would allow the sprinkler to operate before the smoke/heat vent would operate.

Recommended Code Change

Task Group 400 recommends the following code change consisting of Six Parts. This code change provides another solution to allowing an exit travel distance of 400 feet. This code change also considers the fact that firefighting operations are impacted when larger buildings are constructed where the exit access travel distance is allowed to be 400 feet. As a result, mitigation to the firefighting impact is included in the code change.

Part 1
Add Item to 2010 CBC/CFC Table 1016.1 Footnote A as follows:

TABLE 1016.1
EXIT ACCESS TRAVEL DISTANCE[a]

OCCUPANCY	WITHOUT SPRINKLER SYSTEM (feet)	WITH SPRINKLER SYSTEM (feet)
A, E, F-1, M, R, S-1	200	250[b]
B	200	300[c]
F-2, S-2, U	300	400[c]
H-1	Not Permitted	75[c]
H-2	Not Permitted	100[c]
H-3	Not Permitted	150[c]
H-4	Not Permitted	175[c]
H-5	Not Permitted	200[c]
I-2, *I-2.1*, I-3[d], I-4	150	200[c]
L	*Not Permitted*	*200*[c]

For SI: 1 foot = 304.8 mm.
a. See the following sections for modifications to exit access travel distance requirements:
Section 402.4: For the distance limitation in malls.
Section 404.9: For the distance limitation through an atrium space.
Section 407.4: For the distance limitation in Group I-2.

Sections 408.6.1 and 408.8.1: For the distance limitations in Group I-3.
Section 411.4: For the distance limitation in Special Amusement Buildings.
Section 1014.2.2: For the distance limitation in Group I-2 Hospital Suites.
Section 1015.4: For the distance limitation in refrigeration machinery rooms.
Section 1015.5: For the distance limitation in refrigerated rooms and spaces.
Section 1016.3: For increased limitation in Groups F-1 and S-1.
Section 1021.2: For buildings with one exit.
Section 1028.7: For increased limitation in assembly seating.
Section 1028.7: For increased limitation for assembly open-air seating.
Section 3103.4: For temporary structures.
Section 3104.9: For pedestrian walkways.

b. Buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1 or 903.3.1.2. See Section 903 for occupancies where automatic sprinkler systems in accordance with Section 903.3.1.2 are permitted.

c. Buildings equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1

d. Not permitted in non-sprinklered Group I-3 Occupancies.

Add Section 1016.3 to the 2010 CBC/CFC as follows:

1016.3 Group F-1 and S-1 increase. *The maximum exit access travel distance shall be 400 feet (122 m) in Group F-1 or S-1 occupancies where all of the following are met:*

1. The portion of the building classified as Group F-1 or S-1 is limited to one story in height,
2. The minimum height from the finished floor to the bottom of the ceiling or roof slab or deck is 24 feet (7315 mm), and
3. The building is equipped throughout with an automatic fire sprinkler system in accordance with Section 903.3.1.1.

Part 2
Amend Section 910.1 of the 2010 CFC/CBC as follows:

910.1 General. Where required by this code or otherwise installed, smoke and heat vents or mechanical smoke exhaust systems and draft curtains shall conform to the requirements of this section.

Exceptions:

1. Frozen food warehouses used solely for storage of Class I and II commodities where protected by an approved automatic sprinkler system.

2. ~~Where areas of buildings are equipped with early suppression fast response (ESFR) sprinklers, automatic smoke and heat vents shall not be required within these areas. *This exception shall not apply to any state institution or other state-owned or state-occupied buildings and other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal.*~~ *Automatic smoke and heat vents are not required within areas of buildings equipped with early suppression fast-response (ESFR) sprinklers unless any of the following conditions exist:*

2.1. The building is a state institution,
2.2. The building is a state-owned or state-occupied building,
2.3. The building is any of the applications listed in Section 1.11 regulated by the Office of the State Fire Marshal, or
2.4. The area of a Group F-1 or S-1 occupancy protected with the ESFR sprinklers has an exit access travel distance of more than 250 feet (76 200 mm).

Part 3
Amend Section 910.2.1 of the 2010 CFC/CBC as follows:

910.2.1 Group F-1 or S-1. Buildings and portions thereof used as a Group F-1 or S-1 occupancy having more than 50,000 square feet (4645 m^2) of undivided area.

Exception: *Group F-1 aircraft manufacturing buildings and* Group S-1 aircraft repair hangars.

Part 4
Amend Section 910.3.2.2 of the 2010 CFC/CBC as follows:

910.3.2.2 Sprinklered buildings. Where installed in buildings equipped with an approved automatic sprinkler system, smoke and heat vents shall be designed ~~to operate automatically~~ *in accordance with Sections 910.3.2.2.1 through 910.3.2.2.3*.

910.3.2.2.1 Automatic operation. *Smoke and heat vents shall be designed to operate automatically.*

910.3.2.2.2 Control mode sprinkler system. *Smoke and heat vents installed in areas of buildings with a control mode sprinkler system shall have operating elements with a higher temperature classification than the automatic fire sprinklers in accordance with NFPA 13.*

910.3.2.2.3 Early suppression fast-response (ESFR) sprinkler system. *Smoke and heat vents installed in areas of buildings with early suppression fast-response (ESFR) sprinklers shall be equipped with a standard-response operating mechanism with a minimum temperature rating of 360ºF (182ºC) or 100ºF (56ºC) above the operating temperature of the sprinklers, whichever is higher.*

Part 5
Amend Footnote J on Table 2306.2 of the 2010 CFC as follows:

j. Not required when storage areas *with an exit access travel distance of 250 feet (76 200 mm)or less* are protected by early suppression fast-response (ESFR) sprinkler systems installed in accordance with ~~NFPA 13~~ *Section 903.3.1.1*. *This footnote shall not apply to any state institution or state-owned or state-occupied buildings or other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal.*

Part 6
Revise Chapter 47 of the 2010 CFC by amending Section 12.1.1.2 of the 2010 NFPA 13 Standard for the Installation of Sprinkler Systems as follows:

12.1.1.2 Early suppression fast-response (ESFR) sprinklers shall not be used in buildings with automatic heat or smoke vents unless the vents use a ~~high-temperature rated,~~ standard-response operating mechanism *with a minimum temperature rating of 360ºF (182ºC) or 100ºF (56ºC) above the operating temperature of the sprinklers, whichever is higher*.

Also, revise Chapter 35 of the 2010 CBC by amending Section 12.1.1.2 of the 2010 NFPA 13 Standard for the Installation of Sprinkler Systems as follows:

12.1.1.2 Early suppression fast-response (ESFR) sprinklers shall not be used in buildings with automatic heat or smoke vents unless the vents use a ~~high-temperature rated,~~ standard-response operating mechanism *with a minimum temperature rating of 360ºF (182ºC) or 100ºF (56ºC) above the operating temperature of the sprinklers, whichever is higher*.

Rationale for Code Change

Part 1

Part 1 is the main body of the code change. Initially, a simple addition to Footnote A in Table 1016.1 is added to make a reference to a new Section 1016.3.

Section 1016.3 is added to provide the criteria for an increased exit access travel distance of 400 feet in Group F-1 and S-1 occupancies. The criteria for application of this section includes:

1. The travel distance increase is only applicable to areas of the building which are one story in height. The allowance for a travel distance of 400 feet in the 2007 CBC is limited to buildings which are one story in height, so this concept is carried forward.

   This would not preclude a building with a one story warehouse or factory area and a two story office or a mezzanine from also utilizing this section. The section is written so that the one story limitation is only applicable to the area where the 400 foot travel distance is utilized. The two story office building would still be limited to 300 feet as indicated in Table 1016.1.

2. The minimum height from floor to ceiling above, or the underside of the roof deck, must be 24 feet. The 24 feet is measured to the bottom of the roof or ceiling above.

   The height is specified as óminimumô. It is not intended to be applied to an óaverageô height, it is the minimum. It is assumed that beams and purlins will extend down below this height of 24 feet.

   The 24 feet of clearance is based on the ñFire Modeling Analysis Reportò by Aon Fire Protection Engineering.[8] The 24 feet ceiling is used to store the smoke during the fire event and provide time for egress.

3. Protection by a fire sprinkler system designed in accordance with Section 903.3.1.1 (NFPA 13). This reference to NFPA 13 will include sprinkler systems designed with control mode sprinklers, ESFR sprinklers and any other design allowed by NFPA 13.

   Again, the Fire Modeling Analysis Report demonstrates adequate time for evacuation when control mode sprinklers are utilized in buildings with 24 feet minimum to the

[8] ñFire Modeling Analysis Reportò, Aon Fire Protection Engineering, November 29, 2010.

underside of the roof deck or ceiling above. The control mode sprinkler was utilized in the fire modeling to demonstrate the more conservative approach. Certainly, ESFR or specialty sprinklers will provide more water than the control mode sprinkler and would therefore be more effective.

Part 2

This part of the code change is now focused towards the installation of smoke/heat vents. Since the revision in Part 1 will allow an exit access travel distance of 400 feet, buildings will be larger. It can be demonstrated in this manner, if the occupant can travel 400 feet to the closest exit door, then the reverse of that means that a firefighter must drag hose 400 feet from that closest door back to the fire. Certainly this is the worst case, but it does show the point that the firefighting operation becomes more difficult, and more dangerous, with the increased exit access travel distance.

One of the most dangerous aspects of firefighting operations is working on the roof of a building when the fire is just below. Although it is frequently and routinely done, there are many dangers when working on the roof of a building which is burning. But ventilating the building, or exhausting the smoke, is a critical function. Releasing the smoke and heat from a building allows the firefighters to make entry and attack the fire in a safer environment. Releasing the smoke reduces property loss as a result of smoke damage during the fire.

Typical ventilation practices during a fire include creating openings in the roof to allow the hot gases and heated smoke to escape. Smoke/heat vents are one method of providing those openings in the roof. The proposed code change allows larger buildings based on sprinklers and ceiling height rather than on the installation of smoke/heat vents. Typically, ESFR sprinkler systems are installed without smoke/heat vents. One reason for this is that when the smoke/heat vents are open prior to the fire, the smoke/heat vents can delay the operation of the first fire sprinkler. Section 910.1 Exception 2 currently reads that smoke/heat vents are not required in buildings protected with ESFR sprinklers. Part 2 will modify Exception 2 to require smoke/heat vents when ESFR sprinkler systems are used in the following situations:

1. If the building is a state institution, smoke/heat vents will be installed in all cases even when ESFR sprinklers are installed.

2. If the building is a state-owned building or a state-occupied building, smoke/heat vents will be installed in all cases even when ESFR sprinklers are installed.

3. If the building is any occupancy regulated by the State Fire Marshal as indicated in Section 1.11 smoke/heat vents will be installed in all cases even when ESFR sprinklers are installed.

4. If the building is a Group F-1 or S-1 occupancy with an exit access travel distance in excess of 250 feet, smoke/heat vents will be installed in all cases even when ESFR sprinklers are installed.

As was mentioned previously, there is a concern with smoke/heat vents impacting the operation of ESFR sprinklers. To address this situation, revisions are also proposed to CFC/CBC Section 910.3.2.2 (Part 4) and Section 12.1.1.2 of NFPA 13 (Part 6).

Part 3

The revision to 910.2.1 is mainly a clean-up item. This change adds Group F-1 aircraft hangars (manufacturing) to the already exempted Group S-1 aircraft hangars (repair). Currently the Group S-1 aircraft hangar is exempt from the requirement for smoke/heat vents. The Group F-1 aircraft hangar is of a similar construction and design. Essentially this code change will take the exception which applies to hangars where aircraft are repaired, and extend that same exception to the hangar where the same aircraft were built.

Part 4

Section 910.3.2.2 is modified to specify the operating characteristics of smoke/heat vents in sprinklered buildings. This revision is formatted to provide a list of requirements.

Section 910.3.2.2.1 simply relocates the requirement for automatic operation of smoke/heat vents from the previous section.

Section 910.3.2.2.2 adds the requirement that the thermal element of smoke/heat vents shall have a higher temperature rating than the fire sprinklers. This will allow the sprinklers to operate before the smoke/heat vent operates. This is consistent with NFPA 13 Section 12.1.1.1 which states in part ñé roof vents with operating elements that have a *higher temperature* classification than the automatic sprinklers shall be permitted.ò[9] [emphasis added]

Section 910.3.2.2.2 adds the requirement that where an ESFR sprinkler system is installed, the thermal element of smoke/heat vents shall have a temperature rating of at least 100ºF above the sprinkler temperature and a minimum of 360ºF. This will allow the ESFR sprinklers to operate before the smoke/heat vent operates. This is consistent with NFPA 13 Section 12.1.1.2 which states in partñé ESFR sprinklers shall not be used in buildings with automatic heat or smoke vents *unless* the vents use a high-temperature rated, standard response operating mechanism.ò[10] [emphasis added]. This requirement is also consistent with the Factory Mutual Approval Standard for Smoke and Heat Vents, FM 4430 Section 4.8.1 which states in part ñAs an option, heat and smoke vents shall be permitted to be subjected to a modified fire test in order to determine if the product can be used in conjunction with ESFR sprinklers without adversely affecting their ability to activate. This shall be determined by assessing the domeôs ability not to allow venting until a 360ºF (182ºC) fusible link has activated.ò[11]

Therefore, smoke/heat vents are required to be installed, and must be equipped with a fusible link that is above the sprinkler operating temperature. This will ensure that the sprinklers operate

[9] ñNFPA 13, Standard for the Installation of Sprinkler Systemsò 2010 Edition, NFPA, Section 12.1.1.1.
[10] ñNFPA 13, Standard for the Installation of Sprinkler Systemsò 2010 Edition, NFPA, Section 12.1.1.2.
[11] ñApproval Standard for Smoke and Heat Vents FM 4430ò, 2007 Edition, FM Approvals, Section 4.8.1.

prior to the smoke/heat vent. It might also result in smoke/heat vents that do not open on their own during a fire situation. However, California is susceptible to earthquake activity. During a seismic event, the water system could be incapacitated. In that case, the sprinklers will be inoperative, but the smoke/heat vents will operate automatically.

Part 5

This part amends Footnote J on CFC Table 2306.2 by adding the requirement for smoke/heat vents when the exit access travel distance exceeds 250 feet. The revision also correlates the requirements in the footnote with the proposed changes to Section 910.1 in Part 2.

The reference is revised from ñNFPA 13ò to ñSection 903.3.1.1ò to be consistent with code format. Section 903.3.1.1 is the code section which references directly to NFPA 13.

Part 6

This part adds amendments to NFPA 13. These revisions specifically address the temperature rating of the thermal element of smoke/heat vents when utilized with ESFR sprinkler systems. The 360ºF rating comes from the requirements in the FM 4430 Standard, and the 100ºF requirement simply provides a specific separation between the thermal element of the sprinkler and the thermal element of the smoke/heat vent.

Appendix A – Fire Modeling Analysis Report

Fire Protection Engineering

Fire Modeling Analysis Report

Task Group 400

December 20, 2010
(Revised July 20, 2011)

AonFPE No. 2310014-001

Prepared For:

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Executive Summary

The 2009 International Building Code (and 2010 California Building Code) reduced the previously allowed 400 feet exit travel distance in Group S, Division 1 and Group F, Division 1 Occupancies to 250 feet. The intent of this analysis is to establish whether a 400 foot exit travel distance will provide safe conditions for occupant egress during a fire event.

Task Group 400 (Client) engaged Aon FPE to perform fire modeling analysis of a fire incident in a typical large, high ceiling, control-mode sprinkler system equipped warehouse building in order to perform this analysis. The Task Group 400 roster is shown below:

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The analysis incorporates current code requirements for these facilities, as well as compares the calculated occupant egress time in relation to the tenability of the space. A computer model of the building, utilizing the computational fluid dynamics (CFD) software known as Fire Dynamics Simulator (FDS), which is a product of the National Institute of Standards and Technology (NIST), was utilized to evaluate the fire scenario.

The results of a literature search of the fire behavior of expanded, exposed plastic indicates such material has a faster growth rate and heat release rate at first sprinkler operation, however the peak heat release rates are comparable. The prewetting of the cartons is thought to be the reason for slowing the initial fire growth. Although it is known that exposed, expanded plastics are more challenging to control/extinguish by sprinkler operation, modern day computer programs cannot account for this factor, including the difference in smoke production rates. Thus the heat release rate of cartoned, expanded plastics was used in the modeling evaluation.

Highlighted results of the analysis include the following:

- The high ceilings in these large buildings create a massive volume for smoke and toxic gasses to fill before descending to 6 feet above finished floor which is the level that will impact occupants and responders.
- It takes over 10 minutes before the smoke begins to descend from the ceiling.
- The amount of time for an individual to travel 400 feet is 106.95 seconds (1 minute and 47 seconds).
- The additional time an occupant needs to reach an exit is 40 seconds if the exit travel distance is increased from 250 feet to 400 feet.
- Tenable conditions, meaning safe temperatures, ample visibility, and the absence of unsafe toxic gasses, are maintained at 6 feet above the finished floor throughout the facility for the entire duration of the model (20 minutes).

Therefore, this fire model shows that a 400 foot exit travel distance will not provide untenable conditions for the occupants in typical large, high ceiling, control-mode sprinkler system equipped warehouse buildings.

Project Description

The building used for this analysis is considered representative of this type of large, high ceiling warehouse, and includes the following specifications: 680 feet wide, 1,460 feet long, and 24 feet to the underside of the roof deck at the perimeter, increasing to 30 feet to the underside of the roof deck at the ridge line. Classified as Group S, Division 1 and Group F, Division 1 Occupancies, Type V-B or Type III-B construction type was assumed. This analysis also assumes that the building does not rely on smoke and heat vents for smoke removal, but is equipped with control-mode sprinkler system.

Applicable Codes

The current applicable building code in the State of California is the 2007 California Building Code (CBC), which is based on the 2006 International Building Code (IBC). As of January 1, 2011, the State of California will enforce the 2010 CBC, which will be based on the 2009 IBC.

Existing Exit Access Travel Distance Requirements

Exit access travel distance is governed by Section 1016 of the 2006 IBC (2007 CBC).

According to Table 1016.1, Group F-1 and S-1 occupancies, equipped with automatic sprinkler systems, have a maximum exit access travel distance of 250 feet. Table 1016.1, footnote a, also references 2006 IBC (2007 CBC) Section 1016.2, which allows for a maximum travel distance of 400 feet where smoke and heat vents are provided in addition to the automatic sprinkler systems. This travel distance extension predates the International Codes; appearing in the Uniform Building Code in 1973.

2006 IBC (2007 CBC) Section 1016.2 states:

> "**1016.2 Roof vent increase**. In buildings that are one story in height, equipped with automatic heat and smoke roof vents complying with Section 910 and equipped throughout with an automatic sprinkler system in accordance with Section 903.3.1.1, the maximum exit access travel distance shall be 400 feet (122m) for occupancies in Group F-1 and S-1."

Changes to the 2009 IBC (2010 CBC) Travel Distance Requirements

The efficacy of smoke and heat vents has been the subject of an on-going debate at the National level. As a product of that debate, the 2006 IBC Section 1016.2 has been deleted in its entirety in the 2009 IBC effectively eliminating this 400-ft exit access travel distance. This deletion will also eliminate the 400-ft exit access travel distance in the 2010 CBC, which will be enforced as of January 1, 2011. The result of this code change is the elimination of a longstanding exit travel distance provision from the IBC and CBC.

This analysis is not intended to take sides on the smoke and heat vent debate but rather to analyze whether the upcoming reduction in exit access travel distance from 400-ft down to 250-ft is truly warranted in the subject building, based on past performance and a technical analysis of fire scenarios in these buildings.

Proposed Design

The intent of this fire model report is to predict tenable conditions based upon the specific characteristics of the referenced building and offer an engineering judgment that an exit access travel distance extension, to a maximum of 400 feet, is appropriate for the occupants to exit the building before untenable conditions are reached.

Design Justification

The first step in developing an alternate design approach is to determine the goals of the design. From these goals, measurable objectives are determined, and the actual design details must meet these objectives.

The conditions that could occur within a building during a fire situation can be simulated by conducting appropriate fire testing or performing computer modeling. Prior to establishing the design goals, a review of the project parameters and the predicted fire scenario is of benefit.

Sprinkler Technology

Control Mode Density Area (CMDA) sprinkler protection is the oldest and still most commonly used sprinkler technology for the protection of storage. It was developed in the late 1960s in response to warehouse fires resulting from rapid changes in storage technology. In the 1970's, the first sprinkler developed specifically for the protection of storage was the Large-Drop Control Mode Specific Application (CMSA) Sprinklers. The K11.2 sprinkler had a deflector designed to produce a higher proportion of large water drops, enhancing penetration and performance. This was the birth of new sprinkler technology for high-challenge storage occupancies, in which sprinkler orifice size and operating pressure were the measure of sprinkler performance, not discharge density and operating area[1].

Control mode sprinklers are still use today. Sprinkler design criteria for protection of double-row racks with commodities stored up to 25-ft on a building with a maximum building height of 30-ft height was assumed.

The early suppression fast-response (ESFR) sprinkler technology is specifically designed for the high-challenge storage occupancies. The ESFR technology is designed to operate earlier and provide an adequate flow of water to suppress the fire. CMDA sprinklers are designed to control the spread of fire. While the CMDA sprinklers may also extinguish a fire, a satisfactory result from CMDA is to just stop the continued spread of the fire. The CMDA sprinkler was chosen as the more conservative approach father than ESFR technology. If the control mode sprinkler design provides adequate results, the ESFR sprinkler design will provide for improved results.

Fire Modeling Analysis

The analysis is based upon computational modeling utilizing the Fire Dynamic Simulator (FDS), Version 5.4.3 software produced by the National Institute of Standards and Technology (NIST). A computational model is a virtual representation of a physical object or space. Computational Fluid Dynamics (CFD) is the application of mathematical tools to study the dynamics of fluid flow within this virtual model. Many

[1] http://www.pmengineer.com/Articles/Feature_Article/2006/05/01/Meeting-the-Challenges-of-an-Ever-Changing-Storage-Industry

different CFD software packages are available for specific applications. FDS is most appropriate for fire in the built environment.

FDS is a tool that numerically solves a form of the Navier-Stokes equations appropriate for relatively low-speed, buoyant flow with an emphasis on smoke and heat transport from fires. These numerical solutions are achieved in the model by dividing the space into thousands of small, cubical computational cells. The model then computes transient and spatial gradients of quantities such as gas velocity, temperature, density, pressure, and species concentration based on the governing equations of mass, momentum, and energy conservation. These three-dimensional transient solutions are ultimately visualized with a graphic software package known as Smokeview. Smokeview, which was also developed by NIST, is a visualization tool that is critical for a comprehensive evaluation of smoke generation and transport throughout the virtual model in any given fire scenario.[2]

The fundamental performance criterion for this approach is that any occupant who is not intimate with ignition must not be exposed to instantaneous or cumulative untenable conditions. Tenability is judged based upon criteria for visibility, exposure to heat and exposure to noxious gases as discussed in more detail in the Tenability Criteria section of this report.

Design Fire

The type and form of the commodity are the most influential factors in determining the heat release rate of a storage fire[3]. The heat content of the material, the burning rate, the exposed surface area, and how the commodity reacts to the application of water determine the protection requirements. Rack storage fires are generally more severe than solid-piled storage because of better air access and stability of the burning product. Storage height is a key determinant of heat release rate. As more material is exposed vertically, the burning rate increases with increasing storage height.

The overall hazard of a commodity is a function of its heat release rate (kW) which is the product of its heat of combustion (kJ/kg) and burning rate (kg/sec)[4]. The typical storage commodity for a large warehouse could consist of a mixture of products, ranging from Class I to Group A plastic. As a conservative approach, standard plastic commodity was selected. This commodity is recognized to represent the most severe fire hazard of the high density plastics tested[5].

Plastics materials are manufactured as unexpanded and expanded. Generally, the heat release rate for expanded plastics is greater than for unexpanded plastics due mainly to the relatively low density and resulting high burning rate[4]. The heat of combustion for a given plastic material is about the same whether it is expanded or unexpanded[4]. Existing sprinkler design criteria to protect uncartoned expanded plastics commodities in open frame rack storage arrangements utilizing ceiling-level protection was researched. Recommendations to use control model sprinklers are provided in the latest FM Global Loss Prevention Data Sheet 8-9.

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[2] Kevin B. McGrattan, Howard R. Baum, Ronald G. Rehm, Anthony Hamins, Glenn P. Forney, *"Fire Dynamics Simulator – Technical Reference Guide"*, National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 6467, January 2000.

[3] FM Global Property Loss Prevention Data Sheet 8-9 *"Storage of Class I, 2, 3,,4 and Plastic Commodities"*.

[4] FM Global Property Loss Prevention Data Sheet 8-1 *"Commodity Classification "*.

[5] An Engineering Approach to Industrial Fire Protection, Robert Zalosh, January 1994.

Ultrafast Design Fire

An idealized fire model that is of considerable use is the t-squared fire. The heat release rate of this fire is proportional to the square of time. This idealized heat release rate is expressed as:

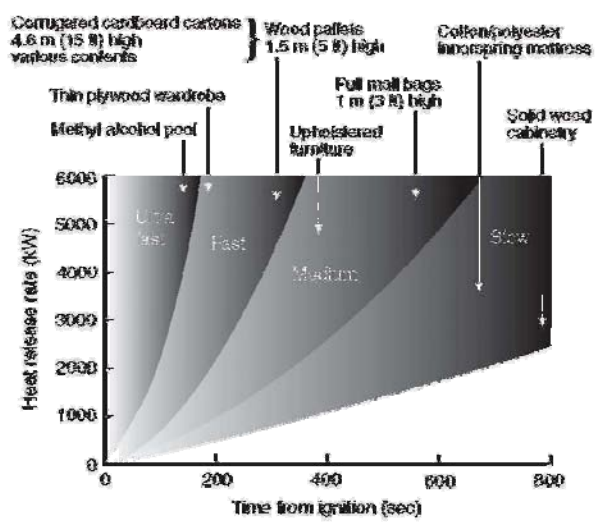
$$E = 1055\left[\frac{t}{t_g}\right]^2 \qquad (1)$$

Where:

E	=	heat release rate of fire (kW)
t	=	time after effective ignition (seconds)
t_g	=	growth time (seconds)

The growth time, t_g, is the interval between the time of effective ignition and the time when the heat release rate of the fire reaches 1,055 kW. For an ultrafast fire, the fire growth rate follows the t-squared fire curve and reaches 1,055 kW in 75 seconds or 10,000 KW in 231 seconds. This "ultrafast" growth design fire was selected due to the expected fuel load in the high-piled rack storage of Group A plastics. Figure No. 1 illustrates a typical t-squared fire curve[6].

Figure No. 1: Fire Growth Rate Model (t^2)



Combustion Model

The combustion model uses a comprehensive method that handles oxygen consumption naturally and solves an equation for a constant scalar quantity, known as the mixture fraction, which is defined as the fraction of gas at a given point in the flow field that originated as fuel. The model assumes that combustion is mixing-controlled, and that the reaction of fuel and oxygen is infinitely fast.

[6] Richard W. Bukowski., "Fire Hazard Analysis", *NFPA Fire Protection Handbook,* 19th ed., A. E. Cote (Ed), National Fire Protection Association, Quincy, MA, 2003, Vol. 1, pp. 3-107.

The detailed fire growth and spread over these three-dimensional fuels is neither explicitly validated by the FDS software, nor is it essential for the evaluation of fire development in this project.

An accurate combustion model requires knowledge of the expected commodities that will be stored at this facility. Rack storage of commodities consisting of a mixture of products, ranging from Class I to Group A plastic is expected. As a conservative approach, high-pile rack storage of Group A plastics was selected as the primary fuel. This commodity is recognized to represent the most severe fire hazard of the high density plastics tested[7]. Available full-scale test data for heat release rates of Group A plastics were gathered from the Factory Mutual Research Corporation (FMRC) Standard Plastic Commodity (polystyrene cups in compartmented cartons).

Using the mixture fraction model, each reaction is assumed to be of the form[8]:

$$\begin{aligned} &C_xH_yO_zN_v\mathrm{Other}_w + v_{O_2}O_2 \rightarrow \\ &v_{CO_2}CO_2 + v_{H_2O}H_2O + v_{CO}CO + v_{Soot}\mathrm{Soot} + v_nN_2 + v_{H2}\,H_2 + v_{Other}\mathrm{Other} \end{aligned} \quad (2)$$

The chemical formula for a common polystyrene cup was identified as $CH(C_6H_5)CH_2$ (MSDS[9]). However, this reaction is too complex to model accurately. A simplified combustion model using Polystyrene $(C_8H_8)_n$ was chosen.

$$[C + H\,(\mathrm{fuel})] + [O_2 + N_2\,(\mathrm{Air})] \rightarrow [CO_2 + H_2O + N_2\,(\mathrm{Heat})]$$
$$C_8H_8 + 10O_2 \rightarrow 8CO_2 + 4H_2O$$

Utilizing the stoichiometric coefficients polystyrene along with the yields of CO, soot, the following parameter were input in the combustion model[10]:

C = 8
H = 8
Soot Yield = 0.164
CO Yield = 0.06
Heat of Combustion = 41,960 kJ/kg

The yield inputs are for well ventilated, flaming conditions.

Tenability Criteria

Exposure of occupants to products of combustion will be maintained below critical values for thermal, respiratory and visibility effects. These minimal exposures will be maintained for a period of time necessary to evacuate the warehouse. The analysis only considers the effect of acute exposures to toxic

[7] An Engineering Approach to Industrial Fire Protection, Robert Zalosh, January 1994.
[8] Kevin B. McGrattan, Glenn P. Forney, *"Fire Dynamics Simulator – User's Manual"*, National Institute of Standards and Technology, Gaithersburg, MD., NISTIR 6469, January 2000.
[9] http://www.tempo-foam.com/engineering/thin_wall_copolymers/styrochem/styrochem_cupgrade_msds.pdf
[10] The SFPE Handbook of Fire Protection Engineering, 3rd edition: Purser, David A.,NFPA / SFPE, 2002.

products, which are likely during a fire. Long-term effects are not considered.[11] The following tenability criteria have been chosen as the basis for the analysis of the fire modeling data presented in this report:

Initial Conditions:
- Interior room temperature: 68°F
- Standard atmospheric conditions (Southern California)

Toxicity:
- Carbon Monoxide (CO): 754 parts per million (ppm) or 0.00075 volume fraction
- Carbon Dioxide (CO2): 10,000 parts per million (ppm) or 0.01 volume fraction

Temperature:
- 150°F (65°C) maximum

Visibility:
- 30 feet (9.144 meters) minimum at 6 ft (1.83 m) above the walking surface

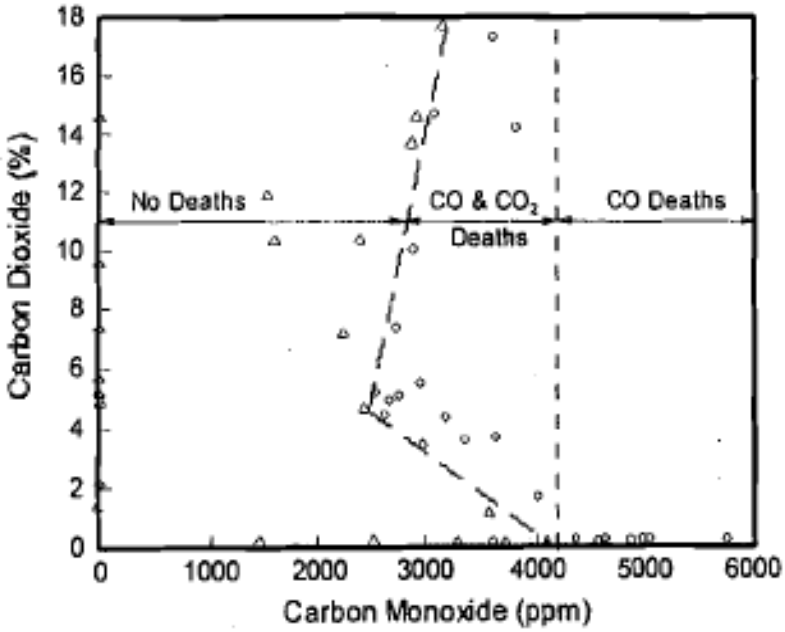
Toxicity

The data compiled in Figure No. 2 is useful for the purposes of this analysis because it provides multiple domains characterizing the hazard posed by exposure to various levels of carbon monoxide and carbon dioxide. For combined exposures occurring within the region bounded by the dashed lines, deaths are predicted. The plot is therefore useful for establishing an order of magnitude perspective on simultaneous exposure to CO and CO2. Note that for exposures to carbon monoxide exceeding approximately 4,000 ppm, the amount of carbon dioxide included in the exposure is irrelevant as the result is fatal due to CO exposure alone. Similarly, for exposure to concentrations of CO below approximately 2,500 ppm, exposure to CO2 is not relevant in producing a fatal dose, though other harmful affects could potentially result from such an exposure.

A 3,000 ppm exposure for 15 minutes CO criteria is cited from the Los Angeles Residential Test Program and is considered to correspond to values for which headaches and abnormal vision may result and could affect the ability of an occupant to escape. Carbon monoxide is recognized as the primary toxic hazard in fires. It is the accumulation of CO in the body that is most critical. However, elevated levels of carbon dioxide pose an additional hazard as they result in an increased rate of breathing and consequently an increase in the rate of uptake of CO. For this reason, exposure to both gases is analyzed in this report.

[11] Drysdale, D., *An Introduction to Fire Dynamics*, N.Y., John Wiley & Sons, 1985.

Figure No. 2: Lethality of Combined Exposure to CO and CO_2



Temperature

The 150°F (65°C) temperature limit is a conservative value based on the effects of heat stroke, or hyperthermia. If an occupant is exposed to a hot environment, especially if the humidity is high, there is a danger of incapacitation or death due to hyperthermia. Prolonged exposure (greater than 15 minutes) to heated environments at elevated temperatures too low to cause burns can still inhibit an occupant in the course of egress. The combination of exposure duration and intensity must be considered to appropriately define the threshold criteria limits; this holds true for gas concentrations as well. A detailed discussion of hyperthermia is presented by Purser.[12]

The humidity of the environment adds to the potential for heat stroke. A humid environment can reduce the temperature limit by as much as 40°F, at a prolonged exposure of one hour[13]. A temperature of 200°F (93°C) is considered to correspond to an upper limit at which loss of consciousness will occur, as cited in the Los Angeles Residential Test Program.[14] Gas temperatures of more than 212°F (100°C) are capable of causing loss of consciousness and death within several minutes. In the NFPA report, Operation School Burning (1959), a criteria of 150°F (65°C) is established, although it is recognized that a human can stand temperatures "considerably above" 150°F for short periods of time[13]. A value of 150°F has been chosen for this analysis to add a factor of safety.

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[12] The SFPE Handbook of Fire Protection Engineering, 3rd edition: Purser, David A.. *"Toxicity Assessment of Combustion Products"*, Section 2, Chapter 6: NFPA / SFPE, 2002., pg. 2-125

[13] The SFPE Handbook of Fire Protection Engineering, 3rd edition: Purser, David A.. *"Toxicity Assessment of Combustion Products"*, Section 2, Chapter 6: NFPA / SFPE, 2002., pg. 2-125

[14] Kung, H., *Field Evaluation of Residential Prototype Sprinkler Los Angeles Fire Test Program*, Factory Mutual Research, 1982.

Visibility

Smoke is tracked along with all other major products of combustion and is used to determine visibility. The most useful quantity for assessing visibility in a space is the light extinction coefficient, K. The intensity of monochromatic light passing a distance L through smoke is attenuated according to[15] :

$$I / I_0 = e^{-KL} \qquad (3)$$

The light extinction coefficient, K is a product of the density of smoke particulate, ρY_s , and a mass specific extinction coefficient that is fuel dependent:

$$K = K_m \rho Y_s \qquad (4)$$

Estimates of visibility through smoke can be made by using the equation:

$$S = C / K \qquad (5)$$

Where *C* is a non-dimensional constant characteristic of the type of object being viewed through the smoke, *C* = 8 was used for light-emitting exit signs. Since *K* will vary from point to point in the domain, the visibility *S* will as well. The recommended visibility distance is 30 feet (9.14 m). The production of smoke is determined by the smoke conversion factor, which is the fraction of fuel mass that is converted to soot.

The input into the simulation is controlled by three parameters related to smoke production and visibility. The first parameter is soot yield, which is the fraction of fuel mass that is converted to soot. The second parameter is called the mass extinction coefficient, and is the K_m in equation (4). Seader and Einhorn obtained K_m values of 7,600 m^2/kg for smoke produced during flaming combustion of wood and plastic[16].

The third parameter is called the visibility factor, the constant C in equation (5), C = 8 for a light emitting exit sign.[17] The estimation of visibility to a light-emitting exit sign is calculated by evaluating the intensity of light passing through the smoke. First, the soot yield is used to determine the mass of smoke produced. The corresponding mass concentration, g/m^3, is then calculated by knowing the size and volume of the warehouse. Taking K_m to be 7,600 m^2/kg for flaming combustion, the light extinction coefficient, K, can be calculated. The visibility is next estimated by using equation (5). The relationship between visibility, S, and the light extinction coefficient, K, is linear. For a light-emitting exit sign, C = 8. Using equation (5) with C = 8, the greatest visibilities will be obtained with small values of K.

For these simulations, 30-foot visibility at and below 6 feet above the highest walking surface is deemed appropriate for providing occupants a means to move away from the fire. However, much greater emphasis is placed on the effects of skin exposure to heat and respiratory exposure to toxic gases, which is likely more accurately assessed by the FDS model.

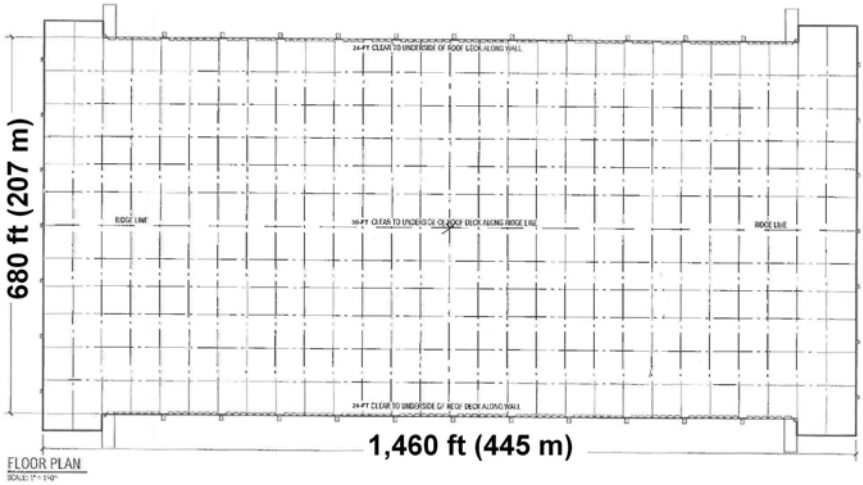
[15] McGrattan, K.B. 2001. Fire Dynamics Simulator. NISTR 6784.NIST, Gaithersburg, MD.
[16] SFPE Handbook of Fire Protection Engineering, 3rd Ed, Section 2, Chapter 13, pp 263.
[17] McGrattan, K.B. 2001. Fire Department Dynamics Simulator. NISTR 6784. NIST, Gaithersburg, MD.

Modeling Parameters

Geometry

The facility is a large warehouse. Figure 3 shows a floor plan view of the facility. The facility is enclosed within a 680 feet x 1,460 x and 24-30 feet tall rectangular volume (206 m x 490 m x 7.32 – 9.14 m). Refer to Appendix A for large view of building. For simplicity the wings at the corners were disregarded in the fire model.

Figure No. 3: Building Geometry



Vents

The limited supply of fresh air starves the fire of oxygen and leads to increased yields of products of incomplete combustion such as soot and carbon monoxide (CO). However, in this large open warehouse with numerous overhead doors around the loading docks, the occurrence of under ventilated fires is not anticipated. The model considered the door openings along the exterior wall by simulating a 2-m (6.6-ft) opening around the entire perimeter of the building. These openings were modeled as open vents to the ambient for the duration of the simulation.

Grid Resolution Analysis

CFD numerical simulations are computationally very expensive. One of the most significant factors influencing the computation time is the size of the computational grid. Because it is possible to over-resolve or under-resolve a space by specifying grids that are too fine or too coarse, it is important to determine an appropriate grid size that would optimize the solution accuracy and time.

Grid Size

Multiple numerical meshes were utilized to compute the solution. Each mesh consisted of uniform rectilinear cells of a characteristic size intended to resolve the smallest turbulent eddies of significance to the final solution.

As a first approximation for the necessary grid cell size to accomplish proper resolution of the turbulent flow, it is generally recommended that the cell size in close proximity to the fire defined by the following equation.

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}} \right)^{2/5} \tag{6}$$

Where:

$\dot{Q} =$ Total heat release rate of the fire (steady state = 10 MW)

$\rho_\infty =$ Density of ambient air

$c_p =$ Specific heat of ambient air

$T_\infty =$ Temperature of ambient air

$g =$ Gravitational acceleration

$$D^* = \left(\frac{\dot{Q}}{1{,}100} \right)^{2/5}$$

The recommended grid size is between ten percent (10%) and twenty percent (20%) of the calculated D*. Grid sizes in close proximity to the fire should be no larger than one-fifth the size of D*.

Given a fire size of 10 MW (10,000 kW), the maximum grid cell size that could be used to accurately describe this fire is calculated as D* = 2.42 meters. The corresponding grid size range is as follows:

(20%) of D* = 0.50 m (20 in)
(10%) of D* = 0.24 m (9.45 in)
(5%) of D* = 0.12 m (4.57 in)

Twenty percent of the size of D* would require a grid size no larger than 0.50 m (20 in) to properly describe a fire. The model assumed a smaller grid size (0.10 m) to accurately model the fire between the flue spaces in the double-row racks.

Sprinkler Activation Grid Size

Simulation of sprinkler activation was modeled around the double-row racks geometry. The rack has 6-inch spaces which required a smaller grid resolution. A piecewise-linear function was used to stretch the mesh starting at the center of the racks. Therefore, the grid resolution was based on a grid transformation with the smallest cells, 0.10 m (4.57 in), at the core of the racks and fire, and larger cells, 0.40 m (15.7 in)

at the outer perimeter of the racks. See Figure No. 4 and 5 for a graphic representation of the rack and sprinklers. Refer to Appendix B for building model grid layout.

Figure No. 4: Grid Meshes at Double-row Rack

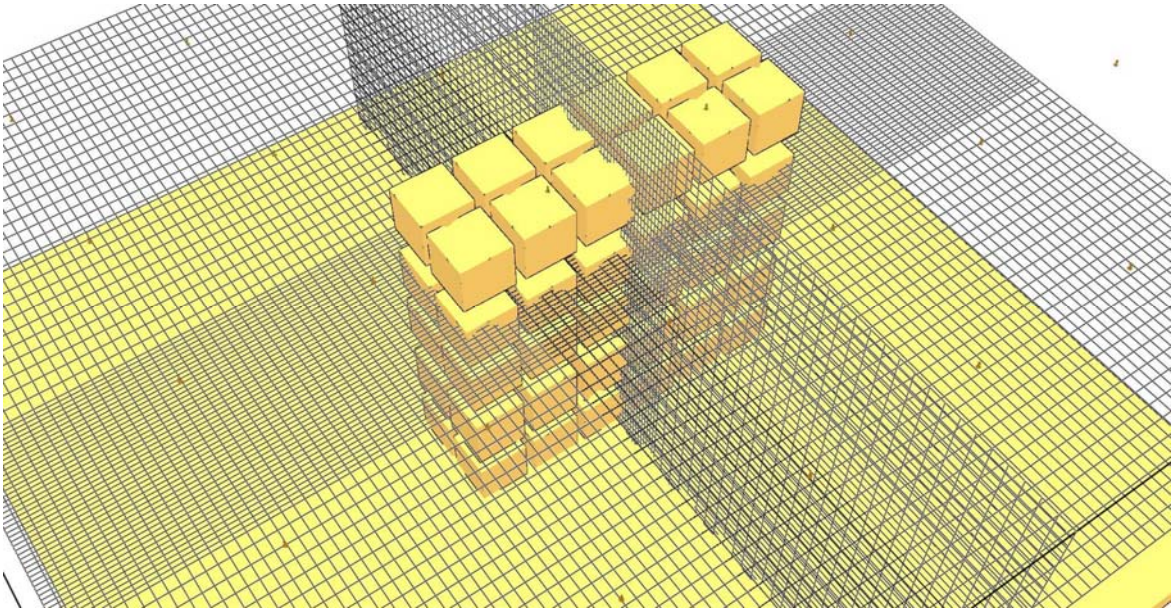
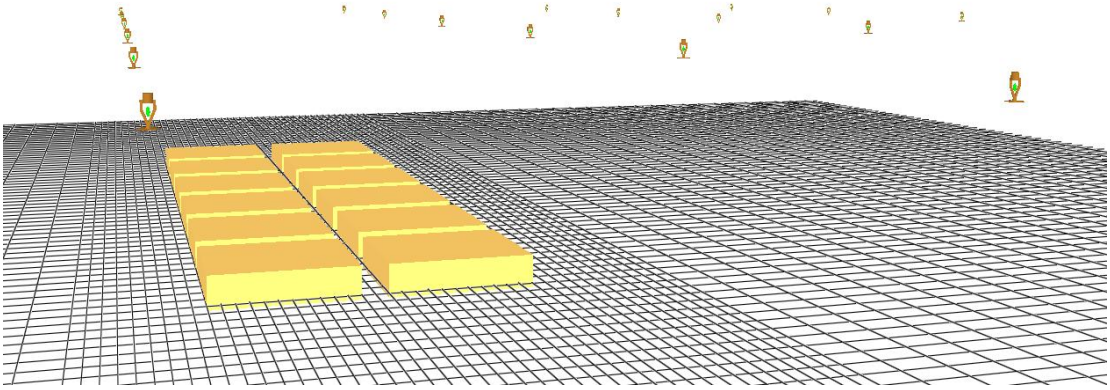
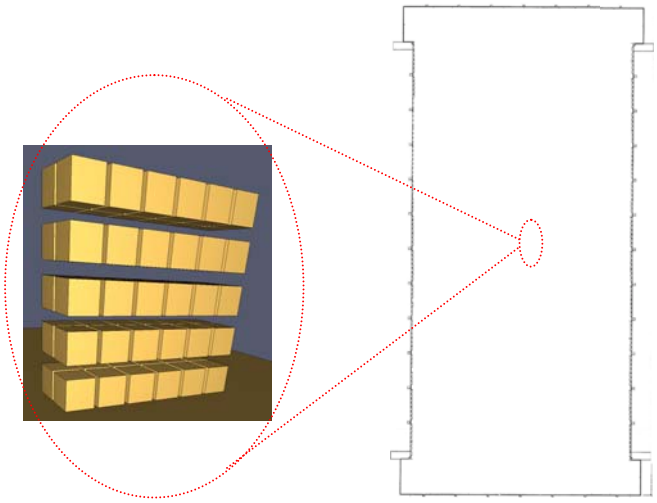


Figure No. 5: Grid Meshes with Sprinklers



The model assumes the fire is located in the center of the warehouse. Figure No. 6 shows the location and rack configuration.

Figure No. 6: Fire Location



Thermocouple Location and Slice Profiles

The fire in the simulation is allowed to burn for twenty (20) minutes (1,200 seconds). This time interval allows the tenability in the space to reach a steady state. In an actual fire scenario, the fire would have decayed significantly. Therefore, the twenty-minute simulation provides a conservative analysis of tenability in the space.

Thermocouple probes (which are used to measure temperature, CO & CO2 levels, and visibility) are simulated to be located at six (6) feet above the finished floor. Slice profiles were also included to visually identify the tenable conditions. Slices or slice planes measure gas-phase data (e.g. visibility, temperature) on an axis-aligned plane.

Surface Input Parameters

The ceiling is assumed to be flat and typically made of panelized wood assembly. The exterior walls are composed of noncombustible material (i.e. tilt-up concrete), and the floors are assumed to be concrete. The ceiling, walls and floors were assumed to be inert surfaces, which is considered to be conservative because inert materials will not absorb heat, leading to higher gas temperatures in the simulation.

Ultrafast Design Fire Scenario

Additional sprinkler activation was simulated by locating the fire on the center of thirty six (36) sprinklers spaced at 10-ft x 10-ft apart. The objective was to determine the time and heat release rate at which the first four (4) sprinklers activate.

Upon sprinkler activation, the fire size (heat release rate) was assumed to remain constant for the remaining time of the simulation. This conservative assumption was selected as the worst-case scenario for both design fires. Table No. 1 outlines the sprinkler activation setup parameters.

Table 1: Sprinkler Activation Setup – Ultrafast Fire

SPRINKLER ACTIVATION			
Design Fire	**# Sprinklers / Location**	**Sprinkler Type**	**Sprinkler RTI m½ s½**
Ultrafast Fire (10 MW)	36 sprinkler with fire on center	Control Mode	80

Modeling Results and Analysis

Fire dynamics analysis and computer modeling is intended to simulate or predict real-world phenomena using scientific principles and empirical data. A model is really an idealized version of a physical system too complex to analyze easily in full without simplification[18]. One of the most widely used tools for engineering calculations is a computational fluid dynamics (CFD) software package known as Fire Dynamics Simulator (FDS) version 5.4.3.

The software, which was created by the National Institute of Standards and Technology (NIST) was designed to model fire-driven fluid flow and has been validated for a number of fire protection engineering applications in the built environment. The FDS software is merely an engine for compiling calculations. Visual counterparts to the software are provided both on the front-end to promote a user friendly interface and the back-end for visualization of the calculated results. These separate graphical user interfaces are known as PyroSim (model input software developed by Thunderhead Engineering) and Smokeview version 5.4.8 (model output software developed by NIST).

The accuracy with which FDS predicts temperatures and heat release rates has been validated with large-scale tests. Testing has shown that FDS temperature predictions were within 15% of the measured temperatures, and heat release rates were within 20% of measured values. The overall accuracy of models (i.e. duplicative of real world results) is within + or – 30%[18].

Sprinkler Activation

The design fire assumed an idealized ultrafast, t-squared fire. The simulation was performed by locating thirty six (36) sprinklers around the fire spaced at 10-ft x 10-ft apart. Sprinklers were labeled “1-nw”, “2-nw”, “3-nw”, etc. Activation of the first four (4) sprinklers is summarized in Table No. 2 on the next page. A plan view of the thirty six (36) sprinklers is shown in Figure No. 7 on the next page.

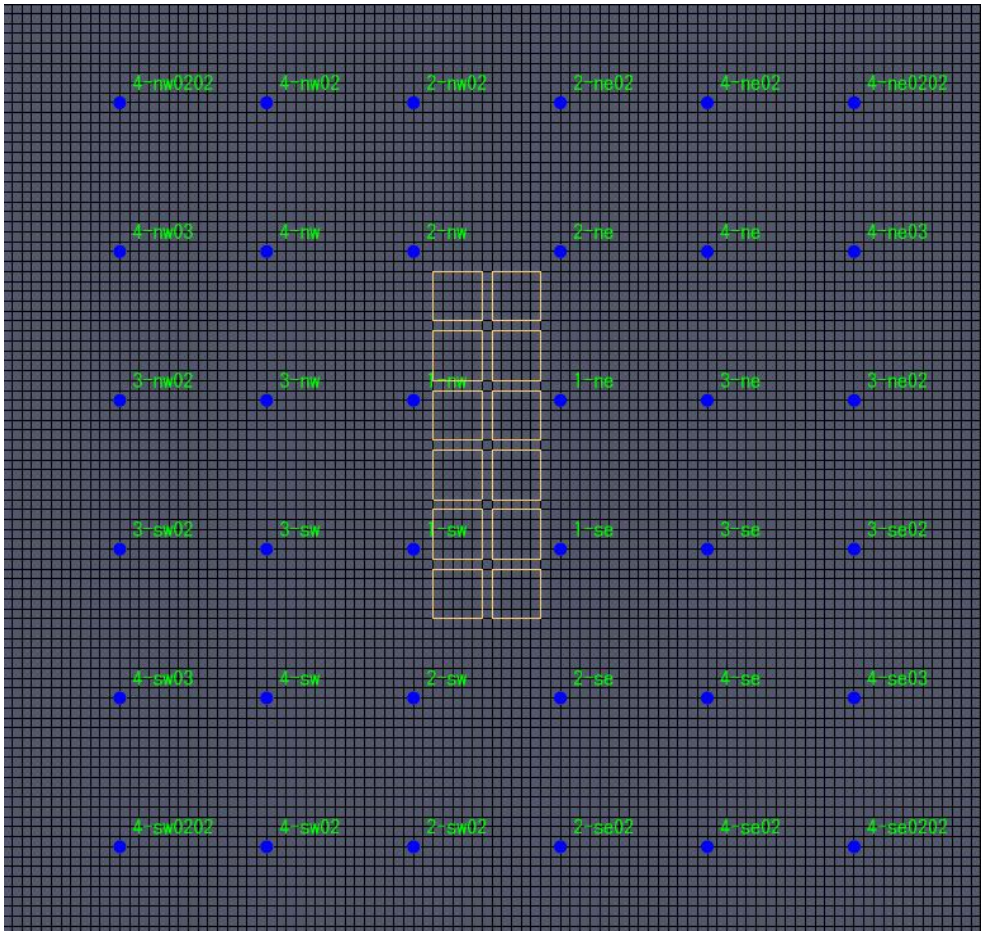
Full-scale test show that the heat release rate decreases after the first sprinkler activation. As a conservative design, the activation of the four (4) sprinklers was simulated to control the fire. After the fourth sprinkler, the heat release rate was assumed to remain constant.

[18] http://fire-dynamics.com/Library/Fire Dynamics & Computer Modeling.ppt

Table 2: Sprinkler Activation Summary – Ultrafast Fire

SPRINKLER ACTIVATION – ULTRAFAST FIRE SCENARIO			
Design Fire	**No. of Sprinklers activated**	**Time (sec) (Min : Sec)**	**Activation HRR (kW)**
Ultrafast Fire	1-nw	232 (3:52)	9,547
	1-se	239 (3:59)	9,664
	1-sw	240 (4:00)	10,088
	1-ne	241 (4:01)	10,316

Figure No. 7: Sprinkler Location (Ultrafast Fire)



The heat release rate after the fourth sprinkler activation (10 MW) was used to simulate the tenable conditions as discussed in the followings sections. Refer to Figure Nos. 8 and 9 and Appendix C for larger graphs.

Figure No. 8: Ultrafast Fire Heat Release Rate (Sprinkler Activation)

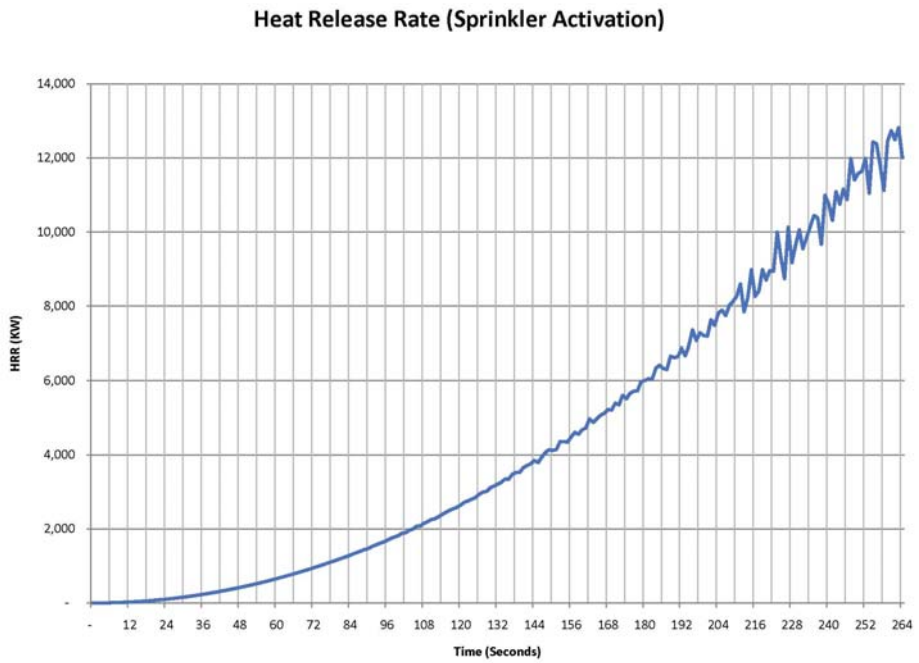
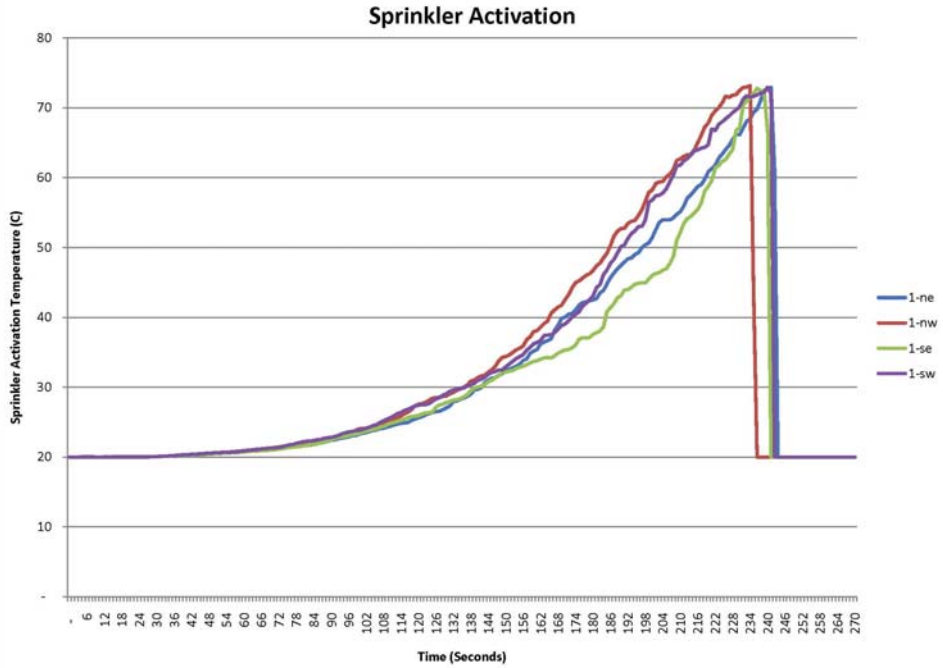


Figure No. 9: Sprinkler Activation of first 4 sprinklers



Sprinkler Controlled Model

The design fire for an ultrafast fire activates four sprinklers within 4 minutes. A fire scenario assumes a heat release rate will remain constant at 10 MW (heat release rate after the fourth sprinkler activation).

Due to the massive size of the building it was determined through the modeling that the slightly sloped (7 feet over 340 feet) ceiling does not affect the overall tenable conditions. Therefore, the geometry of the building was simplified by assuming a ceiling with a maximum height of 24-ft high. This simplification created a conservative simulations since the building roof slopes from 24-ft at its perimeter to 30-ft at its center.

Simplifying the storage rack to a single burning commodity at the floor level allowed the grid size to be increased from 0.10m to 0.50 m. Increasing the grid cell sizes to within the calculated grid size in Grid Size Section decreased the computation time without sacrificing the accuracy of the model.

Table No. 3 summarizes the simulation parameters for the design fire. Figure No. 10 shows the total fire size and the duration of the simulation. Refer to Appendix D-1 for large graph.

Figure No. 10: Heat Release Rate for Entire Simulation

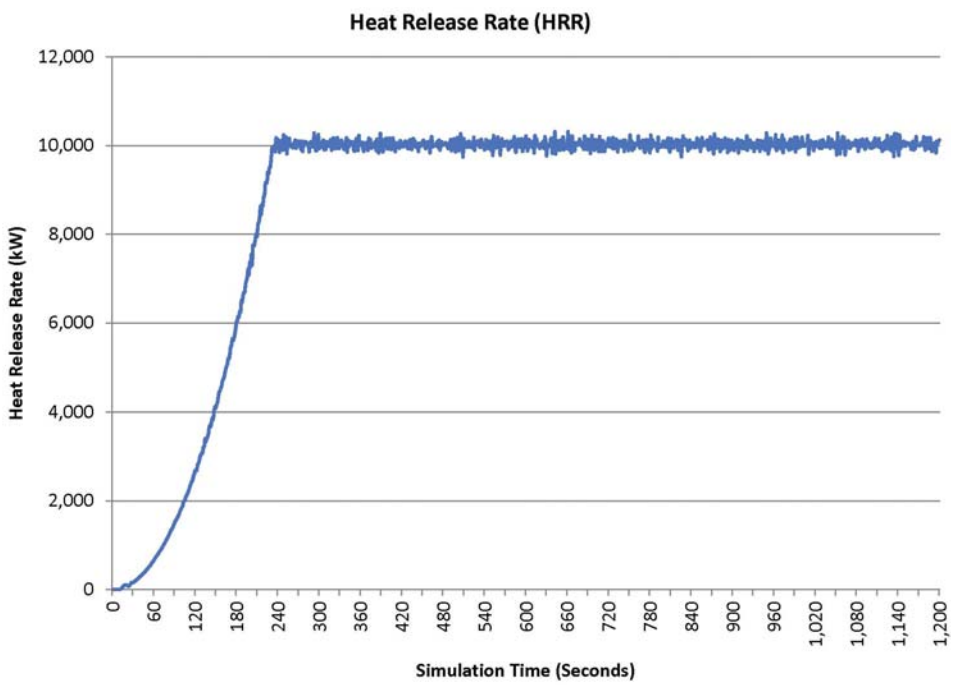


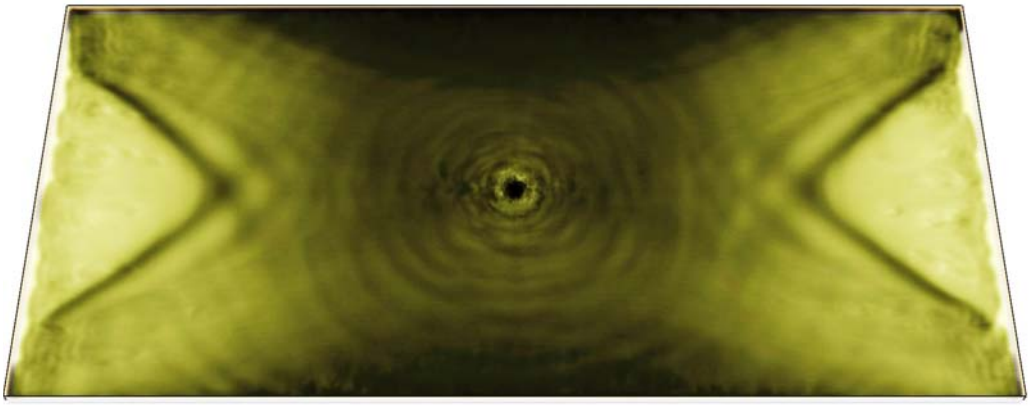
Table 3: Full Building Simulation

SIMULATION (T-SQUARED FIRE)				
Fire Size/ Model No.	**HRR**	**Simul. Time (min)**	**Fire Location**	**Notes**
Ultrafast Fire	10 MW	20	Middle of the bldg	Worst case, flat root, 24-ft

Tenable Conditions on Large Open Space

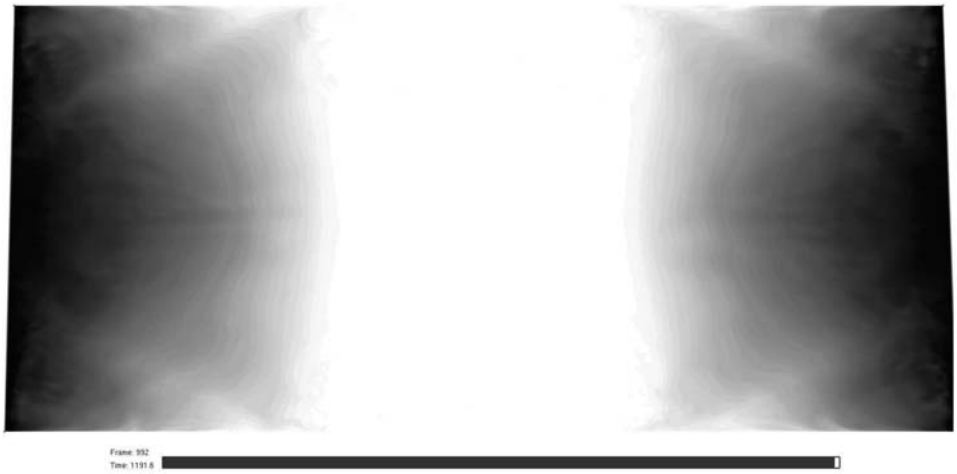
The objective of this analysis is to verify that occupants who are not intimate with ignition must not be exposed to instantaneous or cumulative untenable conditions. The tenable conditions were measured at 6-ft above the finished floor. The simulation indicates that it takes over 10 minutes for the smoke to fill the upper ceiling. Figure No. 11 shows smoke propagation after 10 minutes. View from top at 24 feet elevation in the horizontal plane.

Figure No. 11: Smoke Propagation after 10 Minutes (24 Ft)



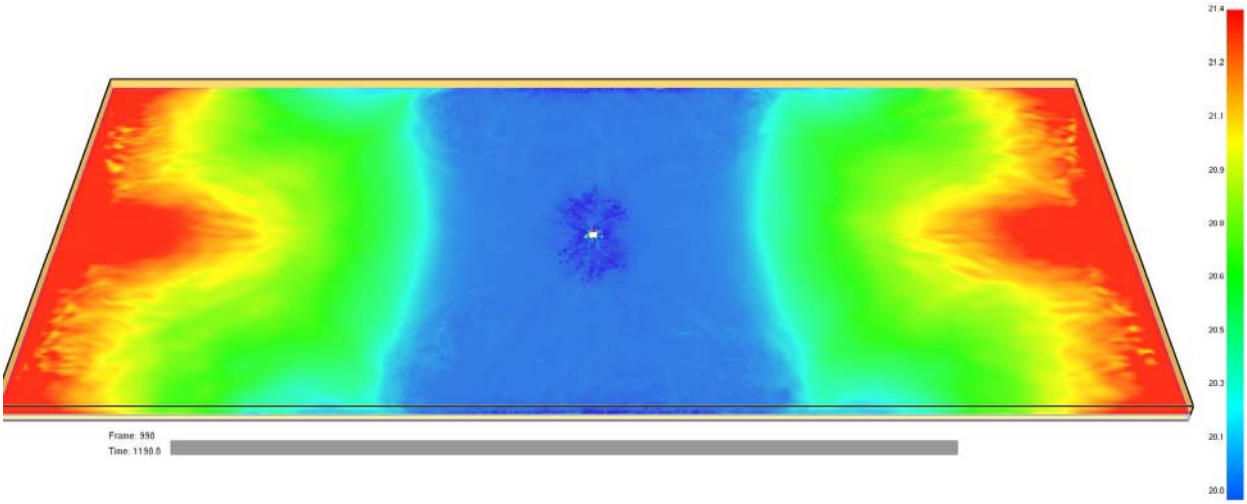
Smoke builds up at the end of the building. Figure No. 12 shows smoke after 20 minutes at an elevation of 6-ft above the finished floor. Refer to Appendix D-4 for additional elevations and times.

Figure No. 12: Smoke Propagation after 20 Minutes (6 Ft)



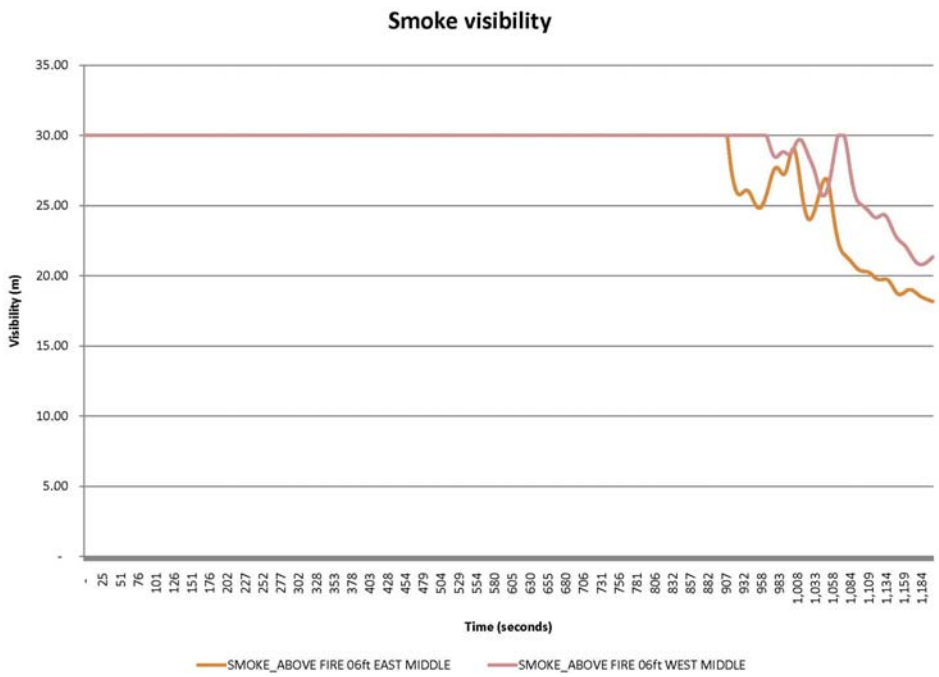
The temperature away from the immediate vicinity of the fire stays near room temperature. As hot gases propagate and accumulate at the far ends, the temperature at 6-ft does not exceed 21 °C (70°F) Figure No. 13 shows a horizontal slice at an elevation 6-ft above the finished floor. Refer to Appendix D-2 for larger graphs. The horizontal temperature slice plane is slightly below the fire burning area. Thus, the temperature around the fire is at room temperature (cold air entrains into the fire).

Figure No. 13: Temperature Top View (6-FT above FF)



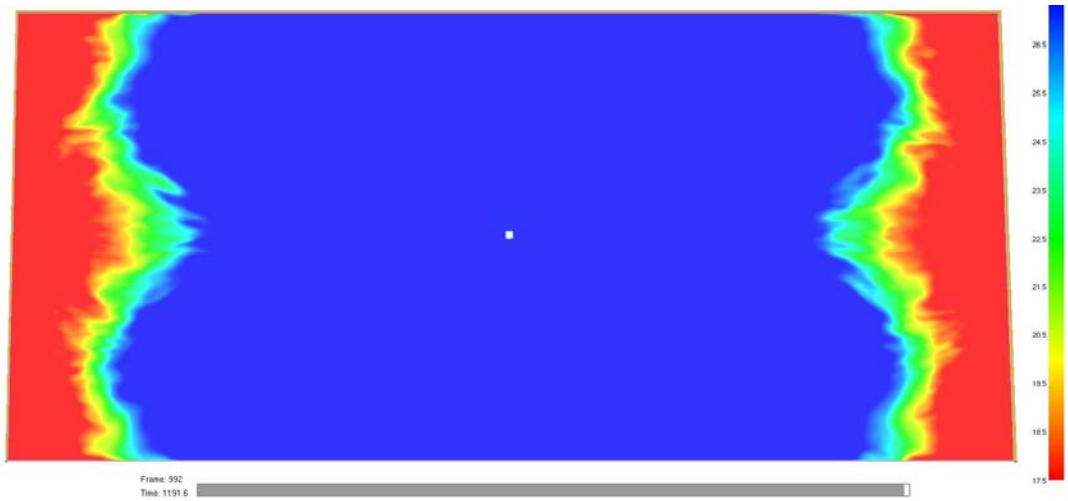
Soot concentration was measured as the smoke accumulates and descends from the ceiling to obscure visibility. Figure No. 14 shows visibility is maintain at 30 m (100-ft) for 15 minutes. Refer to Appendices D-3 for larger graphs.

Figure No. 14: Visibility at 6 ft above finished floor



As the smoke accumulates on the far ends of the building, the visibility decreases. However, the concentration is maintained above critical level, thus allowing occupants clear view of exit signs. Figure No. 15 shows a horizontal slice at 6-ft above finished floor. Refer to Appendices D-3 for larger graphs.

Figure No. 15: Visibility Slice after 20 minutes at 6 ft



Carbon monoxide and carbon dioxide concentrations were also measured at 6-ft above the finished floor. As noted on the Tenability Criteria Section, the critical CO concentration of 754 ppm and CO_2 concentration of 10,000 ppm were measured. The model indicates that the concentration levels are below critical levels as indicted on Figure Nos. 16 and 17. Refer to Appendix D-5 for larger graphs.

Figure No. 16: CO_2 Concentration at 6-ft above Finished Floor

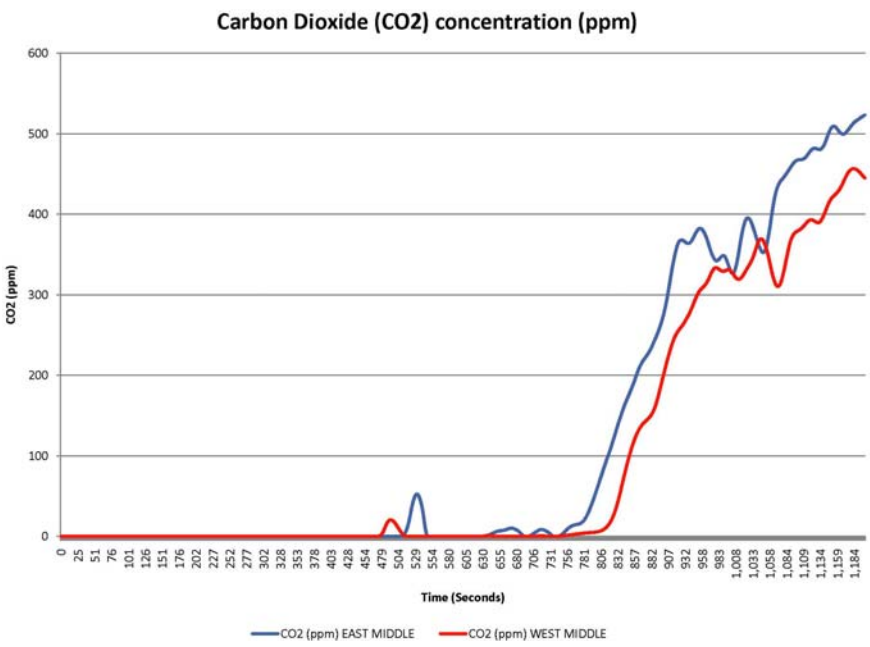
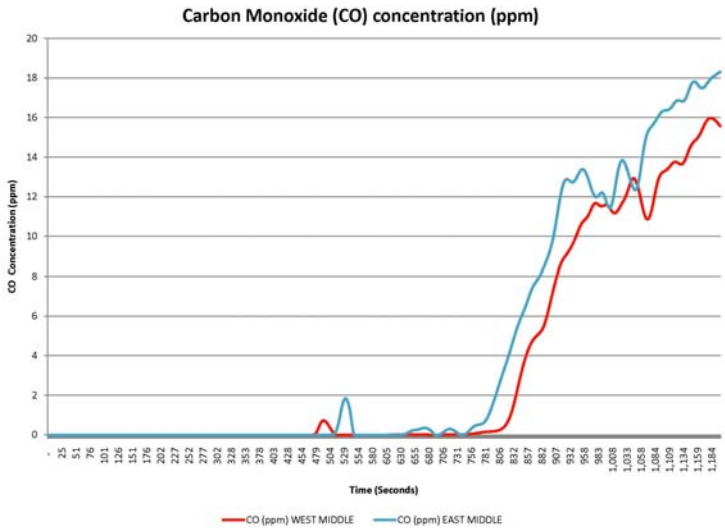


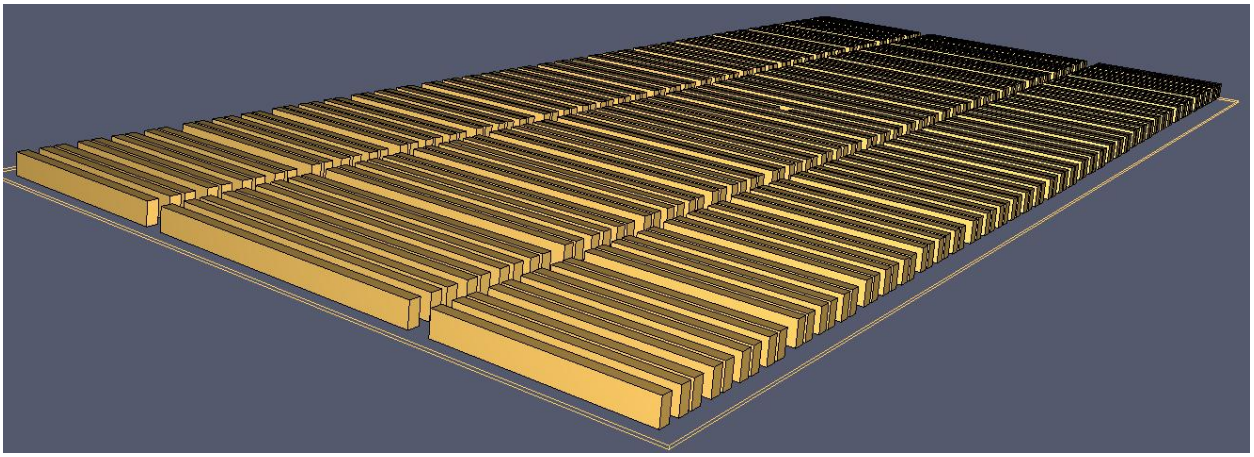
Figure No. 17: CO Concentration at 6-ft above Finished Floor



Tenable Conditions with Solid-Continuous Obstructions

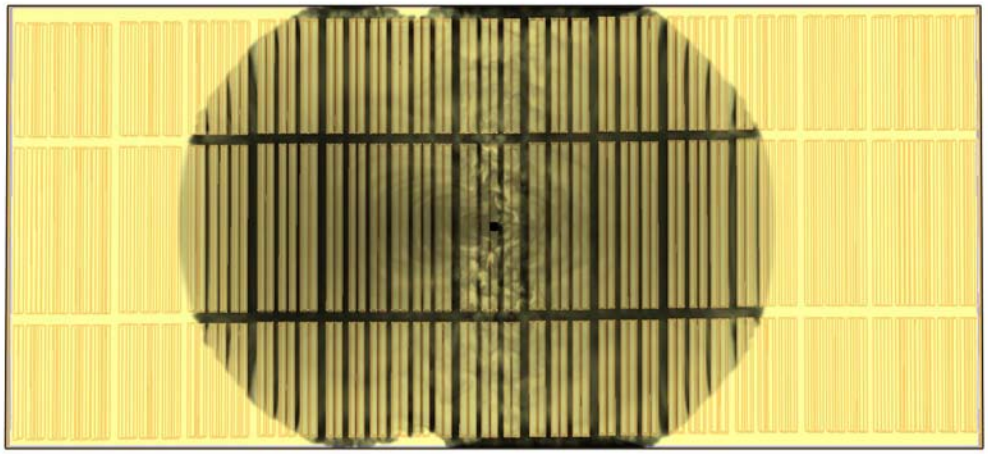
Fire modeling was performed using solid obstructions to represent double-row racks completely filled with solid commodities. The solid obstructions were assumed to be 22-ft in height and were modeled to represent double row racks with 8-ft isles. The objective of the solid-continuous obstruction model was to verify the effect on tenable conditions when the overall volume is significantly reduced. Figure No. 18 shows a floor plan of the space filled with solid blocks representing double-row rack storage. Refer to Appendix E for additional figures.

Figure No. 18: Warehouse with Solid Obstructions Representing 22 ft Racks



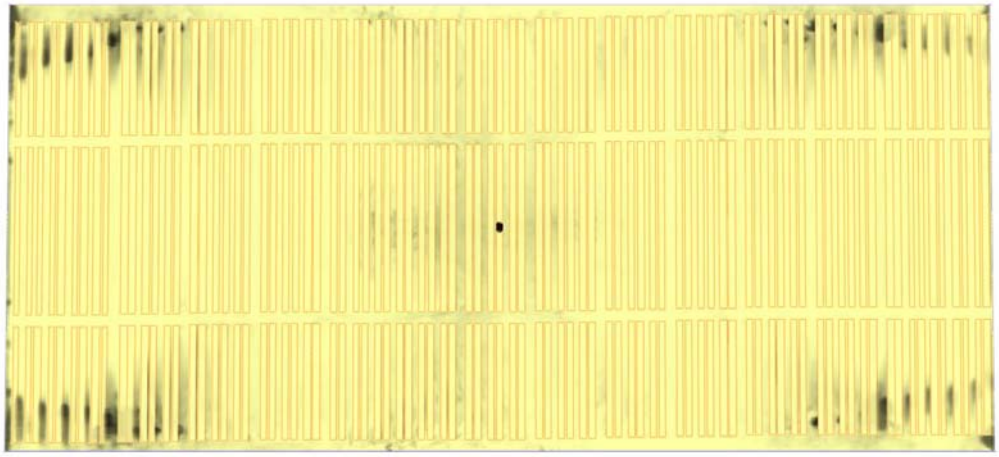
The tenable conditions were measured at 6-ft above the finished floor. The simulation indicates that it takes over 10 minutes for the smoke to fill the upper ceiling. Figure No. 19 shows smoke propagation after 6 minutes. View from top at 24 feet elevation in the horizontal plane is shown in Figure No. 19.

Figure No. 19: Smoke Propagation after 6 Minutes (24 Ft)



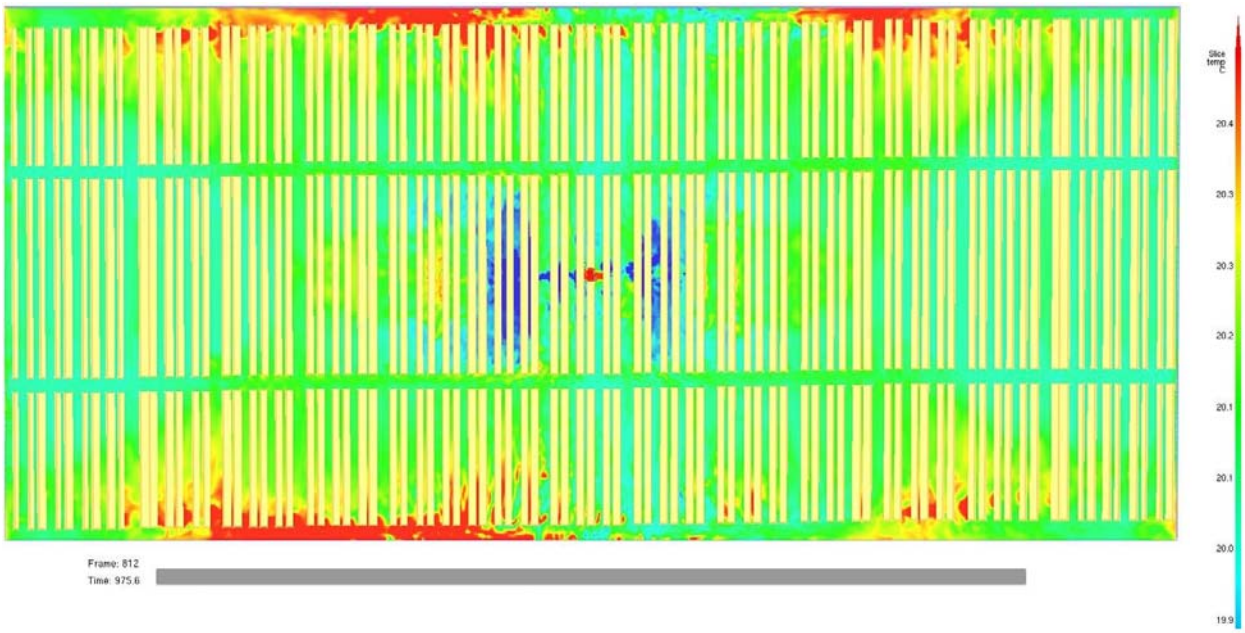
Smoke builds up at the perimeter of the building. Figure No. 20 shows smoke after 15 minutes at an elevation of 6-ft above the finished floor. Refer to Appendix E for large figures.

Figure No. 20: Smoke Propagation after 15 Minutes (6 Ft)



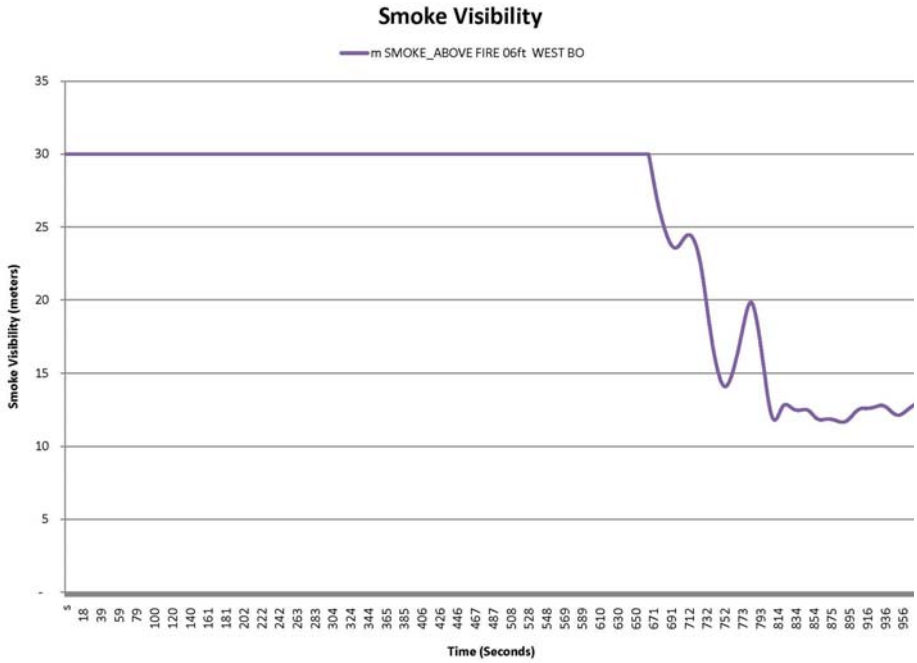
The temperature away from the immediate vicinity of the fire stays near room temperature. As hot gases propagate and accumulate at the perimeter of the building, the temperature at 6-ft does not exceed 21 °C (70°F) Figure No. 21 shows a horizontal slice at an elevation 6-ft above the finished floor. Refer to Appendix E for larger figures.

Figure No. 21: Temperature Top View (6-FT above FF)



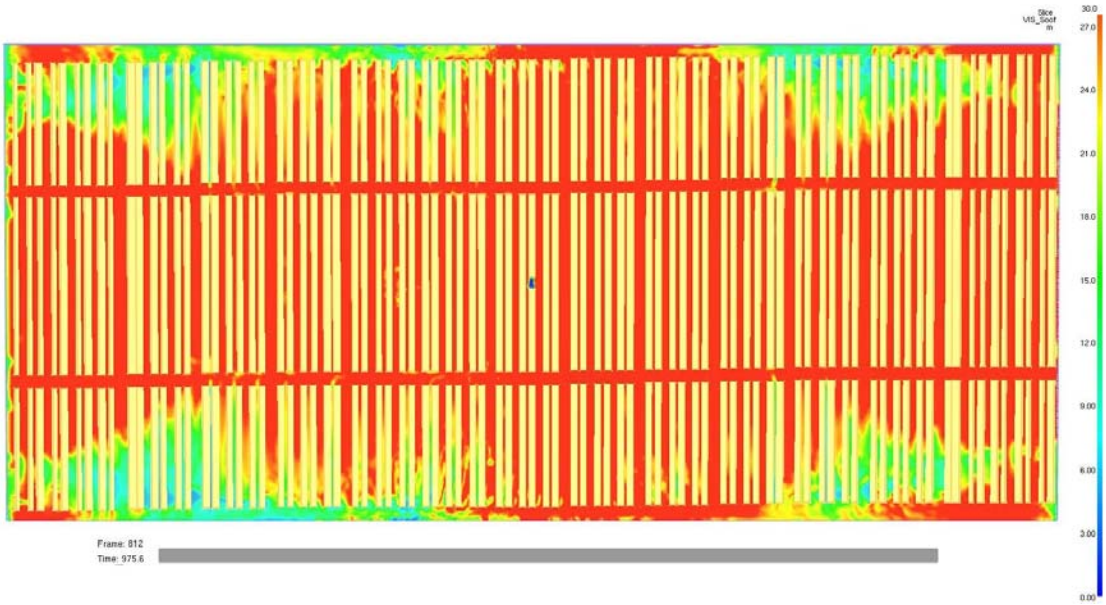
Soot concentration was measured as the smoke accumulates and descends from the ceiling to obscure visibility. Figure No. 22 shows visibility is maintained at 30 m (100-ft) for 10 minutes. Refer to Appendices E for larger figures.

Figure No. 22: Visibility at 6 ft above finished floor



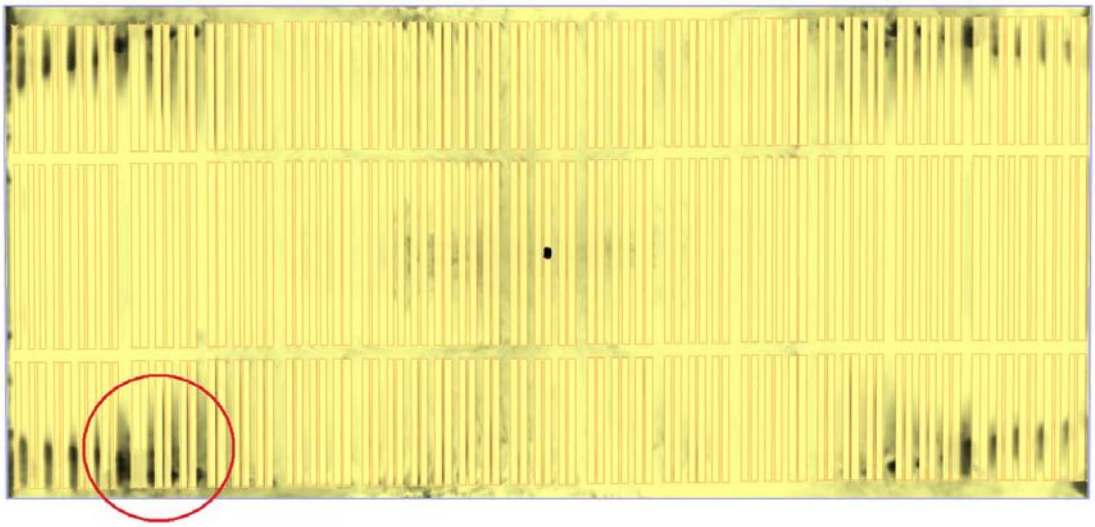
As the smoke accumulates on the far end of the building, the visibility decreases. However, the concentration is maintained above critical level, thus allowing occupants clear view of exit signs. Figure No. 23 shows a horizontal slice at 6-ft above finished floor. Refer to Appendices E for larger figures.

Figure No. 23: Visibility Slice after 15 minutes at 6 ft



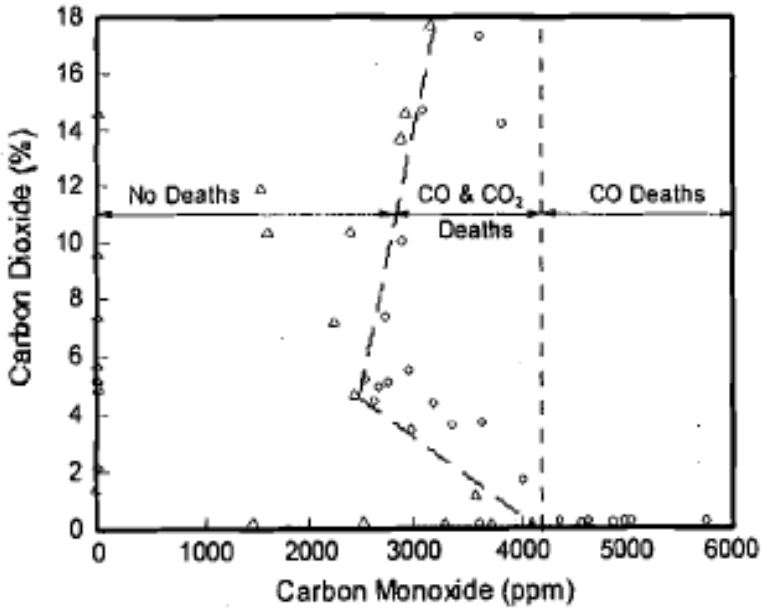
The toxic concentrations of carbon monoxide and carbon dioxide were measured at the locations were the largest amount of smoke is expected to accumulate. Figure No. 24 shows the location of the CO and CO_2 where the concentrations were the highest. This location represents the worst-case scenario because the model assumes the racks are solid obstructions and smoke accumulates between the 8-ft isles.

Figure No. 24: Location of CO and CO_2 Concentration at 6-ft above Finished Floor



Carbon monoxide and carbon dioxide concentrations were measured at 6-ft above the finished floor at the location indicated in Figure No. 24. Refer to Figure No. 25 for the lethality of combined exposure of CO and CO_2.

Figure No. 25: Lethality of Combined Exposure to CO and CO_2



An average concentration CO of 1,500 ppm was measured at the worst-case location. Refer to Figure No. 26 for CO concentration. As noted on the Tenability Criteria Section, CO concentration of 4,000 ppm is lethal to occupants. The average concentration of 4% (40,000 ppm) was measured for CO_2.

At the CO concentration of 1,500 ppm concentration, the CO2 concentration is not a credible threat to life. Because this conservative model assumes racks are solid objects, the toxic gas concentrations are expected to accumulate faster than in an open warehouse. Nevertheless, the concentration levels are not significantly high to be of concern to the occupants during egress. Refer to Figure Nos. 26, 27 and Appendix E for CO and CO2 concentrations graphs.

Figure No. 26: CO Concentration at 6-ft above Finished Floor

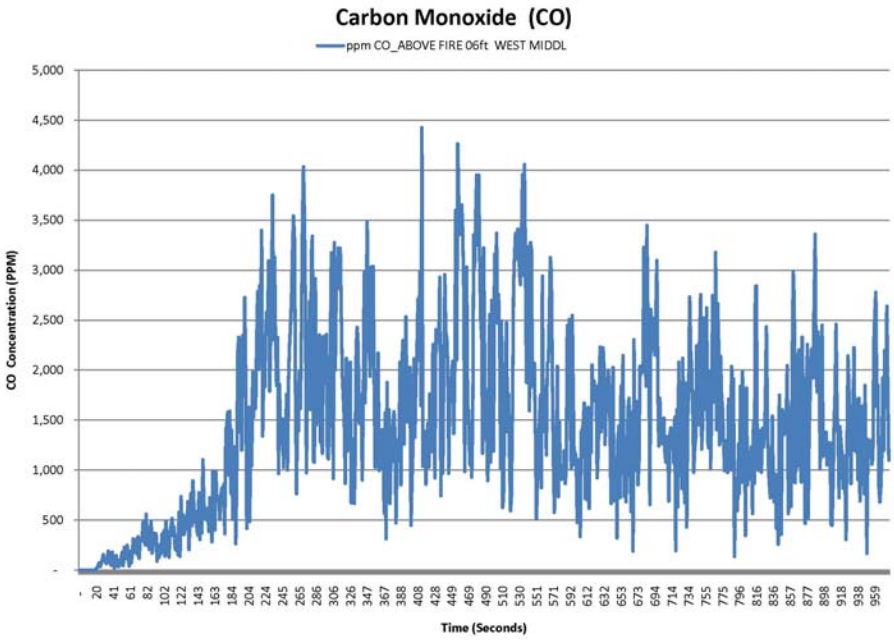
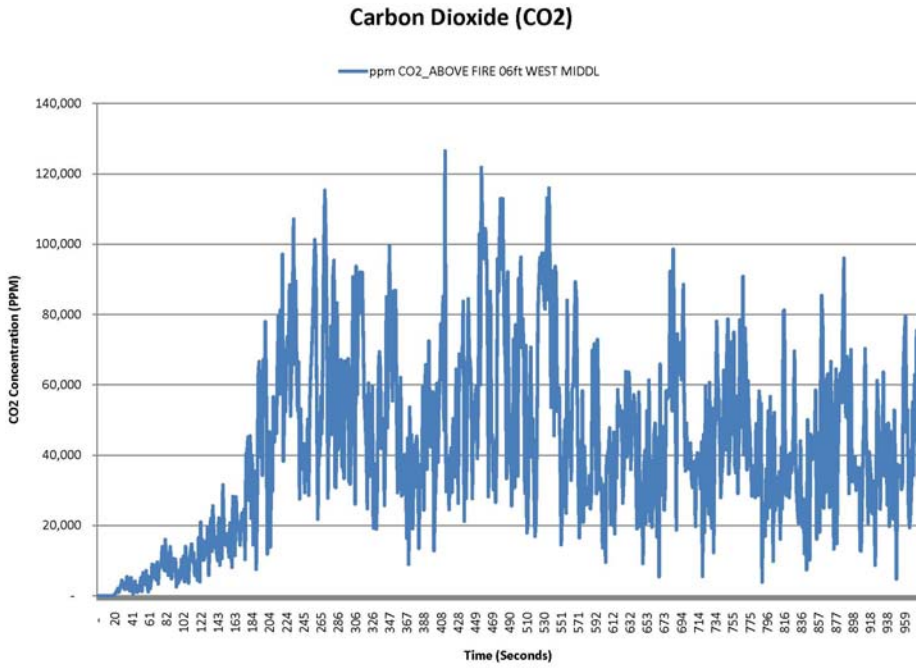


Figure No. 27: CO_2 Concentration at 6-ft above Finished Floor

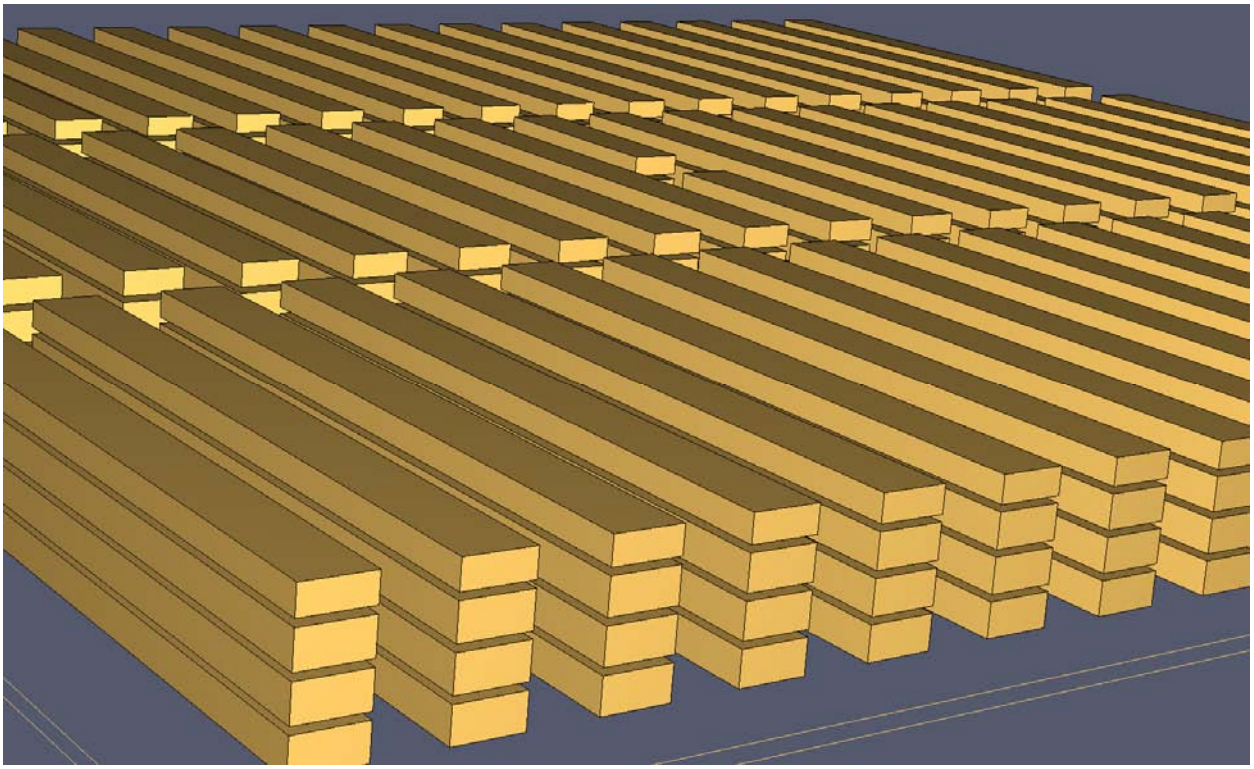


Tenable Conditions for Smaller Building

Fire modeling for a warehouse with and without solid-continuous obstructions was conducted for a large facility (approximately 990,000 square feet). Although not typical, these large facilities could be subdivided or subleased into smaller spaces. Therefore, additional fire modeling was performed to compare the effects of a significantly smaller building on tenable conditions.

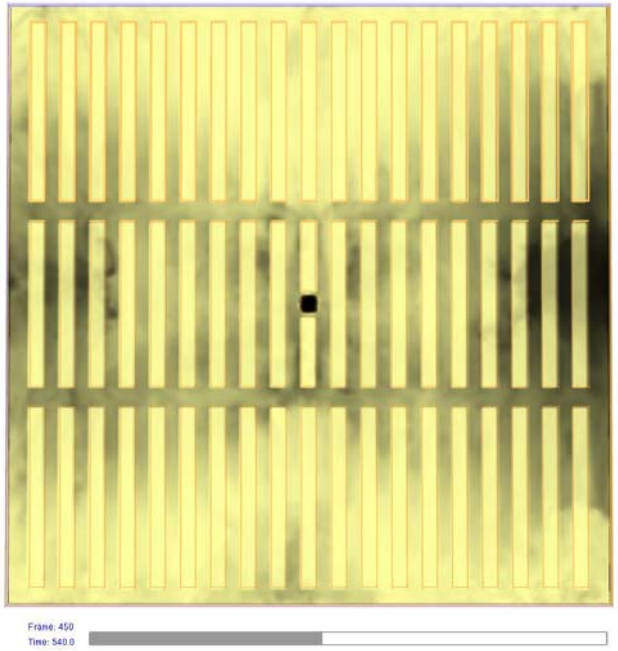
A building measuring 400-ft x 400-ft (approximately 160,000 square feet) was selected as the smallest building that could require a travel distance great than 250-ft. The model parameters, including building height, construction type, fire size, and commodity type were kept the same as in the previous models. Representation of double-row racks and pallets were included as solid obstructions. Double-row racks were assumed to be 22-ft in height separated by 8-ft wide aisles. Again, the objective of the obstructions was to verify the effect of reduced volume on tenable conditions. Figure No. 28 shows an isometric view of the space filled with solid block representing double-row rack storage.

Figure No. 28: Smaller Building with Obstructions



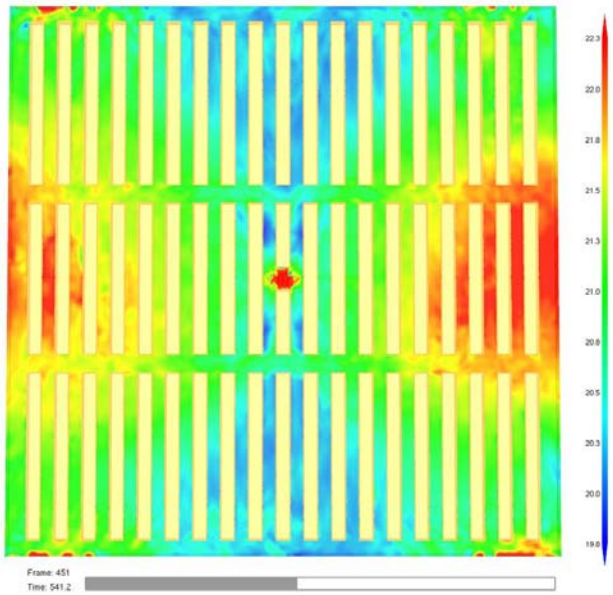
The tenable conditions were measured at 6-ft above the finished floor. Smoke descends from the ceiling significantly faster as expected. Figure No. 29 shows smoke the layer after 9 minutes at an elevation of 6-ft above the finished floor. Refer to Appendix F for large figures.

Figure No. 29: Smoke Propagation after 9 Minutes (6 Ft above finished floor)



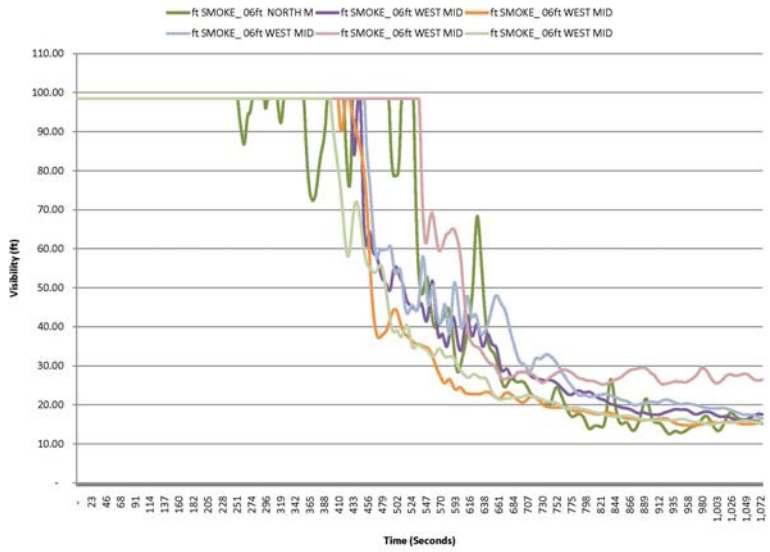
The temperature away from the immediate vicinity of the fire stays near room temperature. As hot gases propagate and accumulate at the perimeter of the building, the temperature at 6-ft does not exceed 23 °C (73°F) Figure No. 30 shows a horizontal slice at an elevation 6-ft above the finished floor. Refer to Appendix F for larger figures.

Figure No. 30: Temperature Top View after 9 Minutes (6 Ft above finished floor)



Soot concentration was measured as the smoke accumulates and descends from the ceiling to obscure visibility. Figure No. 31 shows visibility is maintained at 30 m (100-ft) for 9 minutes. As the smoke accumulates, the visibility decreases. Refer to Appendices F for larger figures.

Figure No. 31: Visibility at 6 ft above finished floor



Carbon monoxide and carbon dioxide concentrations were also measured at 6-ft above the finished floor. The model indicates that the concentration levels are below critical levels as indicted on Figure Nos. 32 and 33. Refer to Appendix F for larger graphs.

Figure No. 32: CO Concentration at 6-ft above Finished Floor

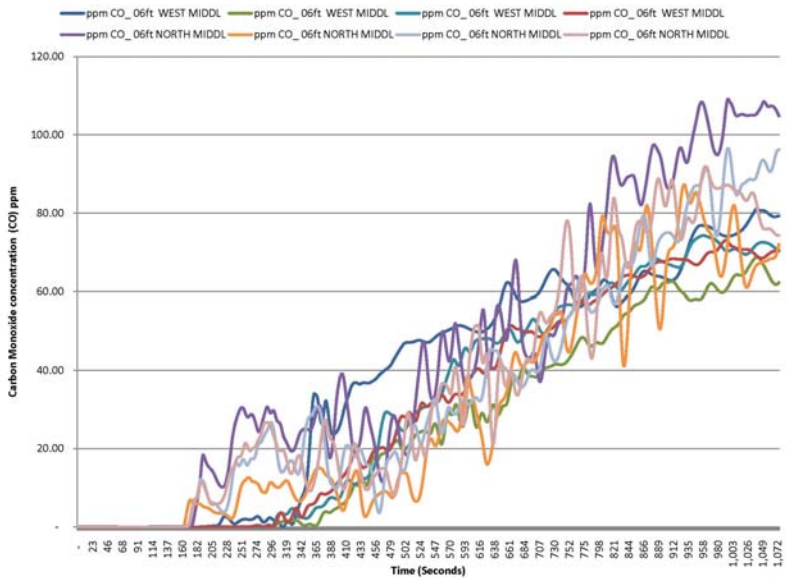
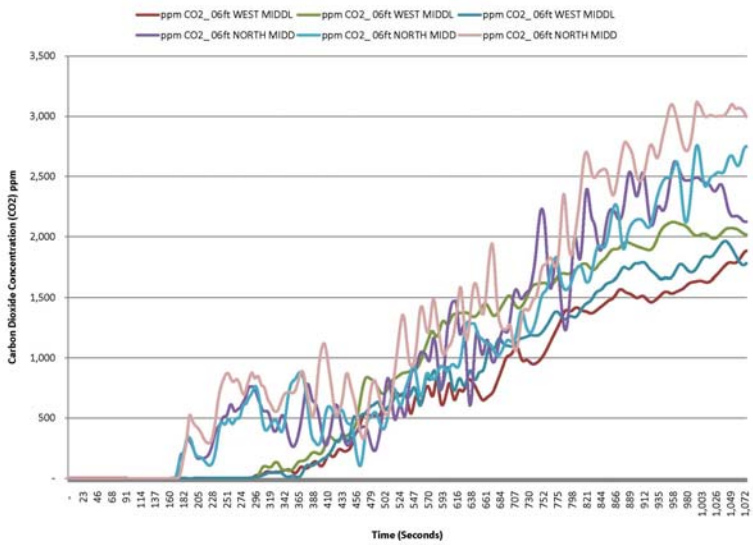


Figure No. 33: CO_2 Concentration at 6-ft above Finished Floor



Results Summary

Performance of the fire protection strategy was evaluated in terms of the impact of the event on the level of tenability throughout the area of interest. Tenability may be measured on the basis of exposure to both heat and toxic gases characteristic of the products of combustion as well as the resulting visibility imposed by the presence of these gases in paths of egress.

The criterion for thermal tenability utilized throughout this analysis is exposure for any duration to gas temperatures exceeding 150°F (65°C). Above this threshold, exposure to hot gases is limited by skin pain as opposed to hyperthermia[19]. Hyperthermia / heat stroke is the result of prolonged exposure to a heated environment. The focus for thermal tenability is on the potential for hazardous exposures during the period of time required to egress. Criteria for visibility are less precise given the significance of the potential presence of eye irritants and the relatively scarce available data on the corresponding influence on walking speed. For these simulations, 30-foot visibility is deemed appropriate for providing occupants a means to move away from the fire. However, much greater emphasis is placed on the effects of skin exposure to heat and respiratory exposure to toxic gases, which is likely to be more accurately assessed by the FDS model.

Exposure to toxic gases is a complex issue that may be reasonably approached with a focus on the combined effects of exposure to carbon monoxide, carbon dioxide and decreased levels of oxygen. The intake of carbon monoxide is hazardous due to the generation of carboxyhemoglobin in the blood stream of the exposed persons. This hazard may be magnified by the presence of increased levels of CO_2 and decreased O_2, which promote more rapid breathing (as well as decreased pH levels in blood) and therefore an increased rate of uptake of toxins. In an effort to calculate these combined effects, experimental data is referenced in Figure No. 2 on page 9.

[19] Klote, J. and Milke, J. Principles of Smoke Management. American Society of Heating, Refrigerating and Air-Conditioning Engineers & Society of Fire Protection Engineers, Atlanta: 2002, pg. 43-44.

Tenability is evaluated by comparing output data from the simulation to the established acceptable level for toxicity, temperature and visibility. The maximum acceptable temperature is 150°F (65.6°C). The temperature away from the immediate vicinity of the fire was approximately 70°F (21°C) measured at 6 feet above the finished floor at the far end of the building where hot gases accumulate after 15 minutes.

Table No. 4 summarizes the tenable condition for the design fire for the open space without obstructions.

Table 4: Building without Obstruction Simulation Result

SIMULATION RESULTS (ULTRAFAST T-SQUARED FIRE)					
Fire Size/Model	**Sprinkler Controlled Fire (kW)**	**Simulation Time (sec)**	**Tenability Temperature at 6-ft (F)**	**Tenability Visibility at 6-ft (ft)**	**Tenability CO/CO2 at 6-ft (ppm)**
Ultrafast Fire	10,000	1,200	21 C (70 F)	Over 9.14 m (30-ft)	CO under 20 ppm CO_2 under 500 ppm

Table No. 5 summarizes the tenable condition for the design fire for the space with solid-continuous obstructions.

Table 5: Building with Solid-Continuous Obstruction Simulation Result

SIMULATION RESULTS (ULTRAFAST T-SQUARED FIRE)					
Fire Size/Model	**Sprinkler Controlled Fire (kW)**	**Simulation Time (sec)**	**Tenability Temperature at 6-ft (F)**	**Tenability Visibility at 6-ft (ft)**	**Tenability CO/CO2 at 6-ft (ppm)**
Ultrafast Fire	10,000	900	21 C (70 F)	Over 9.14 m (30-ft)	Average 1,500 ppm CO and Average 4% CO_2

The simulation results indicate that smoke propagation for large open spaces requires significant time to fill the upper ceiling. Tenable conditions at 6 feet above the floor were found to be maintained at areas away from the fire.

Furthermore, sprinkler activation is expected to control the fire. The fire model scenario assumes the fourth sprinkler activates at 4 minutes and 1 second. As a conservative approach, a sprinkler-controlled fire was assumed to keep the fire at 10 MW for the duration of the simulation (20 minutes).

Therefore, fire models for large facilities with and without solid-continuous obstructions estimate tenable conditions are maintained for the total time it takes occupant to egress the space.

The additional fire modeling performed to compare the effects of a significantly smaller building indicate that tenable conditions are maintained for the calculated time it takes an occupant to reach an exit. Table No. 6 summarizes the tenable condition for a smaller building with solid obstructions representing rack storage.

Table 6: Smaller Building with Obstructions Simulation Result

SIMULATION RESULTS (ULTRAFAST T-SQUARED FIRE)					
Fire Size/Model	**Sprinkler Controlled Fire (kW)**	**Simulation Time (sec)**	**Tenability Temperature at 6-ft (F)**	**Tenability Visibility at 6-ft (ft)**	**Tenability CO/CO2 at 6-ft (ppm)**
Ultrafast Fire	10,000	1200	23 C (73 F)	Over 9.14 m (30-ft)	40 ppm CO and 1,000 ppm CO_2

Time-Based Egress Analysis

Time-based egress analyses can be utilized to determine the evacuation time of an individual from a building during a fire event. The evacuation time includes three (3) main components; the amount of time from ignition of the fire until notification, the delay time between hearing the fire alarm and beginning to evacuate the building, and the amount of time it takes that individual to reach an exit or other safe location.

The time until notification is the amount of time it takes from ignition of the fire until the fire alarm activates. Based on the results of the fire sprinkler activation model, the first sprinkler activates approximately at 3 minutes, 52 seconds (232 seconds) and the fourth sprinkler activates at 4 minutes, 1 second (241 seconds).

Delay time is the amount of time it takes an individual to perceive that the fire alarm is activated and begin to travel towards an exit. Table 3-13.1 of the Society of Fire Protection Engineers (SFPE) Fire Protection Handbook identifies the estimated delay time in a facility of this nature to approximately 4 minutes (240 seconds)[20].

The primary objective of this analysis is to consider the impact of increasing travel distance from 250 feet to 400 feet. The average walking speed of an able-bodied adult walking alone is 3.74 feet per second (1.14 m/sec)[21]. This is a conservative estimate as people tend to run rather than walk during an emergency. The time to travel from the worst-case location in the building to the exit is calculated by dividing the total distance by the speed of the individual. Calculation for a 250-foot travel distance is provided below:

$$Time = \left[\frac{\text{Distance}}{Speed}\right] = \left[\frac{250\,feet}{3.74\,feet/sec}\right] = 66.85\,sec$$

The above calculation shows the amount of time for the individual to travel 250 feet is 67 seconds.
The total amount of time from ignition until an occupant reaches an exit, calculated by adding each of the four components, is 8 minutes, 59 seconds (539 seconds). This is the total amount of time assuming fire

[20] Handbook of Fire Protection Engineering, 3rd edition: Proulx, Guylene. *"Movement of People: The Evacuation Timing"*, Section 3, Chapter 13: SFPE, 2002, Table 3-13.1
[21] Fire Protection Handbook, 20th edition: Fahy, Rita F. *"Calculation Methods for Egress Prediction"*, Section 4, Chapter 2: NFPA, 2008, Table 4.2.2

alarm notification is initiated after the 1st sprinkler activates and there is a delay time of 4 minutes (240 seconds).

$$Total\ time(sec) = 232 + 240 + 67 = 539 \text{ seconds}$$

Using the same calculation method, the amount of time for the individual to travel 400 feet is 106.95 seconds for a difference of 40.1 seconds.

$$Time = \left[\frac{\text{Distance}}{Speed}\right] = \left[\frac{400\ feet}{3.74\ feet/sec}\right] = 106.95\ sec$$

With a 400 foot travel distance the total amount of time from ignition until an occupant reaches an exit, calculated by adding each of the four components, is 11 minutes, 10 seconds (670 seconds). This is the total amount of time assuming notification is provided when the 1st sprinkler activates with delay time of 4 minutes (240 seconds).

$$Total\ time(sec) = 232 + 240 + 107 = 670 \text{ seconds}$$

The modeling results have shown that tenability is maintained for the required duration to exit the building.

Summary and Conclusion

Ensuring the life safety of the occupants in any building requires multiple strategies to be used in concert. In the referenced building, the high ceilings and expansive floor plan creates a large volume for the smoke to fill. This volume must be filled before the smoke layer descends to a height that will be of concern to the occupants or the responding fire rescue personnel.

The intent of this analysis is to predict whether a 400 foot exit travel distance will provide safe conditions for occupant or emergency responder egress during a fire event. A computer model of the entire building, utilizing the computational fluid dynamics (CFD) software known as Fire Dynamics Simulator (FDS), was utilized to predict tenable conditions throughout the entire space. The computer model showed that four (4) sprinklers activated within 241 seconds (4 minutes, 1 second).

As a conservative design, tenability conditions were modeled assuming the fire will grow following an ultra-fast, t-squared fire. Furthermore, it was assumed the total heat release rate (10 MW) at the time of the fourth sprinkler activation will remain constant for the remaining 20 minutes simulation. This is a conservative assumption since sprinklers will control the fire and the overall heat release rate and smoke production will be reduced significantly.

Highlighted results of the analysis include the following:

- The high ceilings in these large buildings create a massive volume for smoke and toxic glasses to fill before descending to 6 feet above finished floor which is the level that will impact occupants and responders.

- It takes over 10 minutes before the smoke begins to descend from the ceiling.

- The amount of time for an individual to travel 400 feet is 106.95 seconds (1 minute, 47 seconds).
- The additional time an occupant needs to reach an exit is 40 seconds if the exit travel distance is increased from 250 feet to 400 feet.
- Tenable conditions, i.e. safe temperatures, ample visibility, and the absence of unsafe toxic gasses, are maintained at 6 feet above the finished floor away from the vicinity of the fire for the total time required to reach an exit.

This analysis has shown that the massive open space of the facility combined with the excellent performance of the fire sprinkler system provides adequate tenability such that occupants can safely egress given a 400 foot travel distance.

Sincerely,

Aon Fire Protection Engineering

Prepared By:

Jaime Paucar, P.E.
Project Manager

Reviewed By:

Garner A. Palenske, P.E.
Vice President | US Western Region

JP:nm

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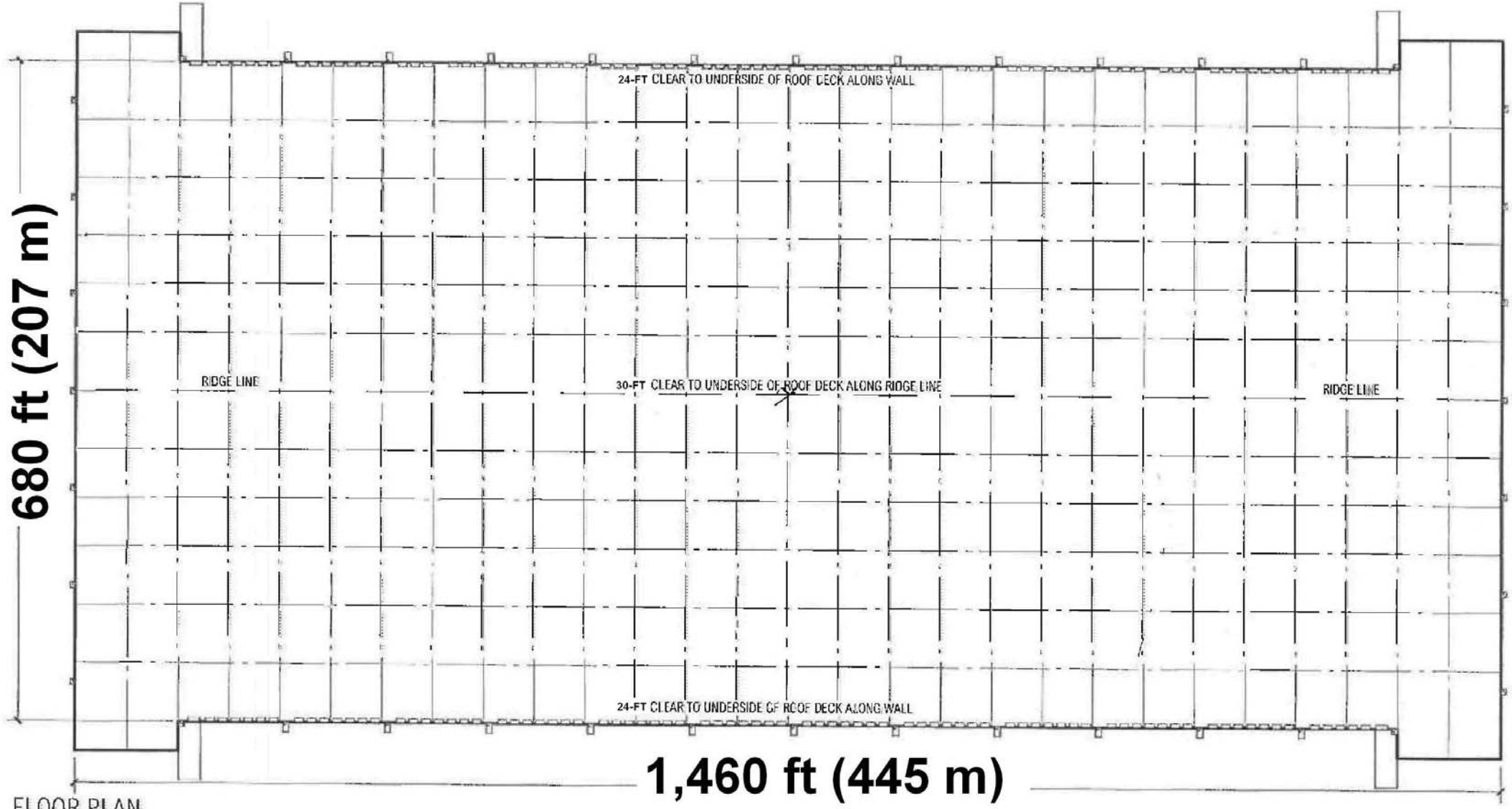
APPENDIX A

FLOOR PLAN VIEW OF FACILITY



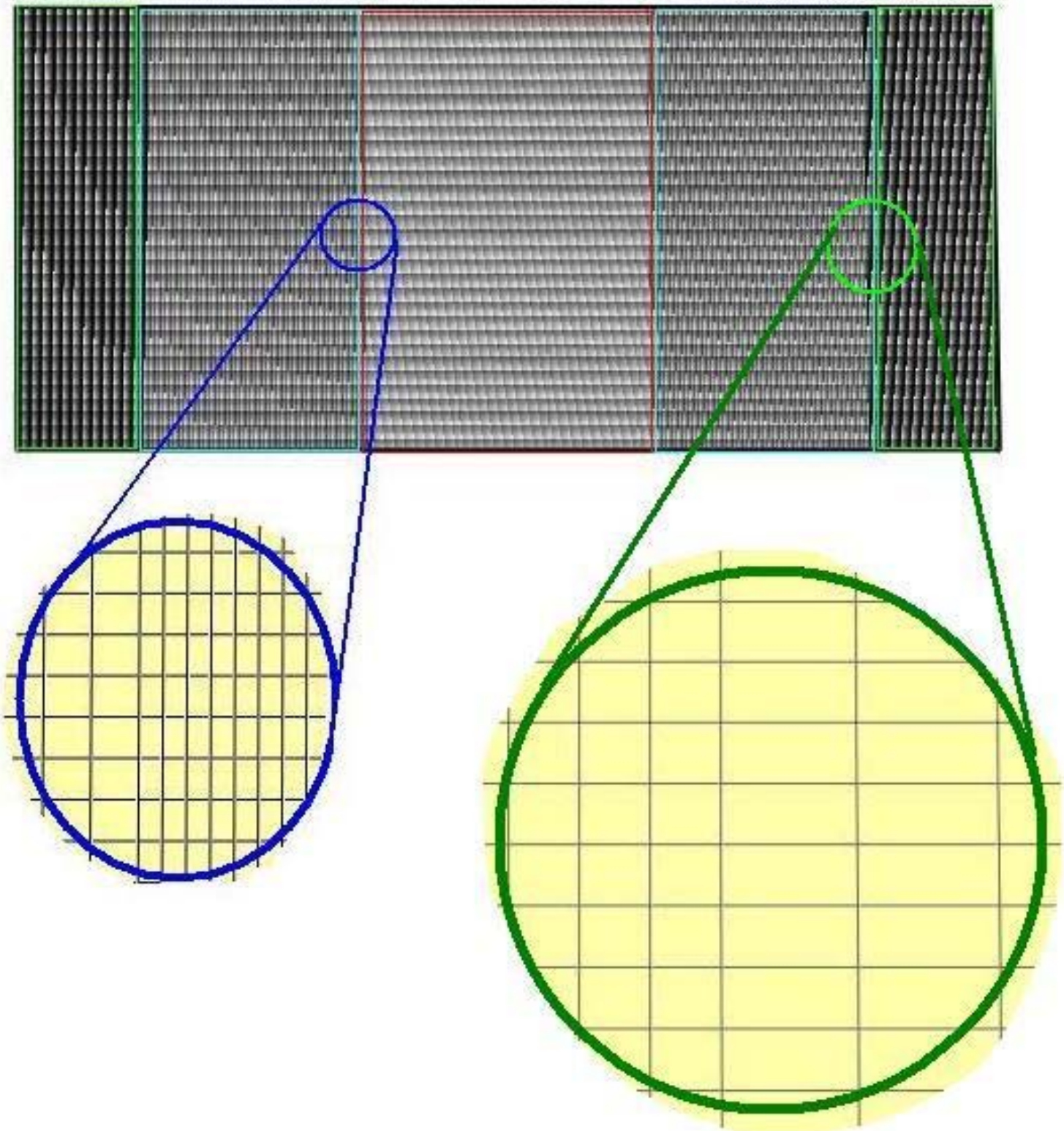
FLOOR PLAN

SCALE: 1" = 140'

APPENDIX B

FIRE MODEL GEOMETRY / MESH

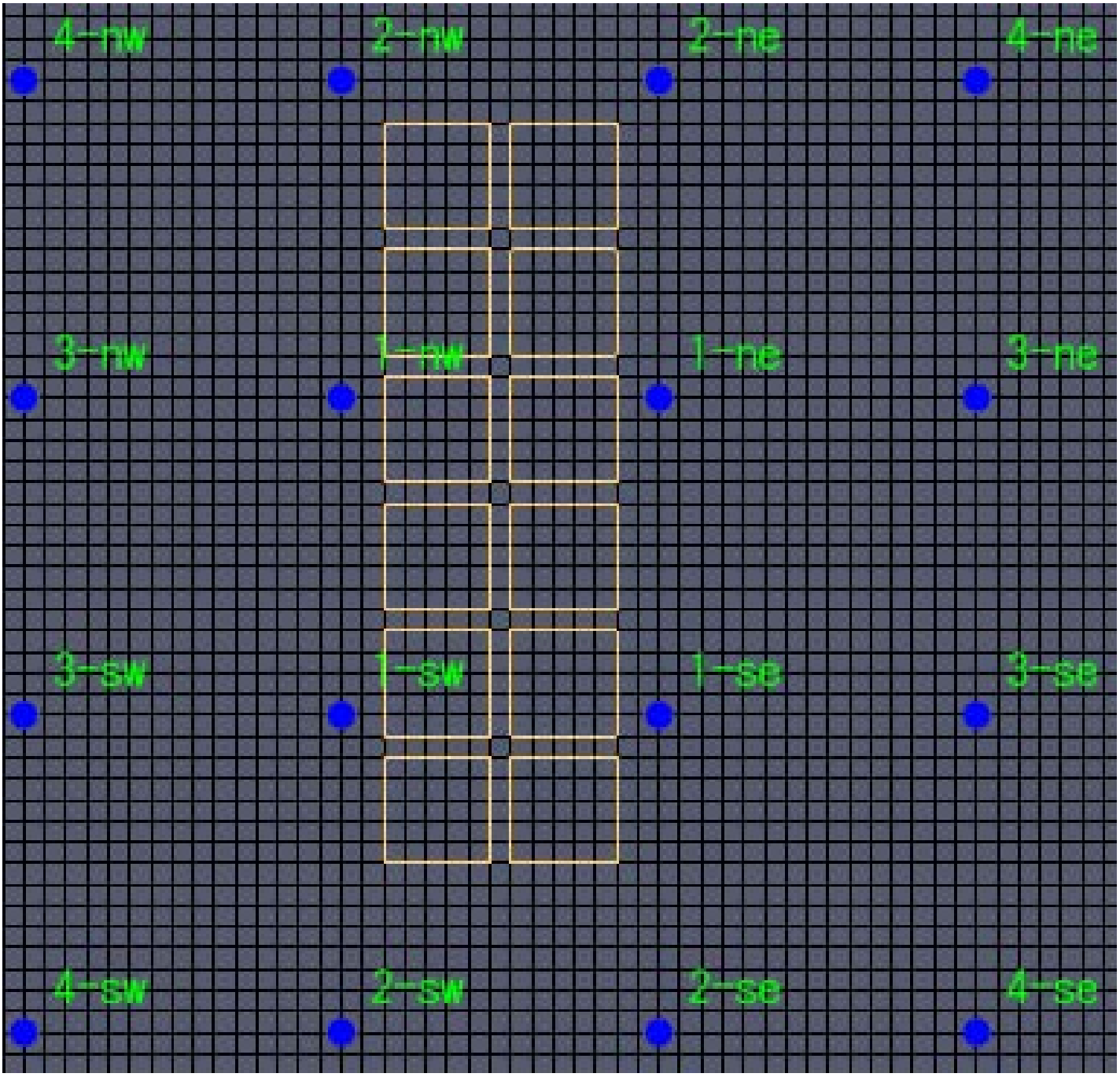
SINGLE MESH - GRID TRANSFORMATION
FINE MESH AT CENTER (0.5 m)
MEDIUM MESH (1.0 m)
LARGE MESH (2.0 m)



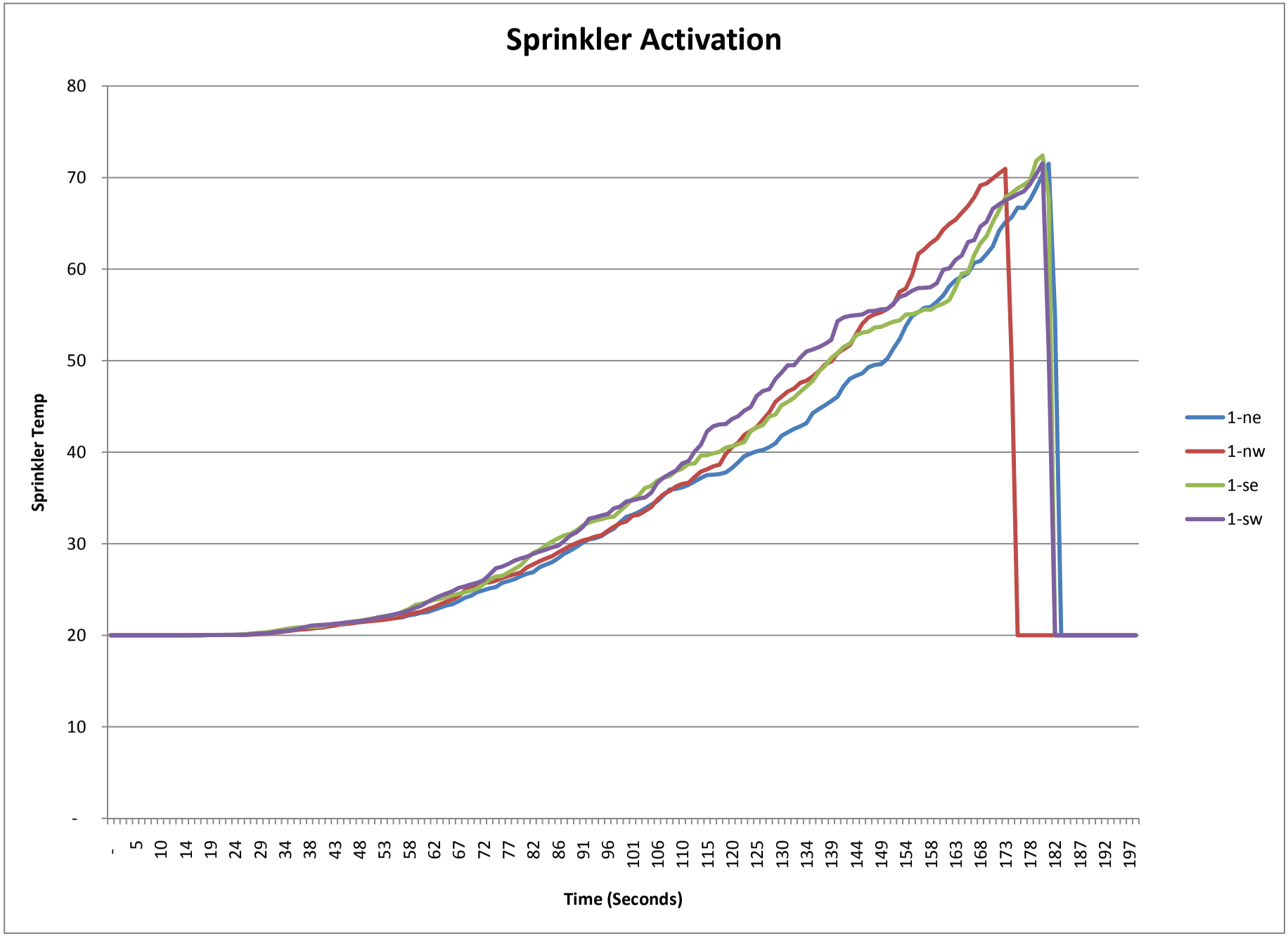
APPENDIX C

SPRINKLER ACTIVATION

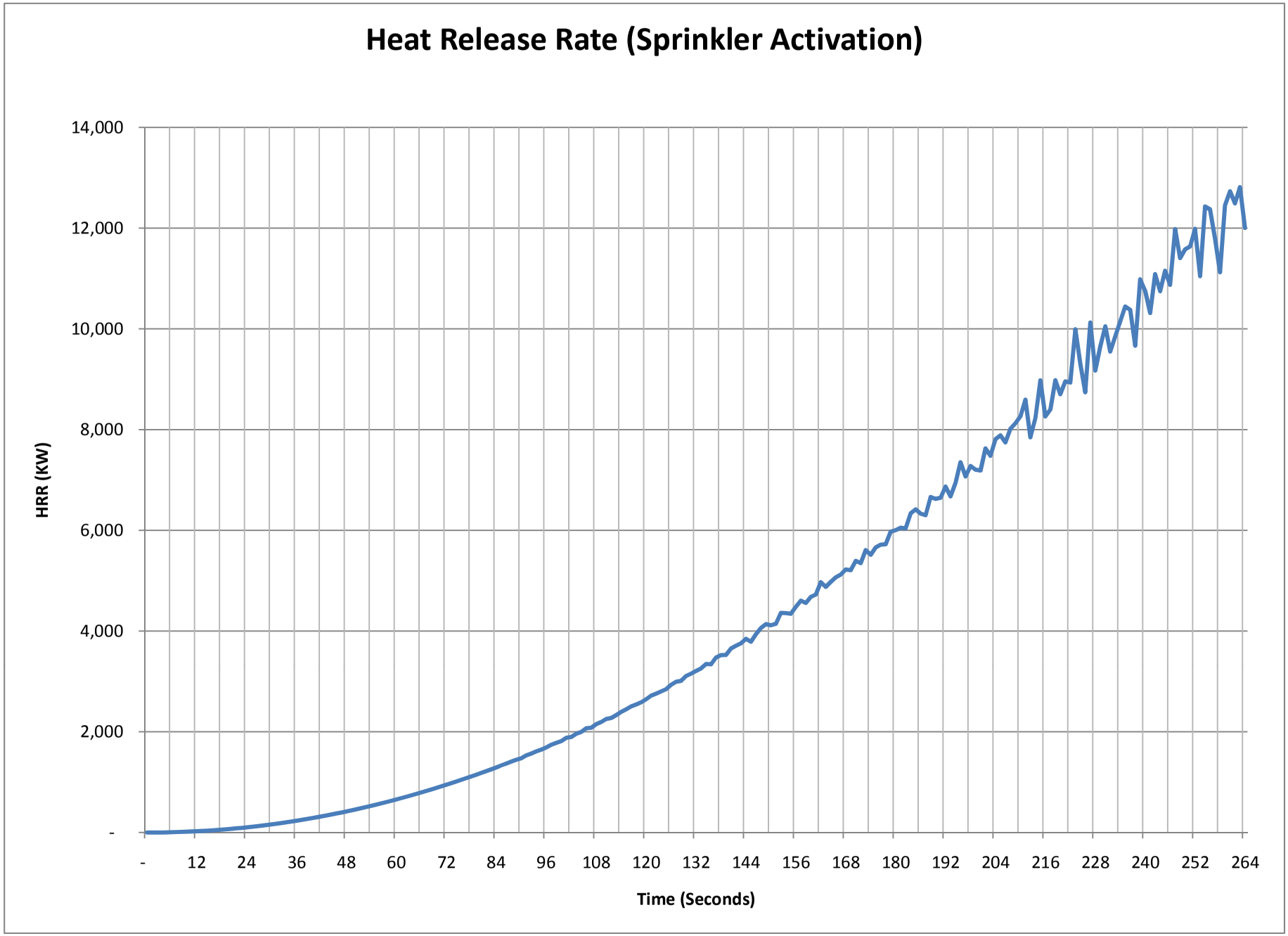
SPRINKLER LAYOUT - PLAN VIEW (ULTRAFAST DESIGN FIRE)
INCLUDES 36 SPRINKLERS



SPRINKLER ACTIVATION GRAPH
(TEMP VS TIME (SECONDS))



HEAT RELEASE RATE (FIRE SIZE) AT SPRINKLER ACTIVATION TIME (kW VS TIME (SECONDS))

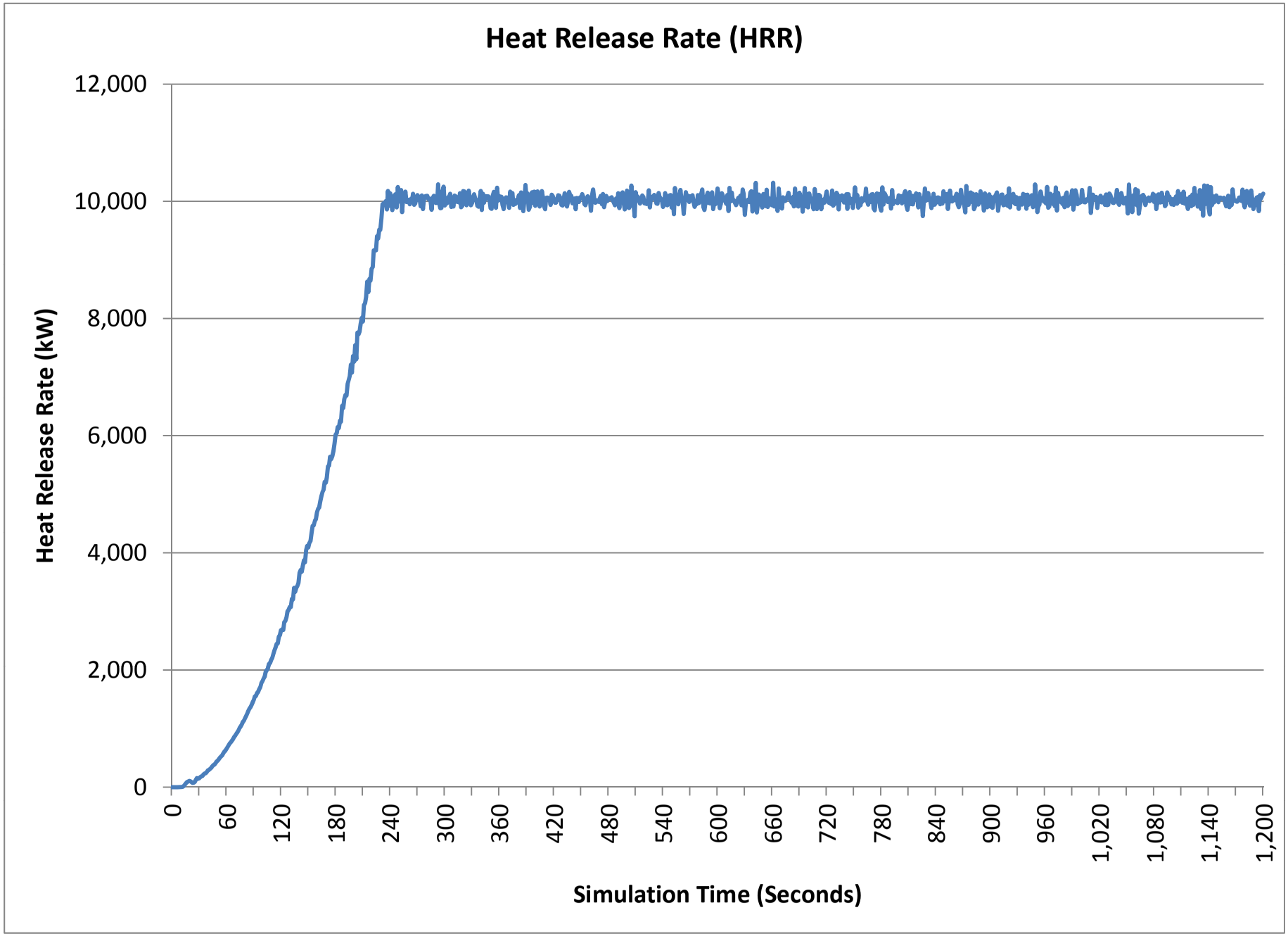


APPENDIX D

ULTRAFAST FIRE – SIMULATION RESULTS
FIRE SIZE: 10 MW
FIRE LOCATION: CENTER

APPENDIX D-1

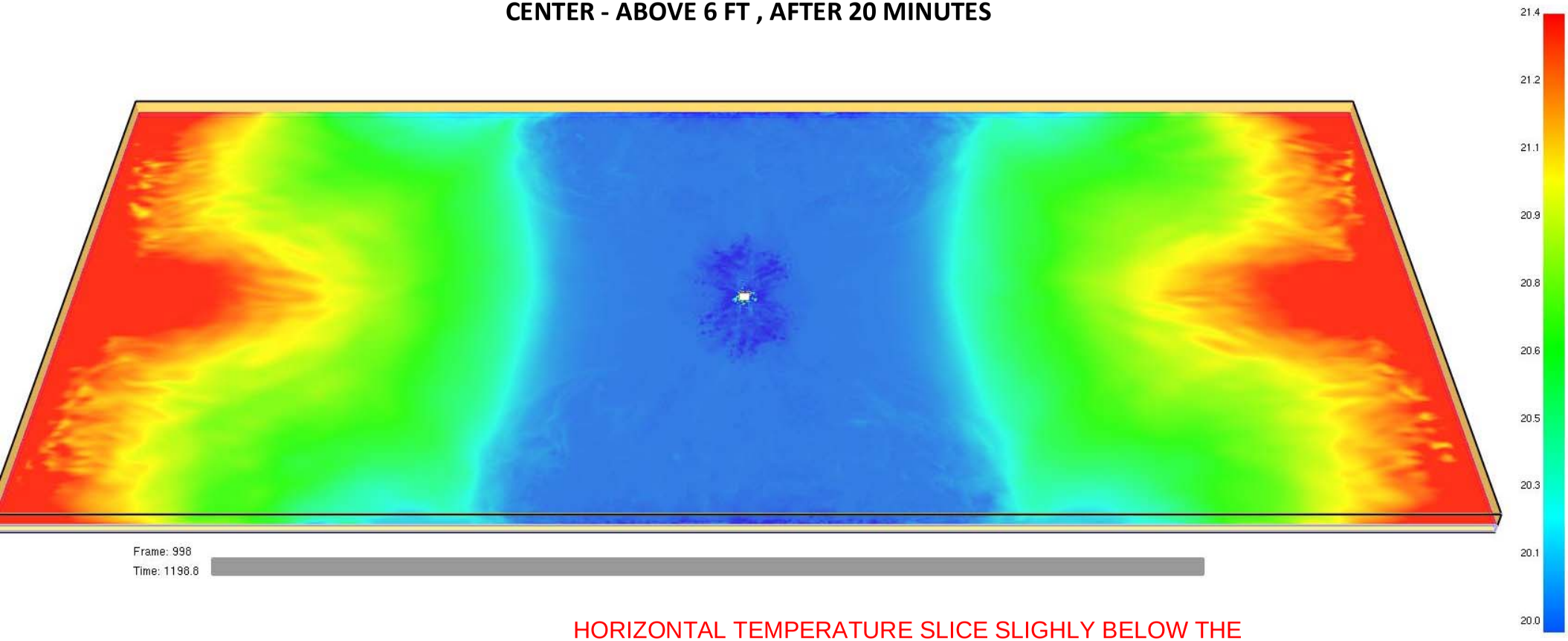
10 MW ULTRAFAST FIRE – HRR


Heat Release Rate (HRR)
Heat Release Rate (kW)
12,000
10,000
8,000
6,000
4,000
2,000
0
0
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1,020
1,080
1,140
1,200
Simulation Time (Seconds)

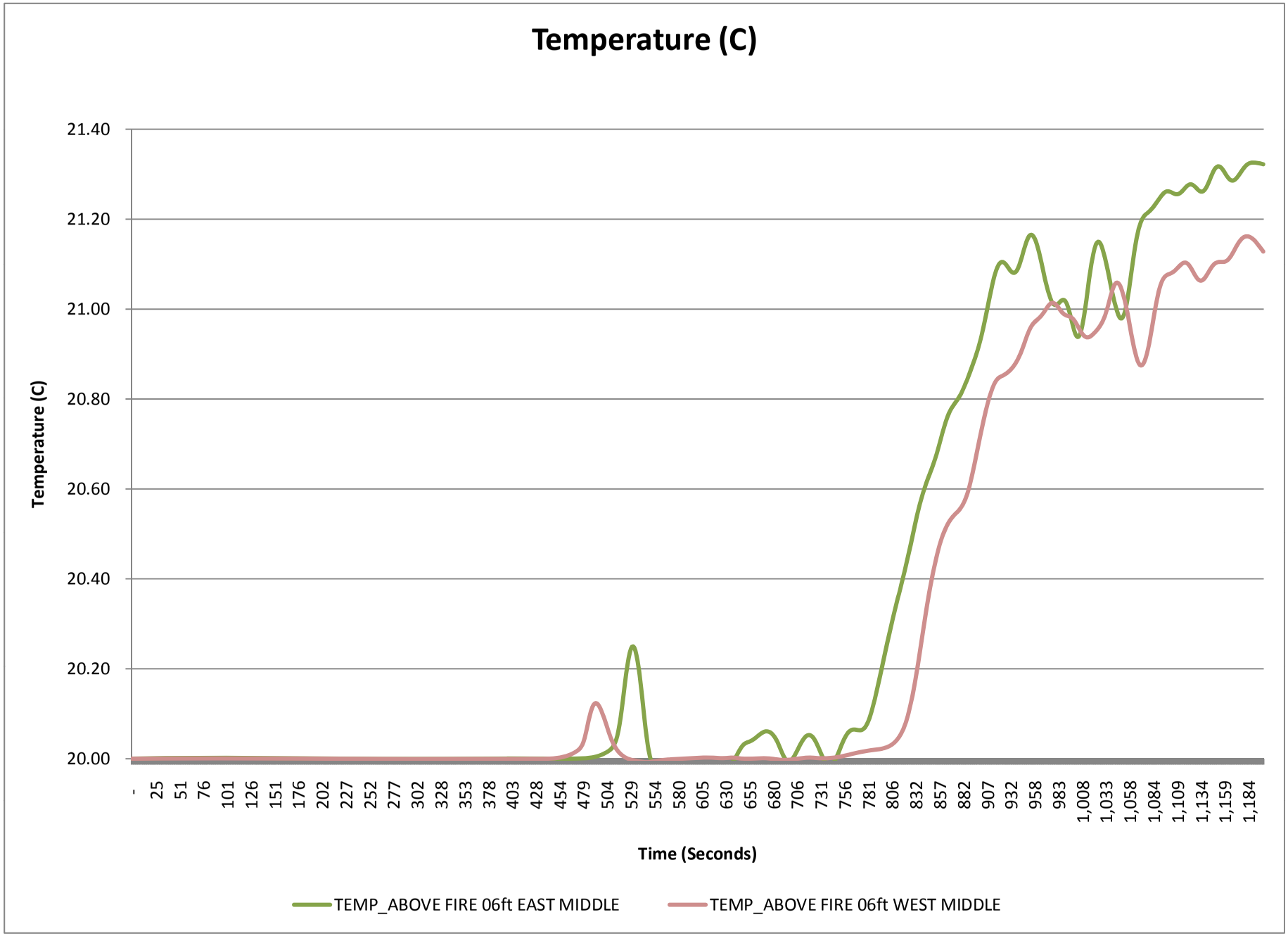
APPENDIX D-2

10 MW ULTRAFAST FIRE – TEMPERATURE SLICES

TEMPERATURE – ULTRAFAST FIRE (10 MW FIRE)
CENTER - ABOVE 6 FT , AFTER 20 MINUTES



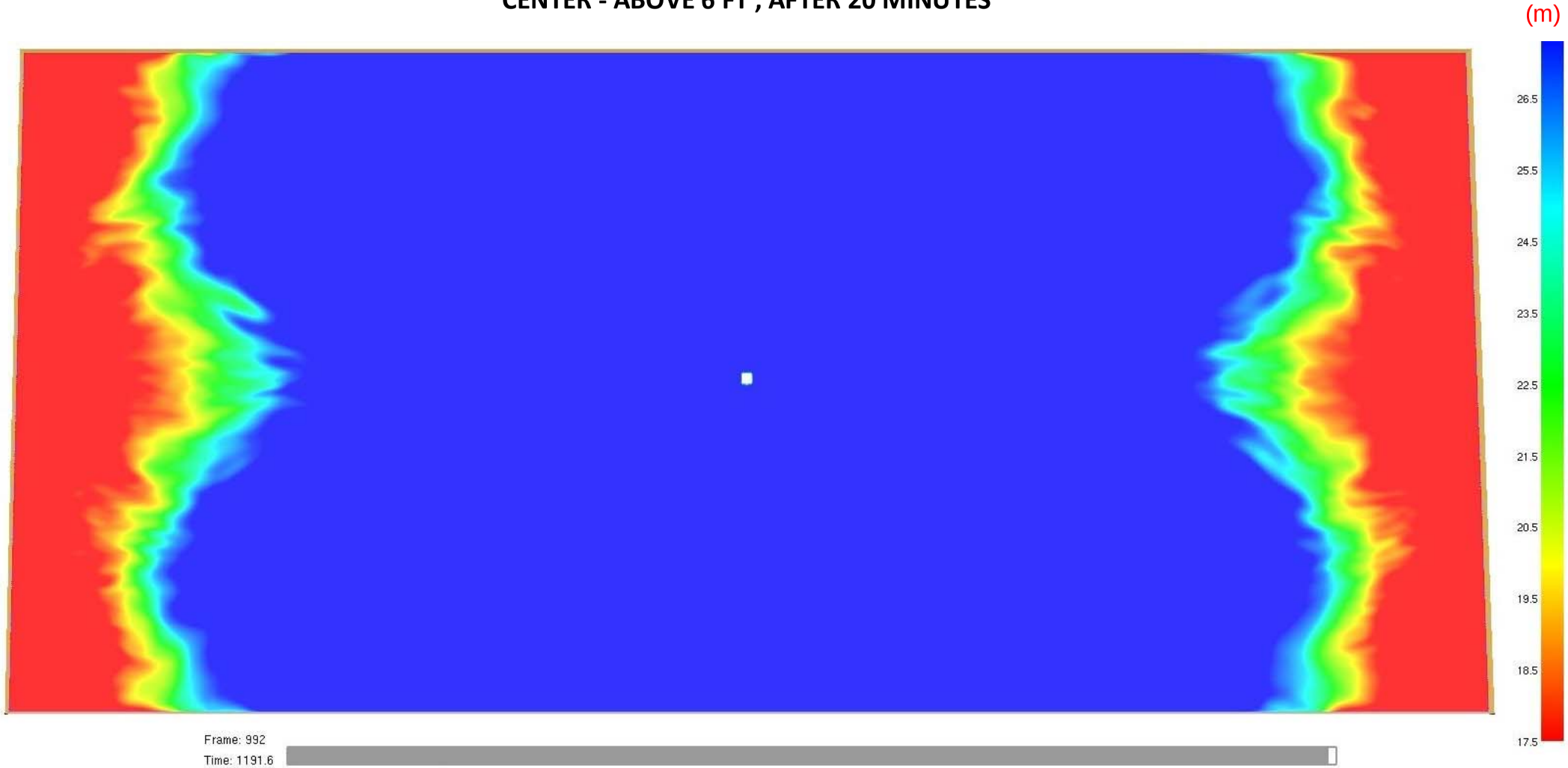
HORIZONTAL TEMPERATURE SLICE SLIGHLY BELOW THE FIRE BURNING AREA. AIR ENTERS THE FIRE PLUME AT ROOM TEMPERATURE.

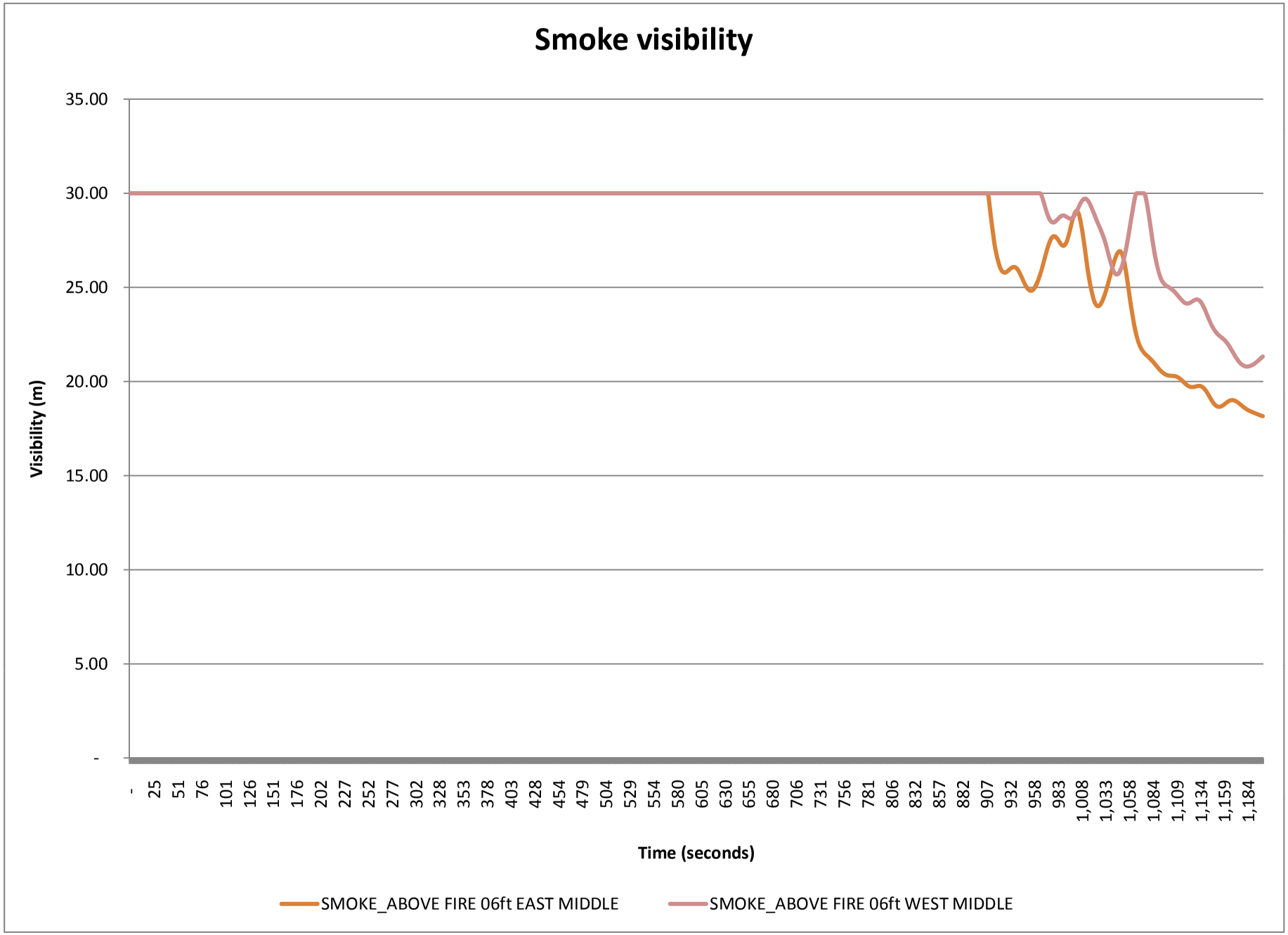

Temperature (C)
21.40
21.20
21.00
20.80
20.60
20.40
20.20
20.00
Temperature (C)
-
25
51
76
101
126
151
176
202
227
252
277
302
328
353
378
403
428
454
479
504
529
554
580
605
630
655
680
706
731
756
781
806
832
857
882
907
932
958
983
1,008
1,033
1,058
1,084
1,109
1,134
1,159
1,184
Time (Seconds)
TEMP_ABOVE FIRE 06ft EAST MIDDLE
TEMP_ABOVE FIRE 06ft WEST MIDDLE

APPENDIX D-3

10 MW ULTRAFAST FIRE – SMOKE VISIBILITY SLICES

VISIBILITY – ULTRAFAST FIRE (10 MW FIRE)
CENTER - ABOVE 6 FT , AFTER 20 MINUTES

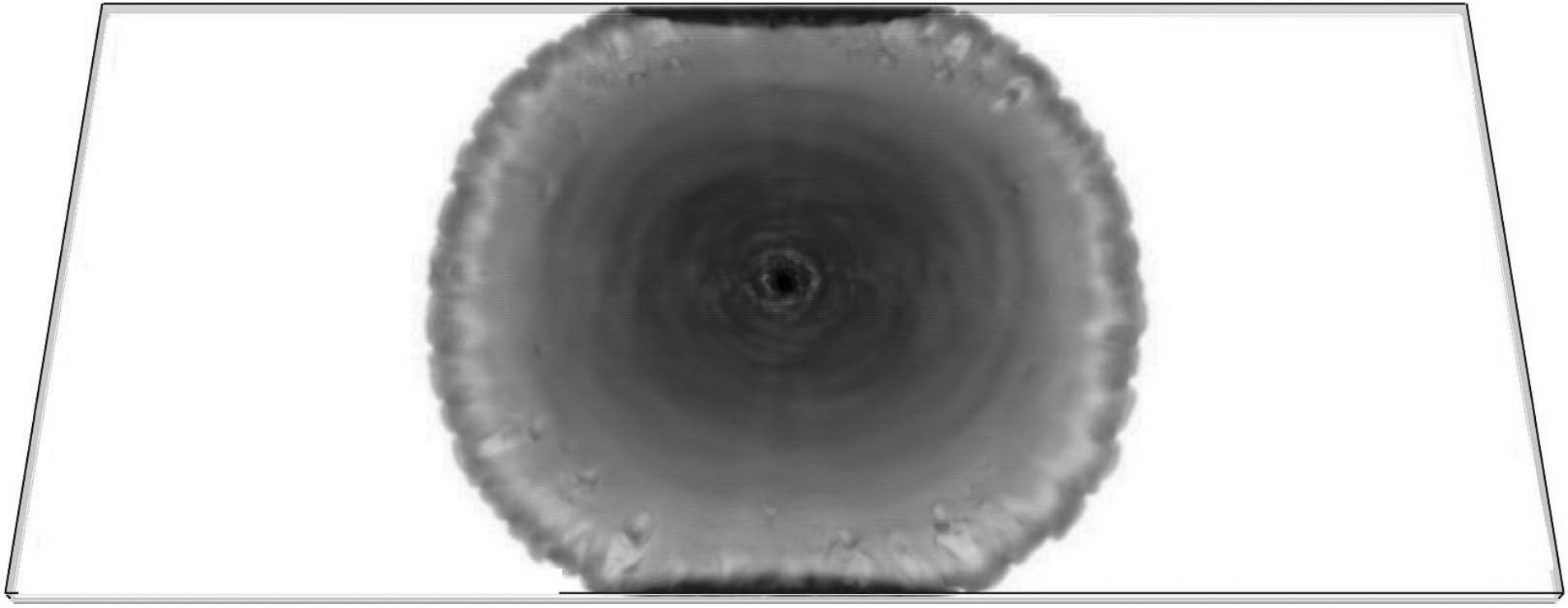



Smoke visibility
35.00
30.00
25.00
20.00
15.00
10.00
5.00
-
Visibility (m)
- 25 51 76 101 126 151 176 202 227 252 277 302 328 353 378 403 428 454 479 504 529 554 580 605 630 655 680 706 731 756 781 806 832 857 882 907 932 958 983 1,008 1,033 1,058 1,084 1,109 1,134 1,159 1,184
Time (seconds)
SMOKE_ABOVE FIRE 06ft EAST MIDDLE
SMOKE_ABOVE FIRE 06ft WEST MIDDLE

APPENDIX D-4

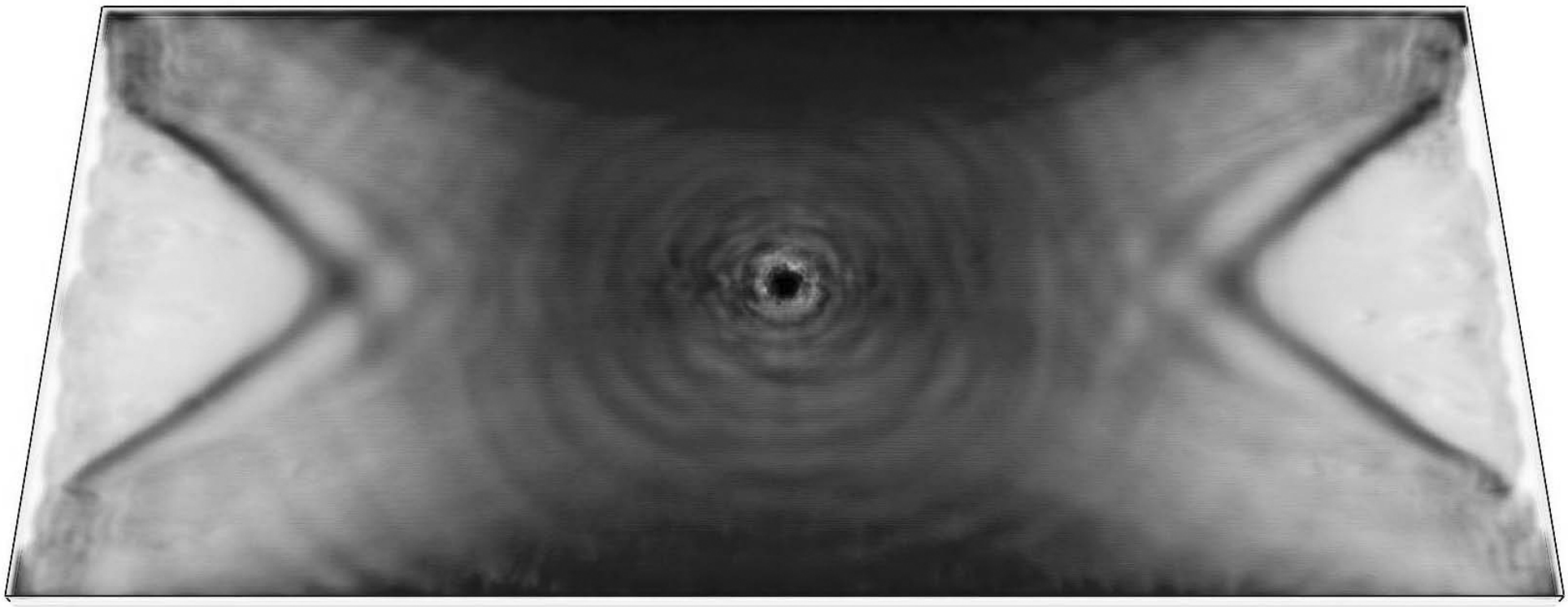
10 MW ULTRAFAST FIRE – SMOKE PROPAGATION SNAPSHOTS

SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
CENTER - AT 24 FT , AFTER 5 MINUTES



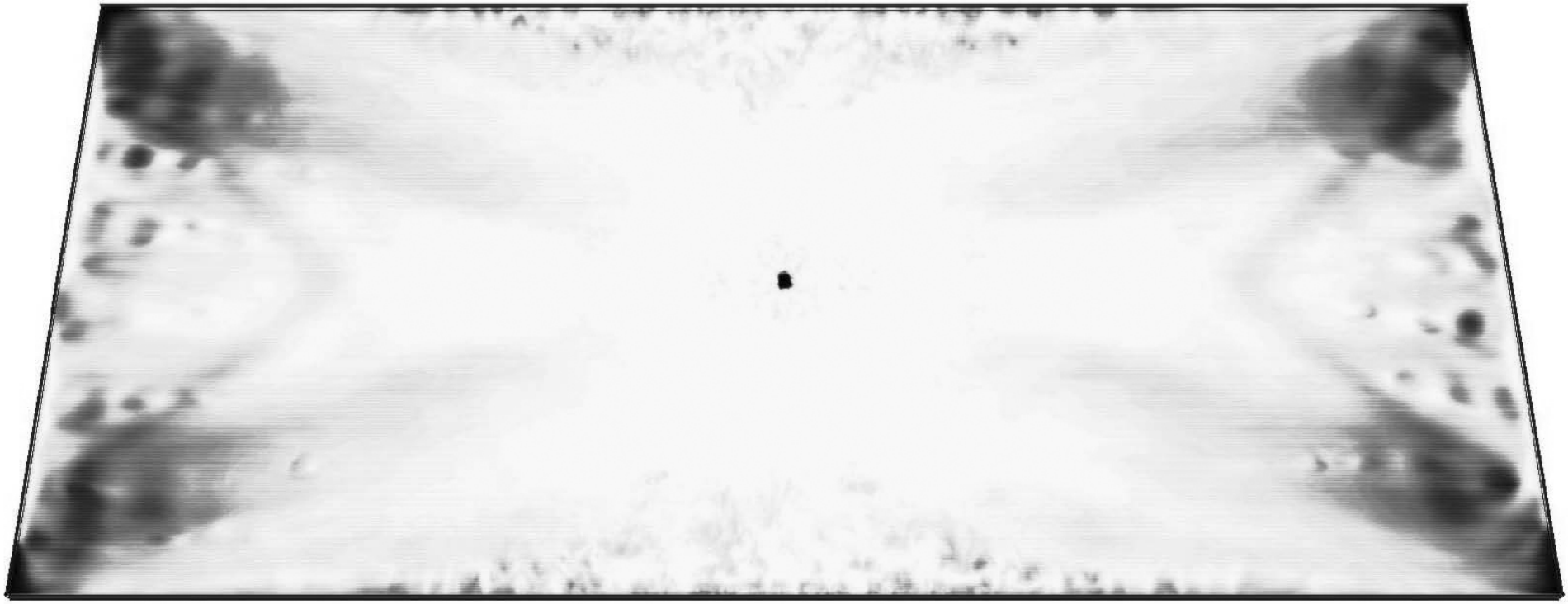
Frame: 249
Time: 300.0

SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
CENTER - AT 24 FT , AFTER 10 MINUTES



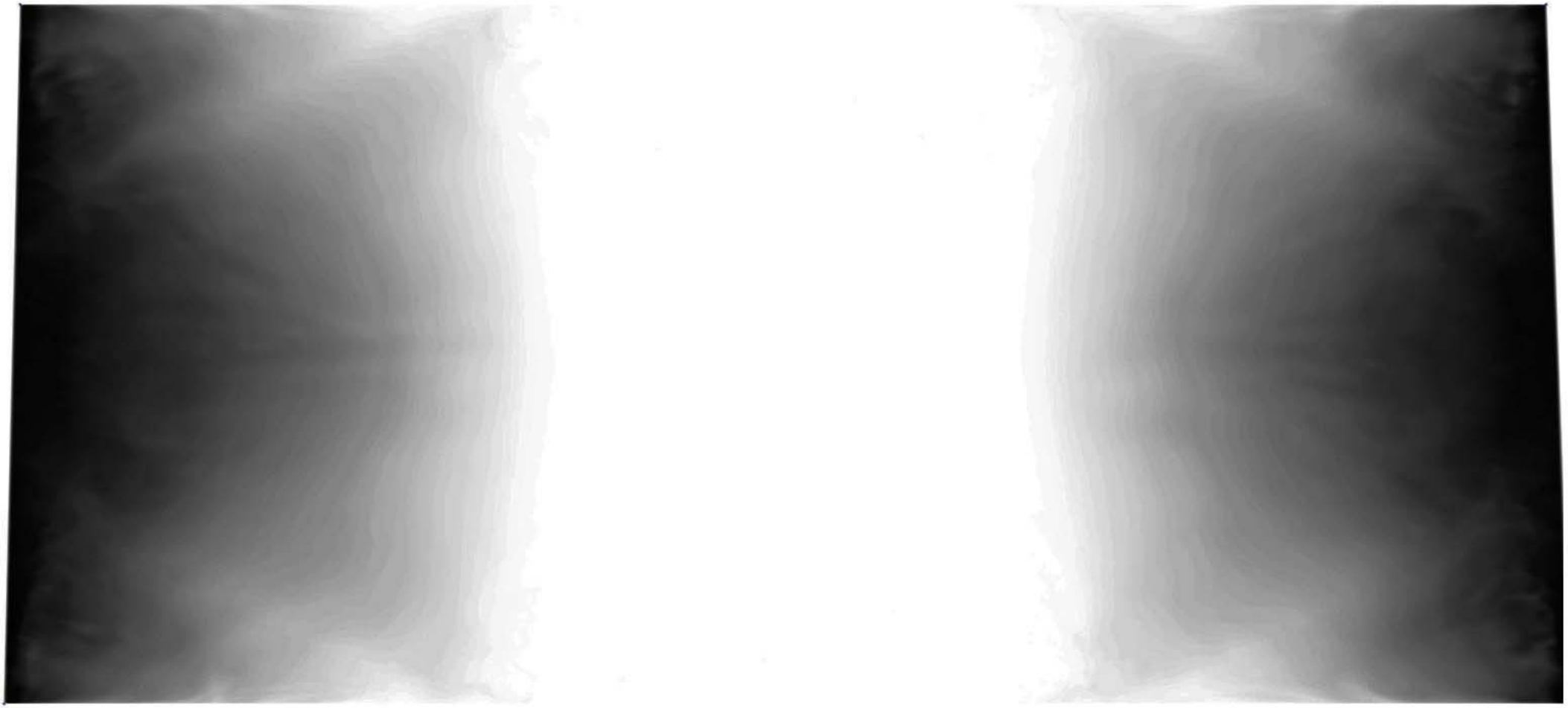
Frame: 499
Time: 600.0

SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
CENTER - ABOVE 10 FT , AFTER 10 MINUTES



Frame: 504
Time: 606.0

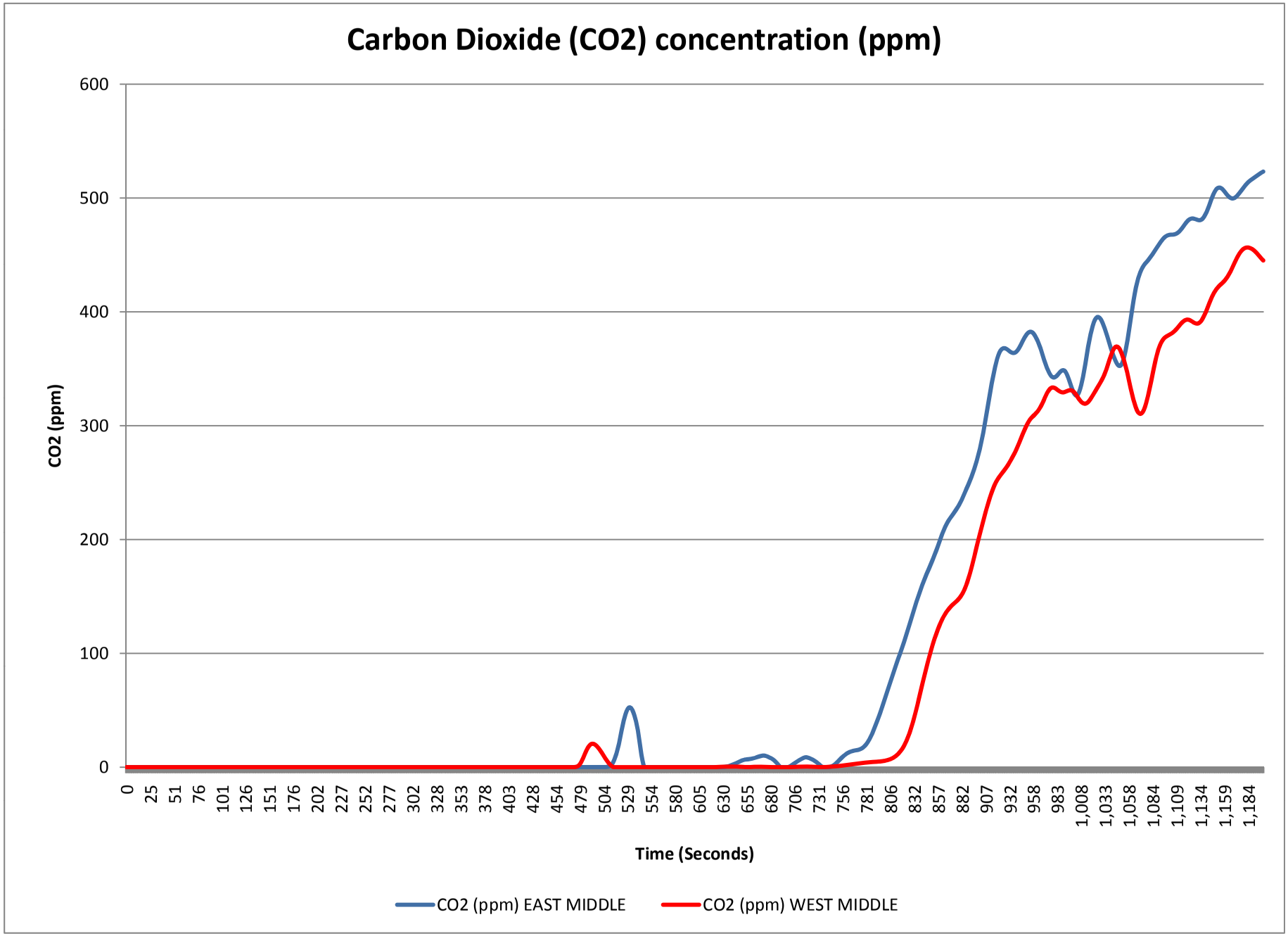
SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
CENTER - ABOVE 6 FT , AFTER 20 MINUTES

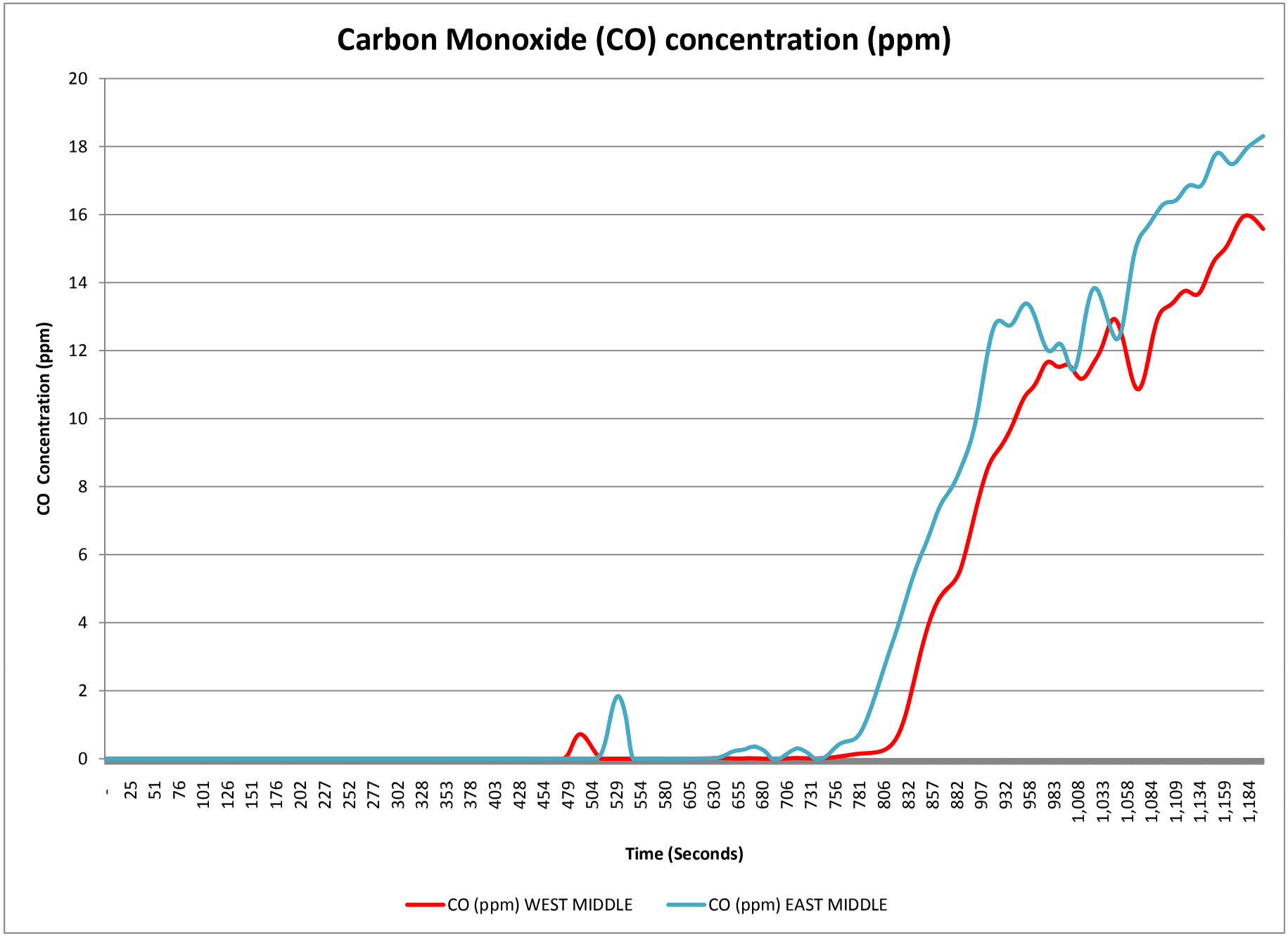


Frame: 992
Time: 1191.6

APPENDIX D-5

10 MW ULTRAFAST FIRE – CO & CO2 CONCENTRATION

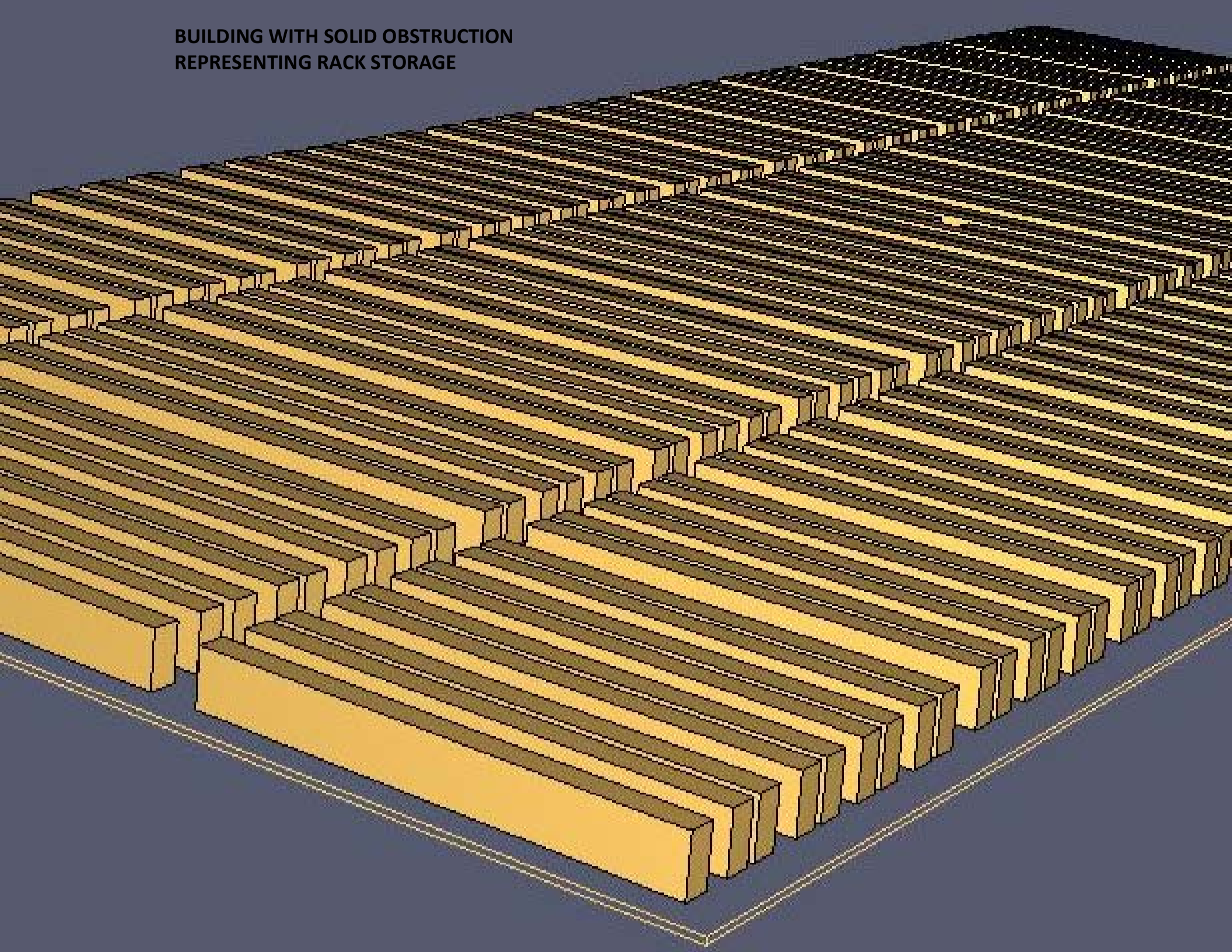

Carbon Dioxide (CO2) concentration (ppm)
CO2 (ppm)
600
500
400
300
200
100
0
0
25
51
76
101
126
151
176
202
227
252
277
302
328
353
378
403
428
454
479
504
529
554
580
605
630
655
680
706
731
756
781
806
832
857
882
907
932
958
983
1,008
1,033
1,058
1,084
1,109
1,134
1,159
1,184
Time (Seconds)
CO2 (ppm) EAST MIDDLE
CO2 (ppm) WEST MIDDLE


Carbon Monoxide (CO) concentration (ppm)
CO Concentration (ppm)
20
18
16
14
12
10
8
6
4
2
0
-
25
51
76
101
126
151
176
202
227
252
277
302
328
353
378
403
428
454
479
504
529
554
580
605
630
655
680
706
731
756
781
806
832
857
882
907
932
958
983
1,008
1,033
1,058
1,084
1,109
1,134
1,159
1,184
Time (Seconds)
CO (ppm) WEST MIDDLE
CO (ppm) EAST MIDDLE

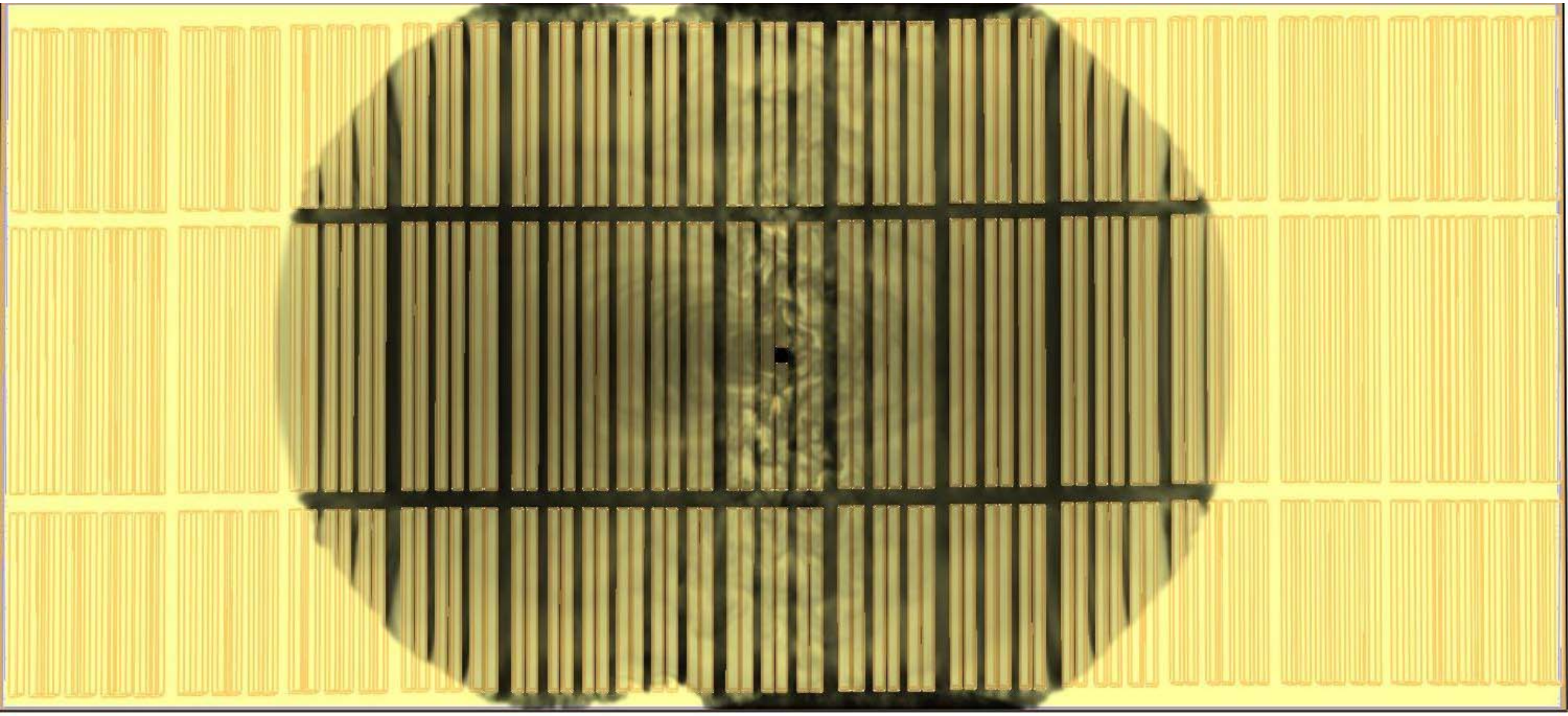
APPENDIX E

ULTRAFAST FIRE WITH OBSTRUCTIONS – SIMULATION RESULTS

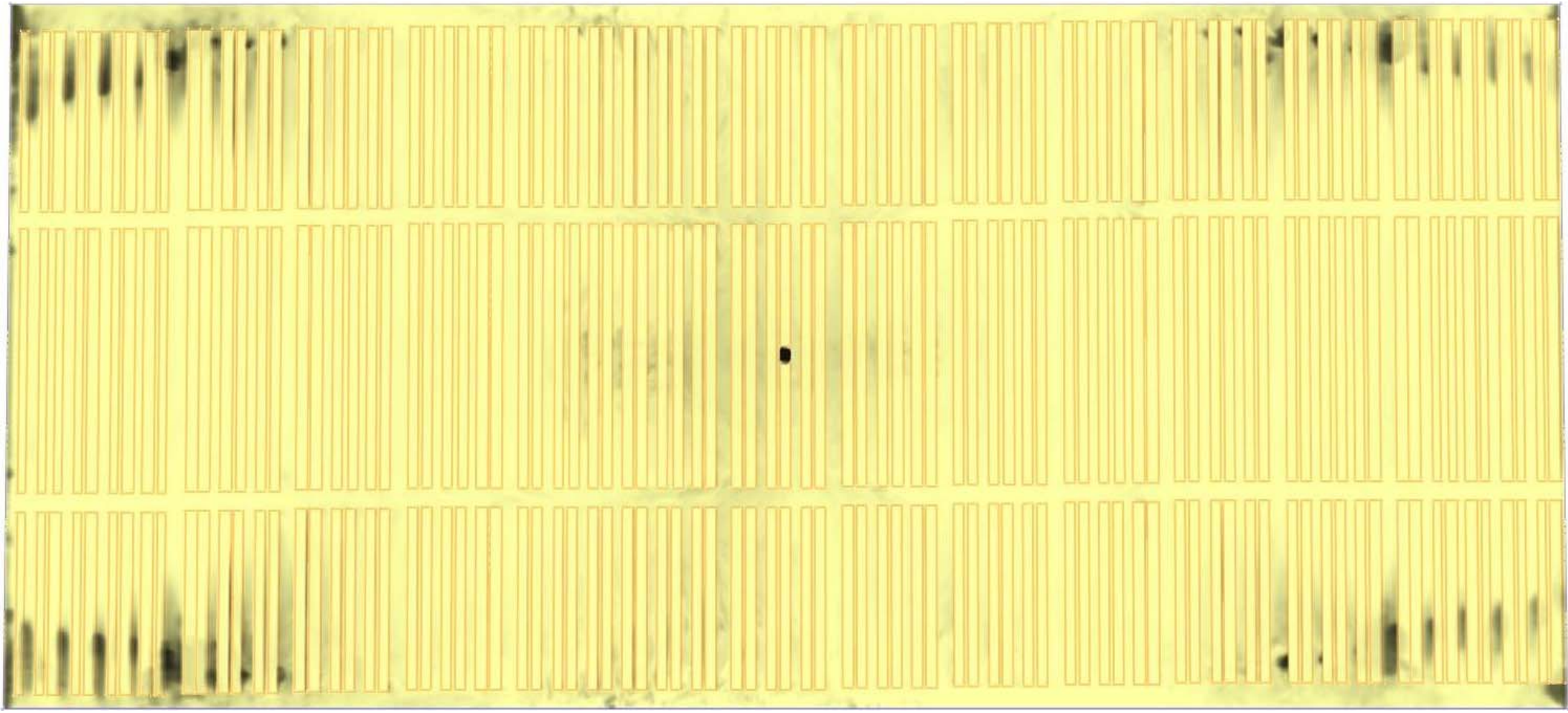
BUILDING WITH SOLID OBSTRUCTION REPRESENTING RACK STORAGE



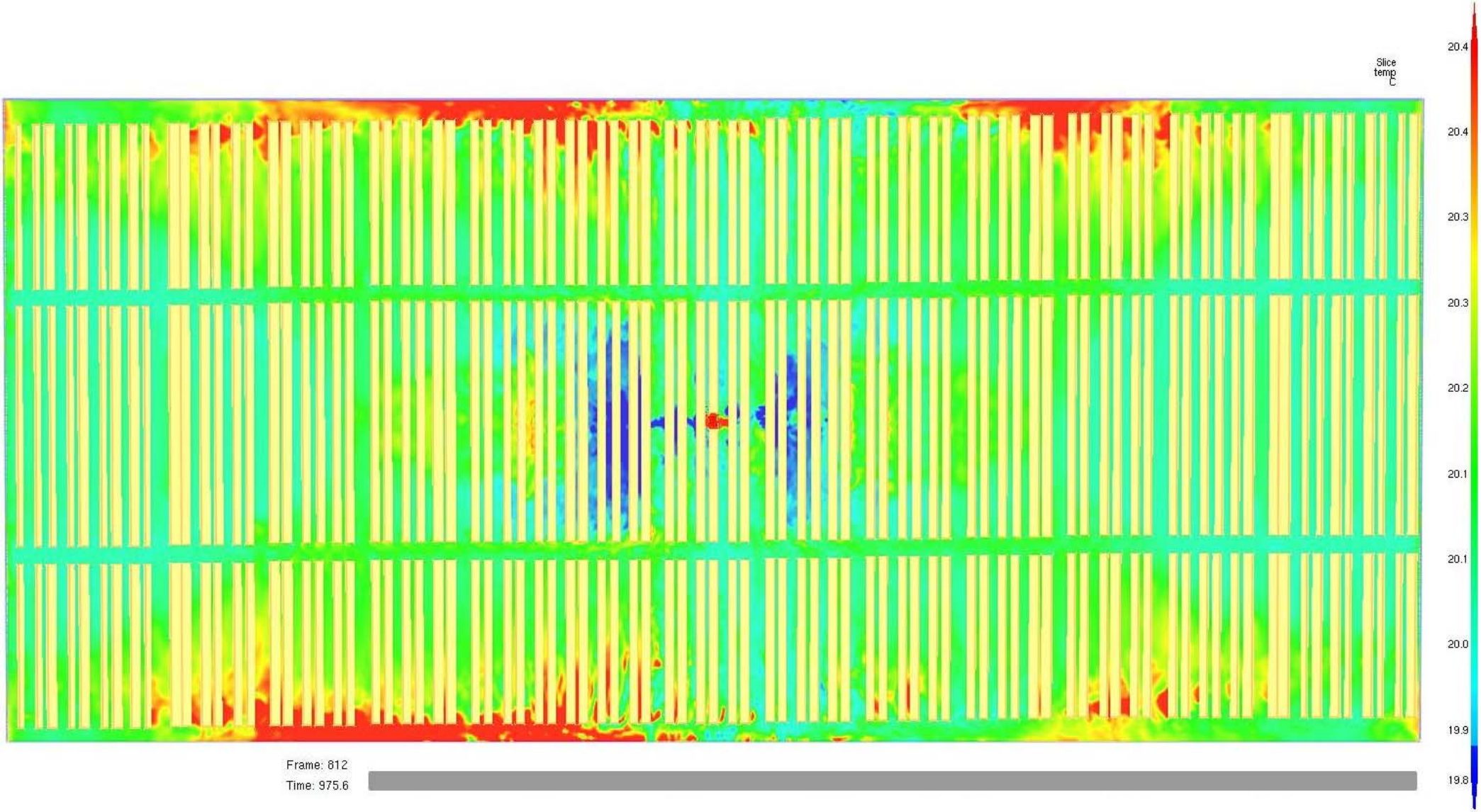
SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
VIEW FROM TOP AT 24 FT , AFTER 6 MINUTES

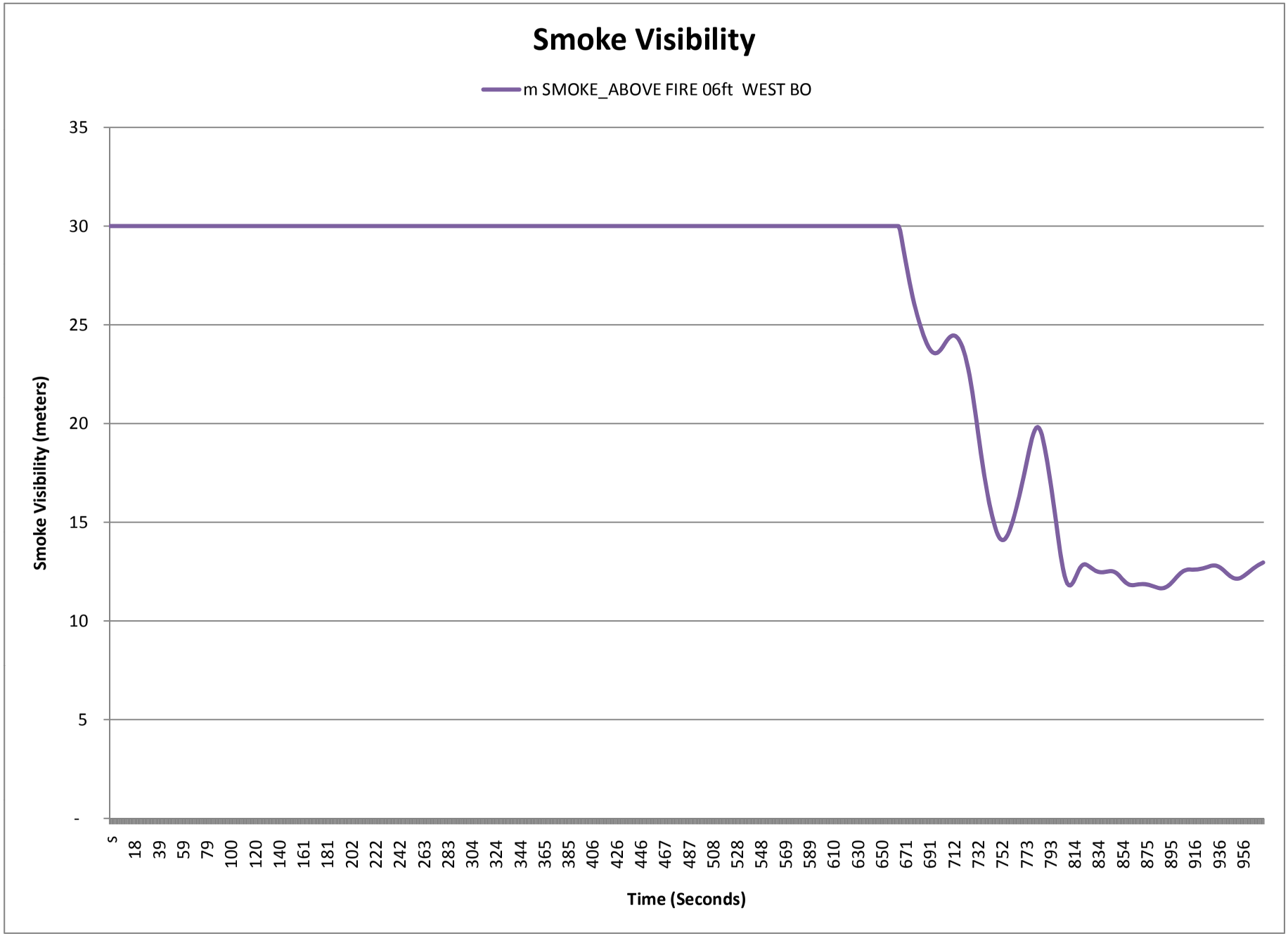


SMOKE SPREAD – ULTRAFAST FIRE (10 MW FIRE)
VIEW FROM TOP AT 6 FT , AFTER 15 MINUTES

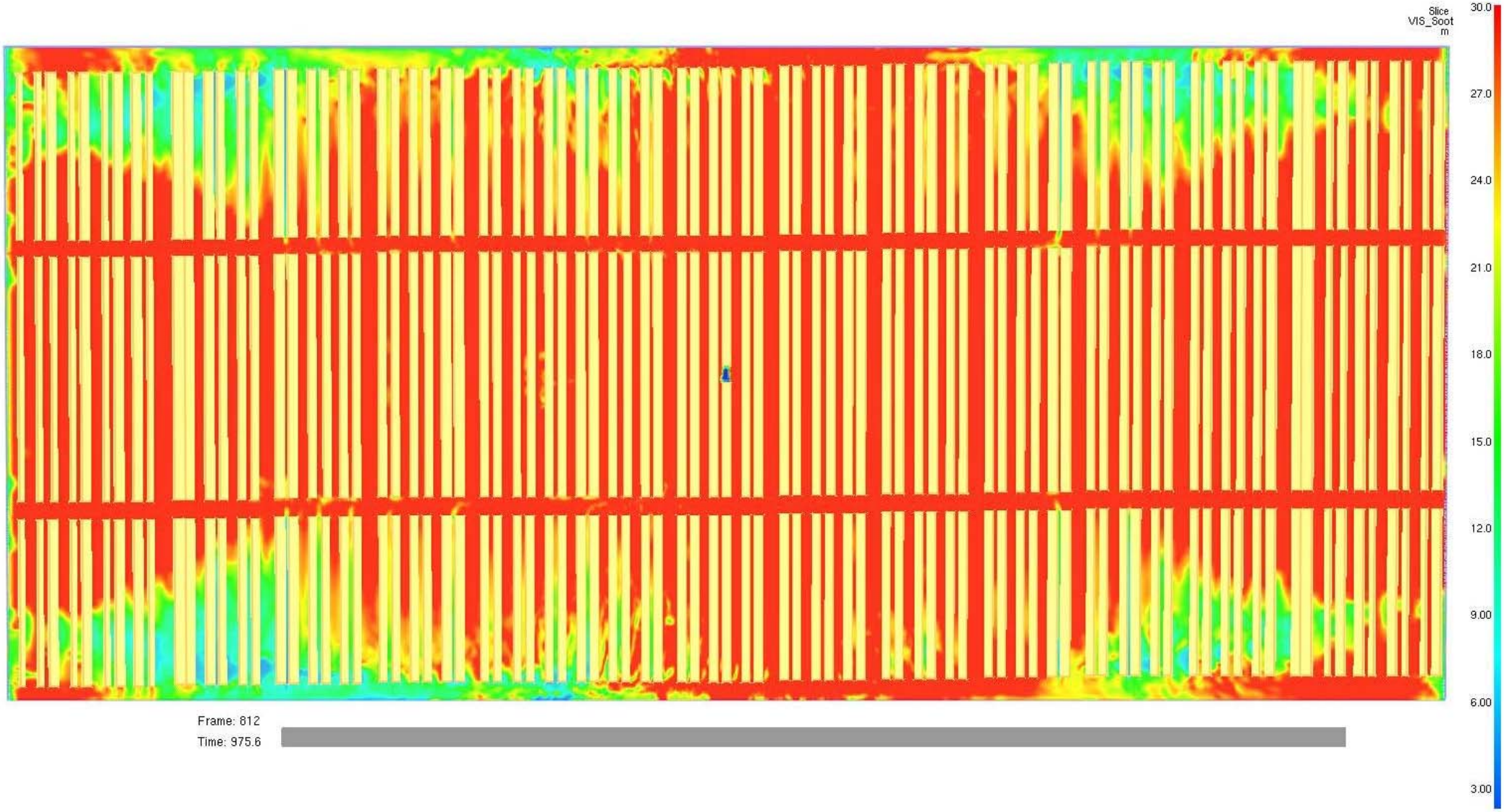


TEMPERATURE – ULTRAFAST FIRE (10 MW FIRE)
VIEW FROM TOP AT 6 FT , AFTER 15 MINUTES

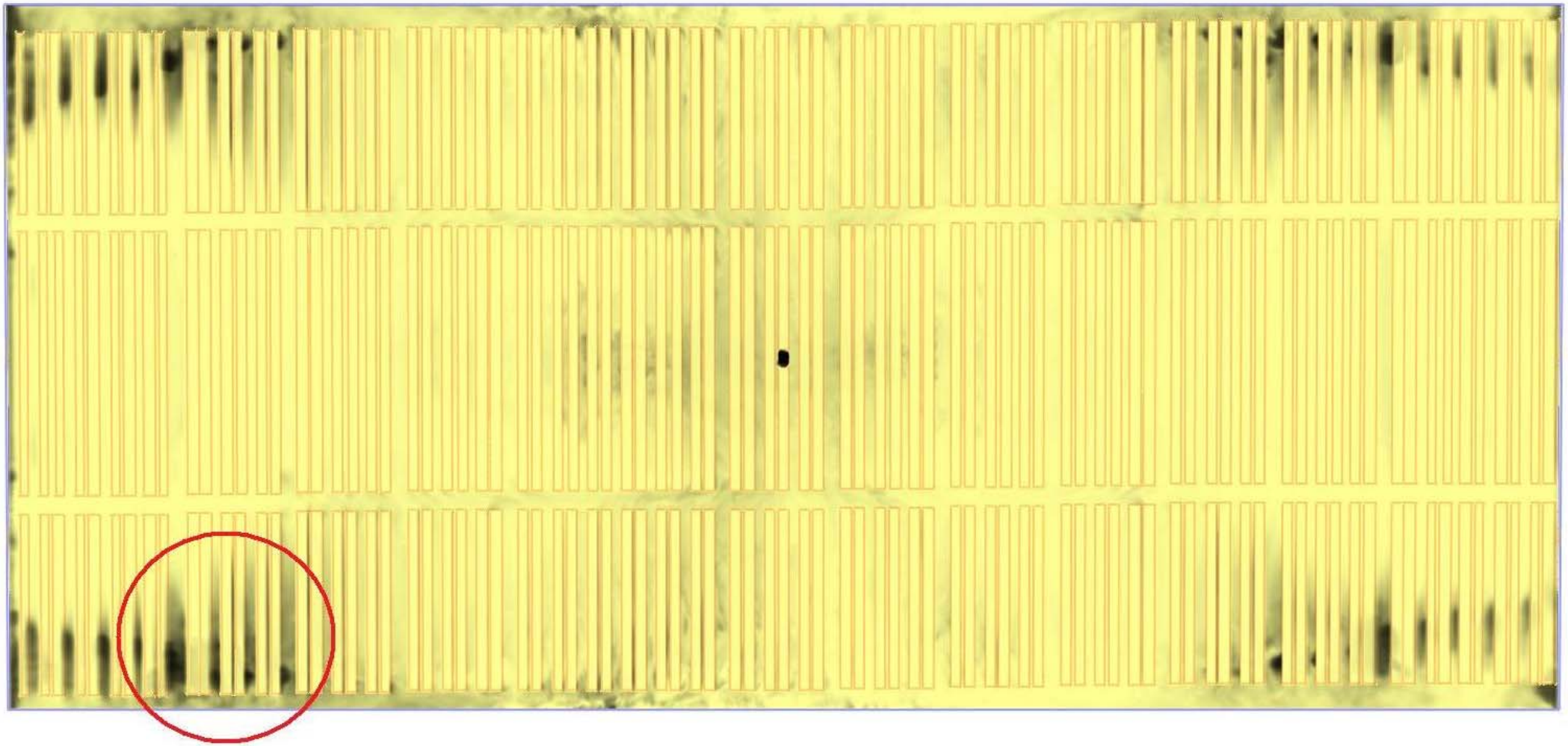


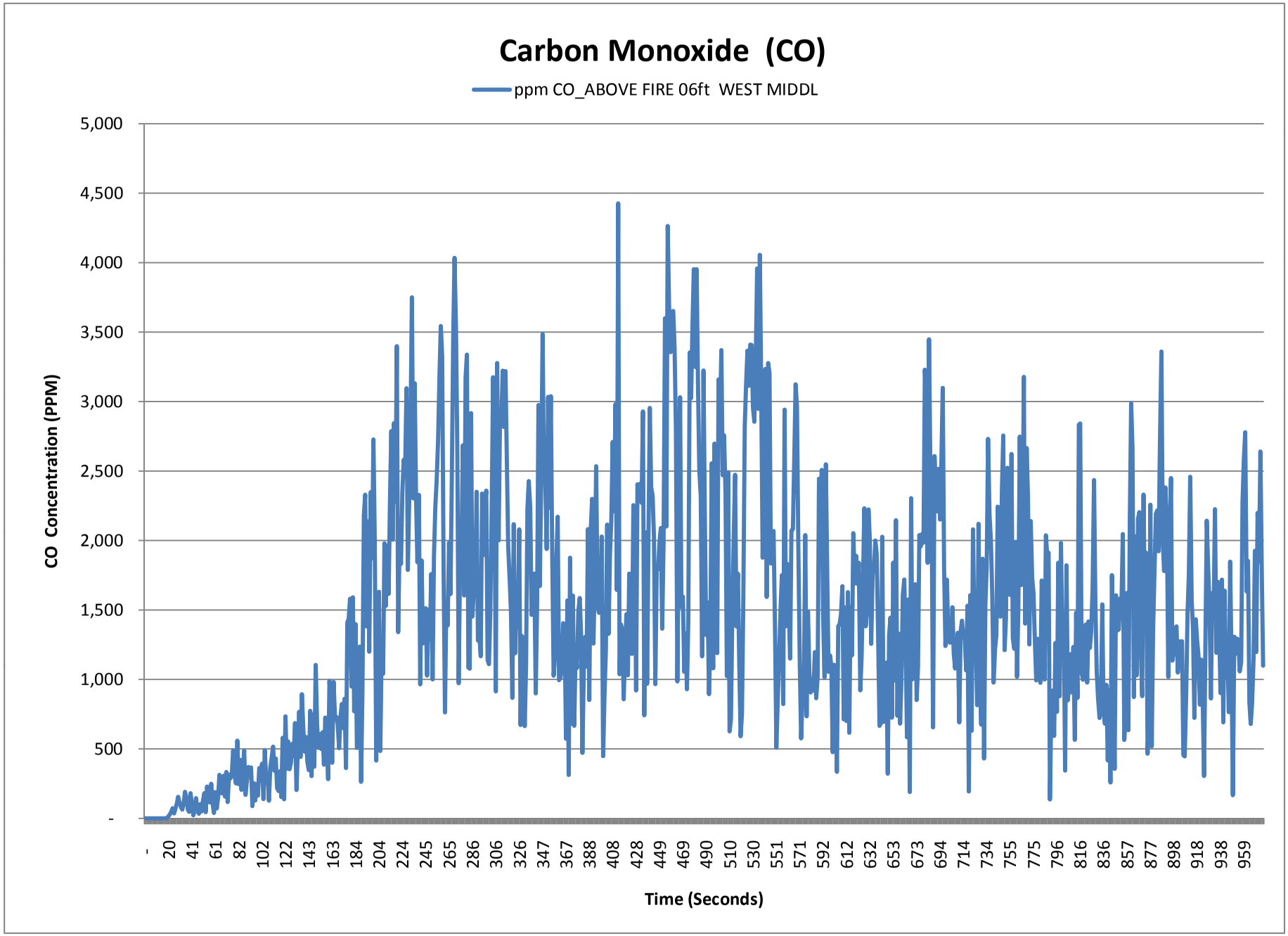

Smoke Visibility
m SMOKE_ABOVE FIRE 06ft WEST BO
Smoke Visibility (meters)
35
30
25
20
15
10
5
-
s
18
39
59
79
100
120
140
161
181
202
222
242
263
283
304
324
344
365
385
406
426
446
467
487
508
528
548
569
589
610
630
650
671
691
712
732
752
773
793
814
834
854
875
895
916
936
956
Time (Seconds)

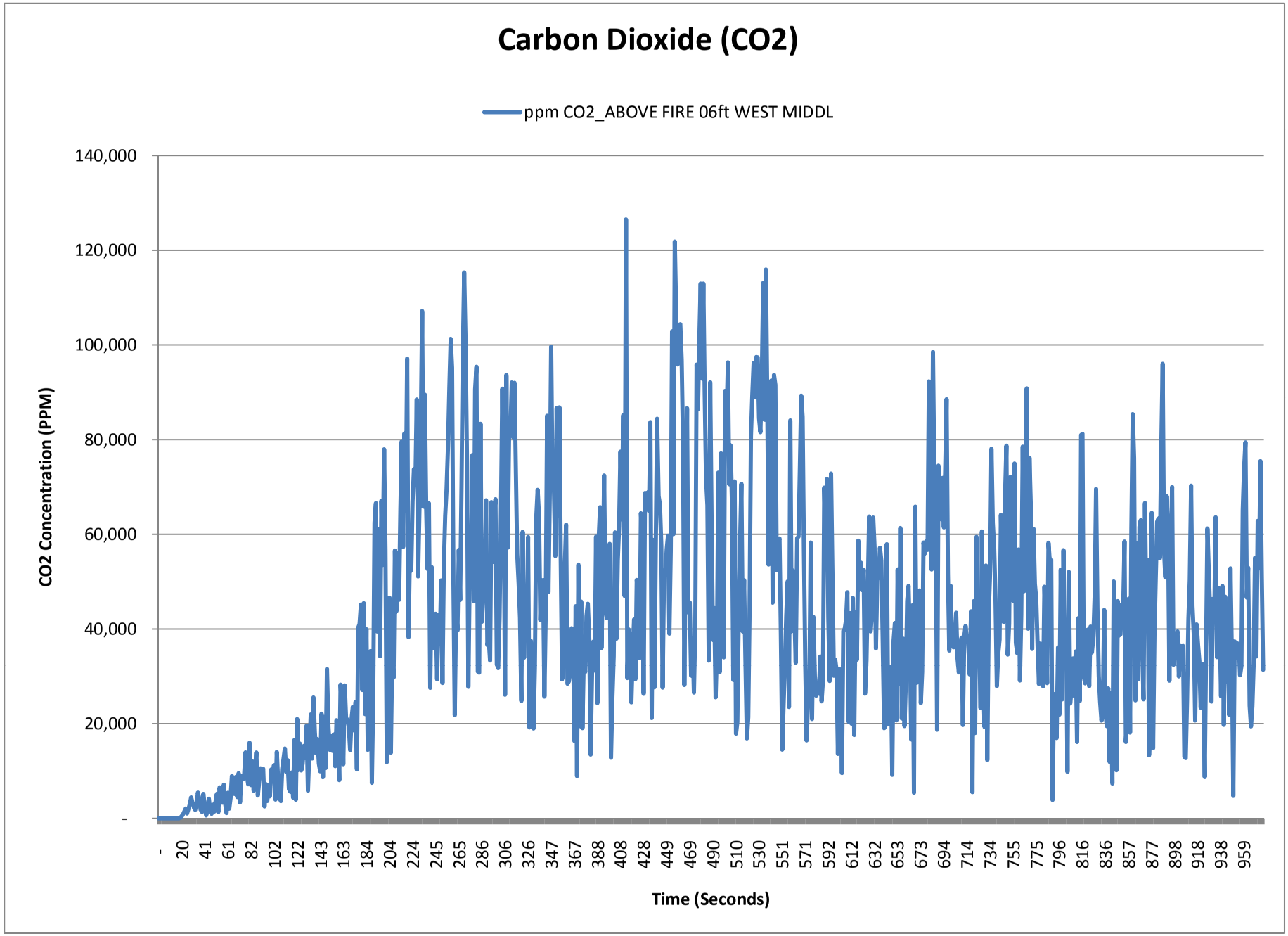
SMOKE VISIBILITY – ULTRAFAST FIRE (10 MW FIRE)
VIEW FROM TOP AT 6 FT , AFTER 15 MINUTES



CO AND C02 CONC ENTRATION LOCATION
WORST-CASE LOCATION



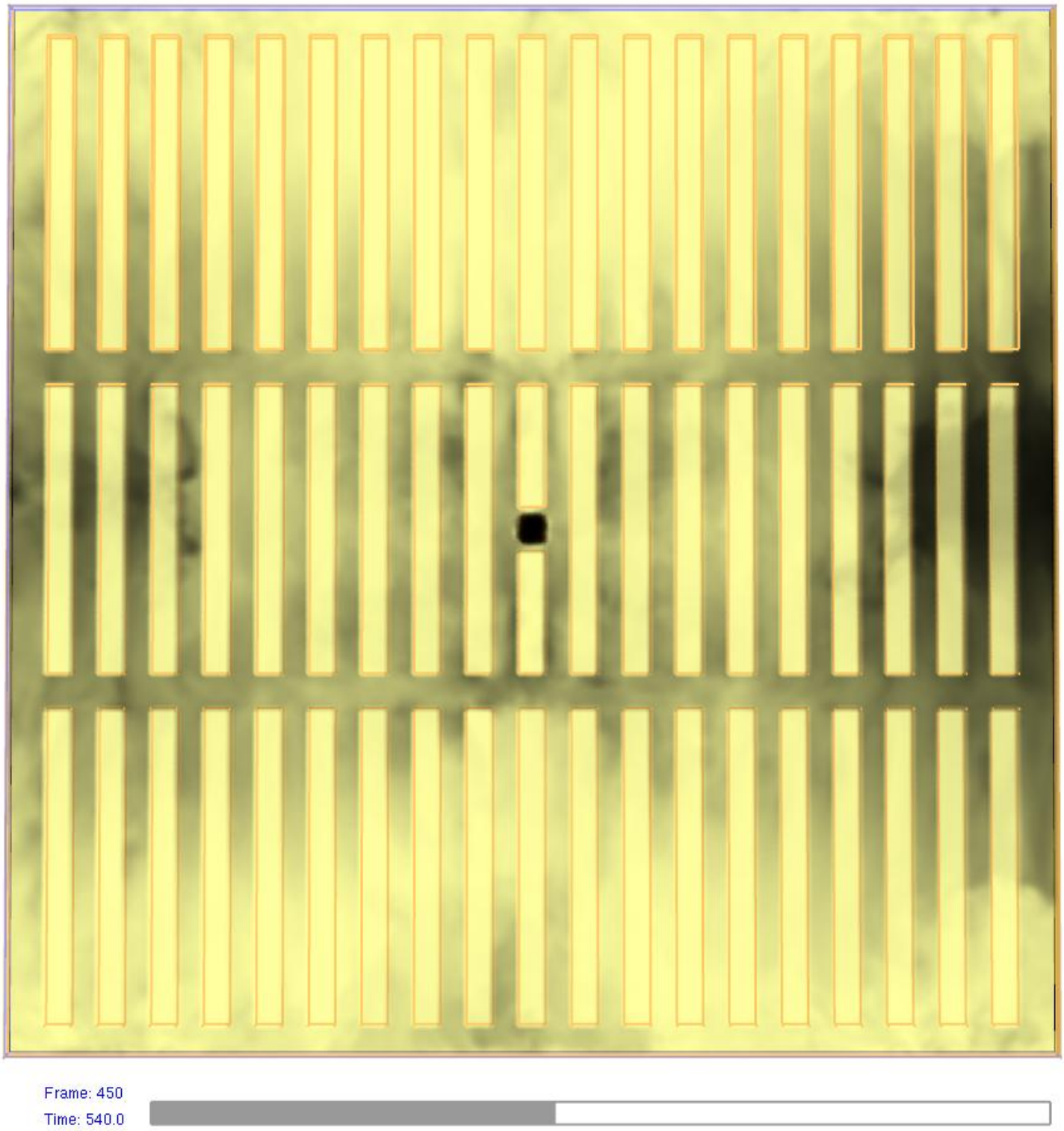

Carbon Monoxide (CO)
ppm CO_ABOVE FIRE 06ft WEST MIDDL
CO Concentration (PPM)
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
-
Time (Seconds)
- 20 41 61 82 102 122 143 163 184 204 224 245 265 286 306 326 347 367 388 408 428 449 469 490 510 530 551 571 592 612 632 653 673 694 714 734 755 775 796 816 836 857 877 898 918 938 959


Carbon Dioxide (CO2)
ppm CO2_ABOVE FIRE 06ft WEST MIDDL
CO2 Concentration (PPM)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
-
Time (Seconds)
- 20 41 61 82 102 122 143 163 184 204 224 245 265 286 306 326 347 367 388 408 428 449 469 490 510 530 551 571 592 612 632 653 673 694 714 734 755 775 796 816 836 857 877 898 918 938 959

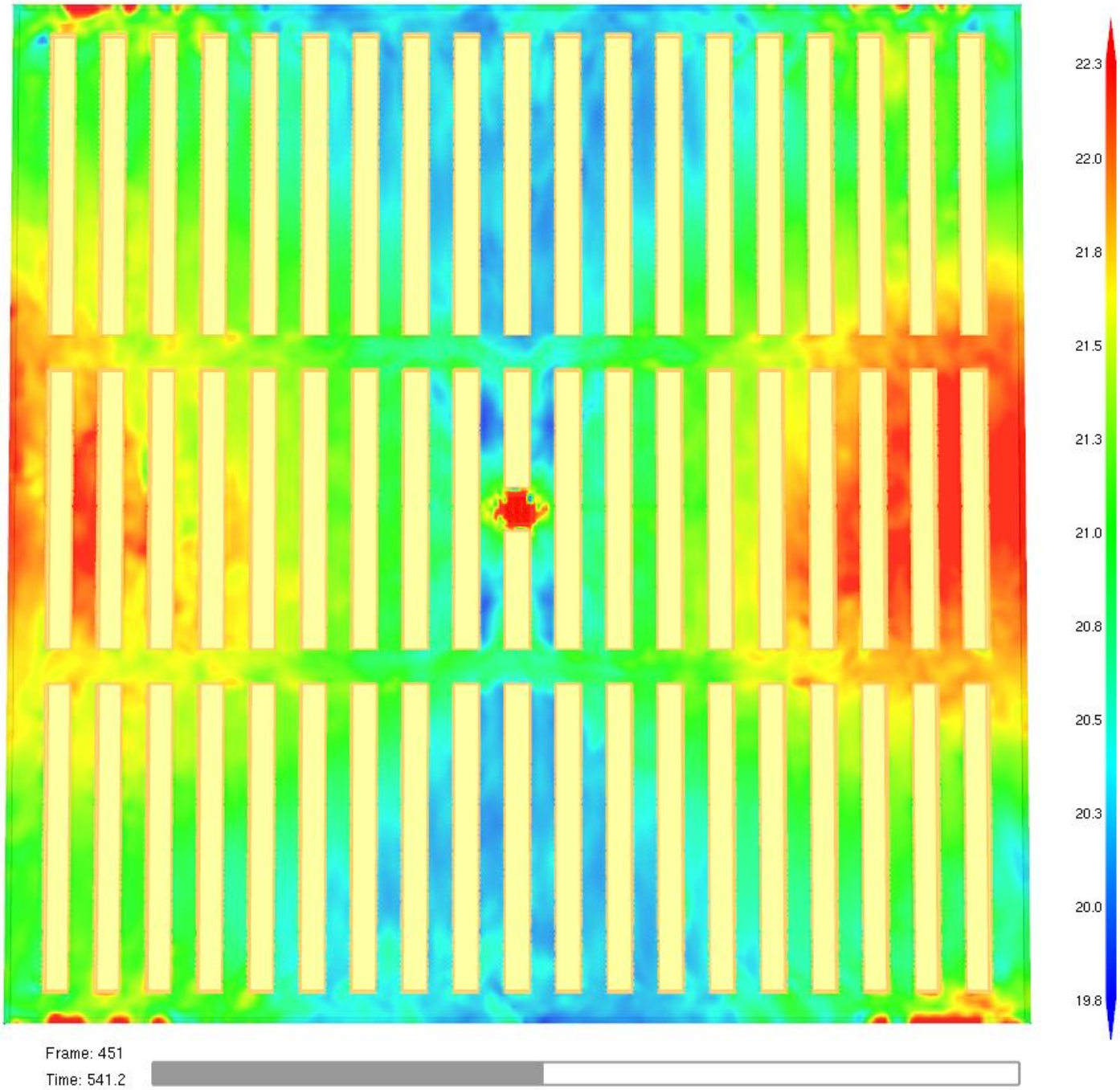
APPENDIX F

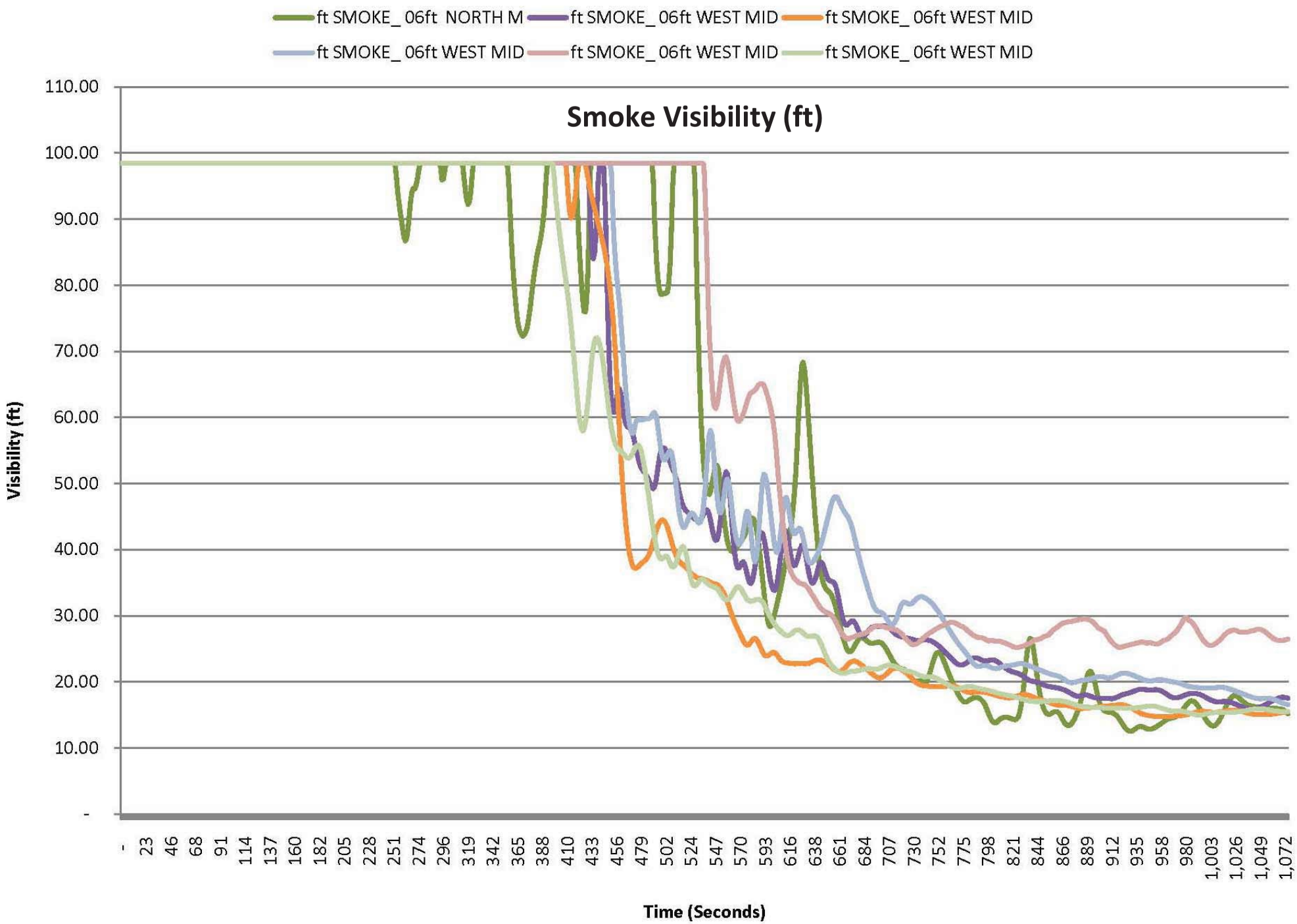
ULTRAFAST FIRE SMALLER BUILDING WITH OBSTRUCTIONS – SIMULATION RESULTS

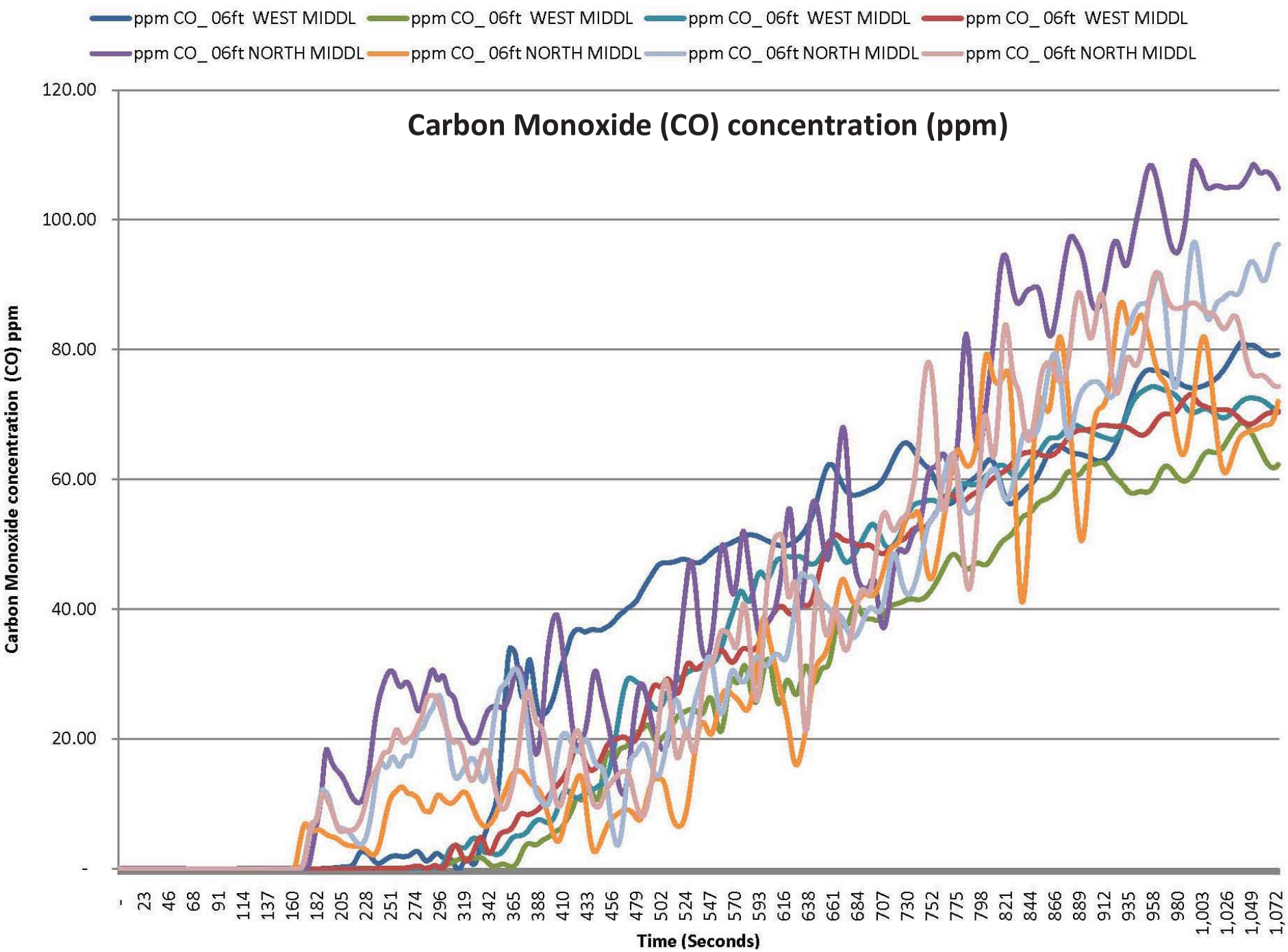
SMOKE VISIBILITY – ULTRAFAST FIRE (10 MW FIRE)
VIEW FROM TOP AT 6 FT , AFTER 9 MINUTES

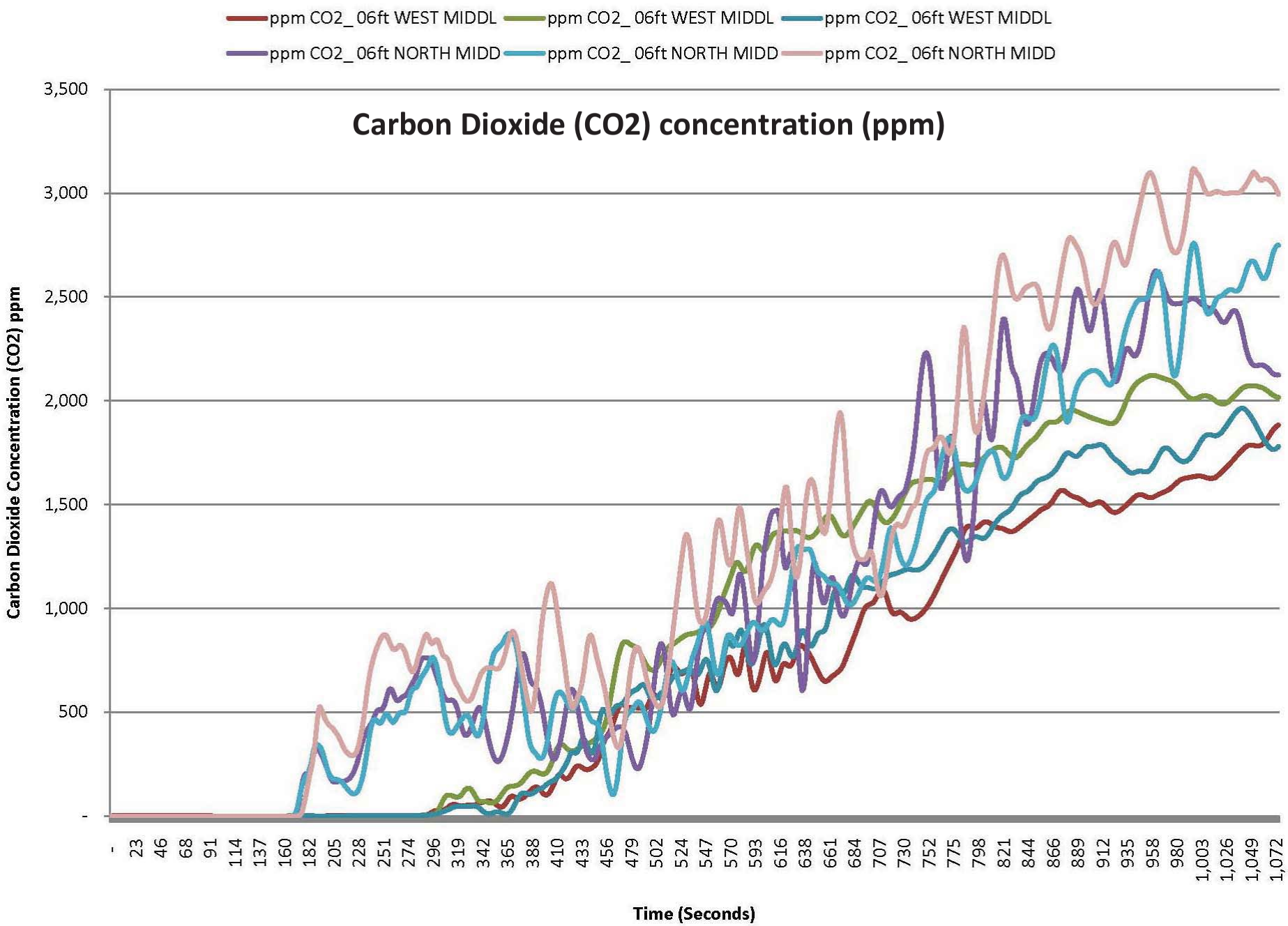


TEMPERATURE – ULTRAFAST FIRE (10 MW FIRE) VIEW FROM TOP AT 6 FT , AFTER 9 MINUTES




ft SMOKE_ 06ft NORTH M
ft SMOKE_ 06ft WEST MID
ft SMOKE_ 06ft WEST MID
ft SMOKE_ 06ft WEST MID
ft SMOKE_ 06ft WEST MID
ft SMOKE_ 06ft WEST MID
Smoke Visibility (ft)
Visibility (ft)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
-
- 23 46 68 91 114 137 160 182 205 228 251 274 296 319 342 365 388 410 433 456 479 502 524 547 570 593 616 638 661 684 707 730 752 775 798 821 844 866 889 912 935 958 980 1,003 1,026 1,049 1,072
Time (Seconds)


ppm CO_ 06ft WEST MIDDL
ppm CO_ 06ft WEST MIDDL
ppm CO_ 06ft WEST MIDDL
ppm CO_ 06ft WEST MIDDL
ppm CO_ 06ft NORTH MIDDL
ppm CO_ 06ft NORTH MIDDL
ppm CO_ 06ft NORTH MIDDL
ppm CO_ 06ft NORTH MIDDL
Carbon Monoxide (CO) concentration (ppm)
Carbon Monoxide concentration (CO) ppm
120.00
100.00
80.00
60.00
40.00
20.00
-
Time (Seconds)


ppm CO2_ 06ft WEST MIDDL
ppm CO2_ 06ft WEST MIDDL
ppm CO2_ 06ft WEST MIDDL
ppm CO2_ 06ft NORTH MIDD
ppm CO2_ 06ft NORTH MIDD
ppm CO2_ 06ft NORTH MIDD
Carbon Dioxide (CO2) concentration (ppm)
Carbon Dioxide Concentration (CO2) ppm
3,500
3,000
2,500
2,000
1,500
1,000
500
-
- 23 46 68 91 114 137 160 182 205 228 251 274 296 319 342 365 388 410 433 456 479 502 524 547 570 593 616 638 661 684 707 730 752 775 798 821 844 866 889 912 935 958 980 1,003 1,026 1,049 1,072
Time (Seconds)