Smoke Control Report

Project No. 7657.00

October 16, 2012

CUMBERLAND COUNTY CIVIC CENTER

PORTLAND, MAINE

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1.0 EXECUTIVE SUMMARY

PURPOSE

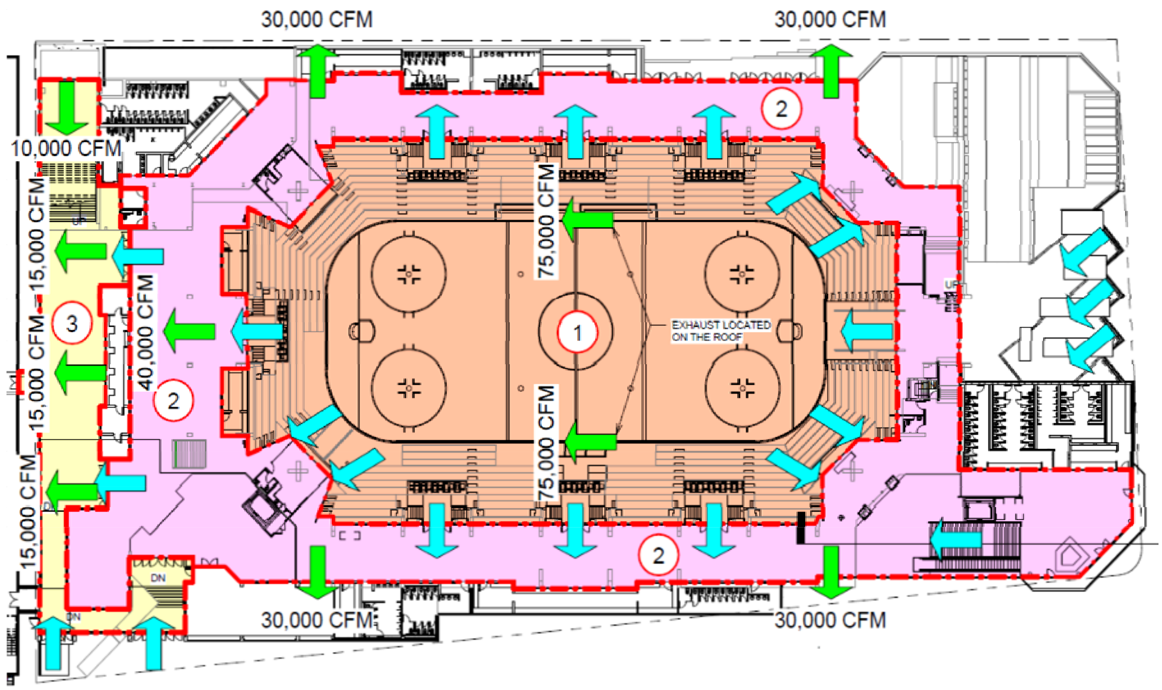
A mechanical smoke control system is required in order to allow the use of smoke-protected assembly seating provisions in the Cumberland County Civic Center. The purpose of the mechanical smoke control system in the Cumberland County Civic Center is to control the accumulation of smoke in the West Lobby, the Seating Bowl, the Main Concourse, and the Mechanical Level Lobby in order to maintain tenable conditions six feet above the highest level of egress in the active smoke control zone in order to allow Arena occupants to exit in accordance with Section 909.8.1 of the 2009 Maine Uniform Building and Energy Code (MUBEC) [an amended 2009 International Building Code (IBC)] and Section 12.4.2.1 (2) (a) of the 2009 Edition *Life Safety Code* (NFPA 101). The proposed smoke control system is designed to achieve these objectives. The proposed mechanical smoke control system will consist of three (3) smoke control zones that encompass the Lobby, the Seating Bowl, and the Main Concourse (which includes a portion of the Mechanical Level that is considered a communicating space in accordance with Section 8.6.6 of the 2009 Edition of NFPA 101) of the Cumberland County Civic Center.

METHODOLOGY

Mechanical Smoke Exhaust

The smoke control system proposed for the Arena achieves the design objectives by way of mechanical exhaust vents designed to operate in each zone of the Arena. A total of eleven (11) mechanical exhaust fans were modeled in the Arena. Please see Figure 1.1 below which provides a plan view illustration of the modeled location of the smoke exhaust fans.

Figure 1.1
Cumberland County Civic Center Modeled Smoke Exhaust Fan Locations



The system was modeled to activate either by beam detectors or automatic sprinklers in the Arena. The beam detectors were essential for proper system operation for a fire in the Seating Bowl of the Arena (an axisymmetric smoke plume design fire scenario). Automatic sprinklers were the primary method of system activation for the design fire scenarios at the Mechanical Level Lobby (a balcony spill plume design fire scenario) and on the Main Concourse (an axisymmetric smoke plume design fire scenario). See Table 1.1 below for the different exhaust fan sizes that were modeled in the Arena (see Figure 1.1 above and the illustrations outlined in Table 1.3 to reference modeled fan locations). Fan sizes given in this report are to be considered the minimum required fan sizes. Reverse stack effect pressure differentials should be considered by the mechanical designer (see Section 3.13.1 of this report for more detail).

Table 1.1
Cumberland County Civic Center Modeled Smoke Exhaust Fan Sizes

SMOKE CONTROL ZONE (FAN LOCATION)	QUANTITY OF FANS	MINIMUM FAN SIZE EACH FAN (CFM)	TOTAL MINIMUM EXHAUST REQUIRED (CFM)
Seating Bowl Zone	2	75,000	150,000
Main Concourse / Mechanical	5	30,000 [a] / 40,000 [b]	160,000
West Lobby & Stairs	4	15,000 [c] / 10,000 [d]	55,000

[a] *The north Main Concourse and the south Main Concourse both require two (2) 30,000 cfm fans each (placed at opposite ends of the concourse)*
[b] *The west Main Concourse requires one (1) 40,000 cfm fan*
[c] *The west Lobby requires three (3) 15,000 cfm fans*
[d] *The west Lobby stairs require one (1) 10,000 cfm fan*

Table 1.2
Cumberland County Civic Center Smoke Control System Activation Mechanisms

SMOKE CONTROL ZONE (FAN LOCATION)	SMOKE CONTROL SYSTEM ACTIVATION MECHANISM(S)
Seating Bowl Zone	Beam Detectors / Manual Control / Automatic Sprinklers
Main Concourse / Mechanical	Automatic Sprinklers / Spot Smoke Detectors [a] / Manual Control
West Lobby & Stairs	Automatic Sprinklers / Spot Smoke Detectors [b] / Manual Control

[a] *Spot smoke detectors were used for primary activation on the Mechanical Level Lobby (automatic sprinklers also present)*
[b] *Spot smoke were used for primary activation in the West Lobby (automatic sprinklers also present)*

Naturally Supplied Make-up Air

Make-up air for the smoke control system will be supplied through natural ventilation provided by overhead doors in the loading dock on the east end of the building and exterior doors that were modeled to open automatically upon system actuation. A sign is recommended in the vicinity of these doors that communicates that these doors are part of the smoke control system and need to be kept in working order. Make-up air will travel from the loading dock through the Seating Bowl and from the exterior doors into other areas of the building. The illustrations outlined in Table 1.3 below represent the make-up air supply plan. The following provides a brief summary of how make-up air will be supplied to each smoke control zone:

1. West Lobby Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will then be transferred to the Main Concourse through the openings on the northeast, southeast, and southwest ends of the Seating Bowl. Make-up air will be supplied to the West Lobby from two doors on automatic openers that connect the Main Concourse and the West Lobby (which will in turn be supplied through the Seating Bowl openings). Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

2. Seating Bowl Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

3. Main Concourse Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will then be transferred to the Main Concourse through the openings on the northeast, southeast, and southwest ends of the Seating Bowl as well as from the doors on automatic openers in the vomitories. Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

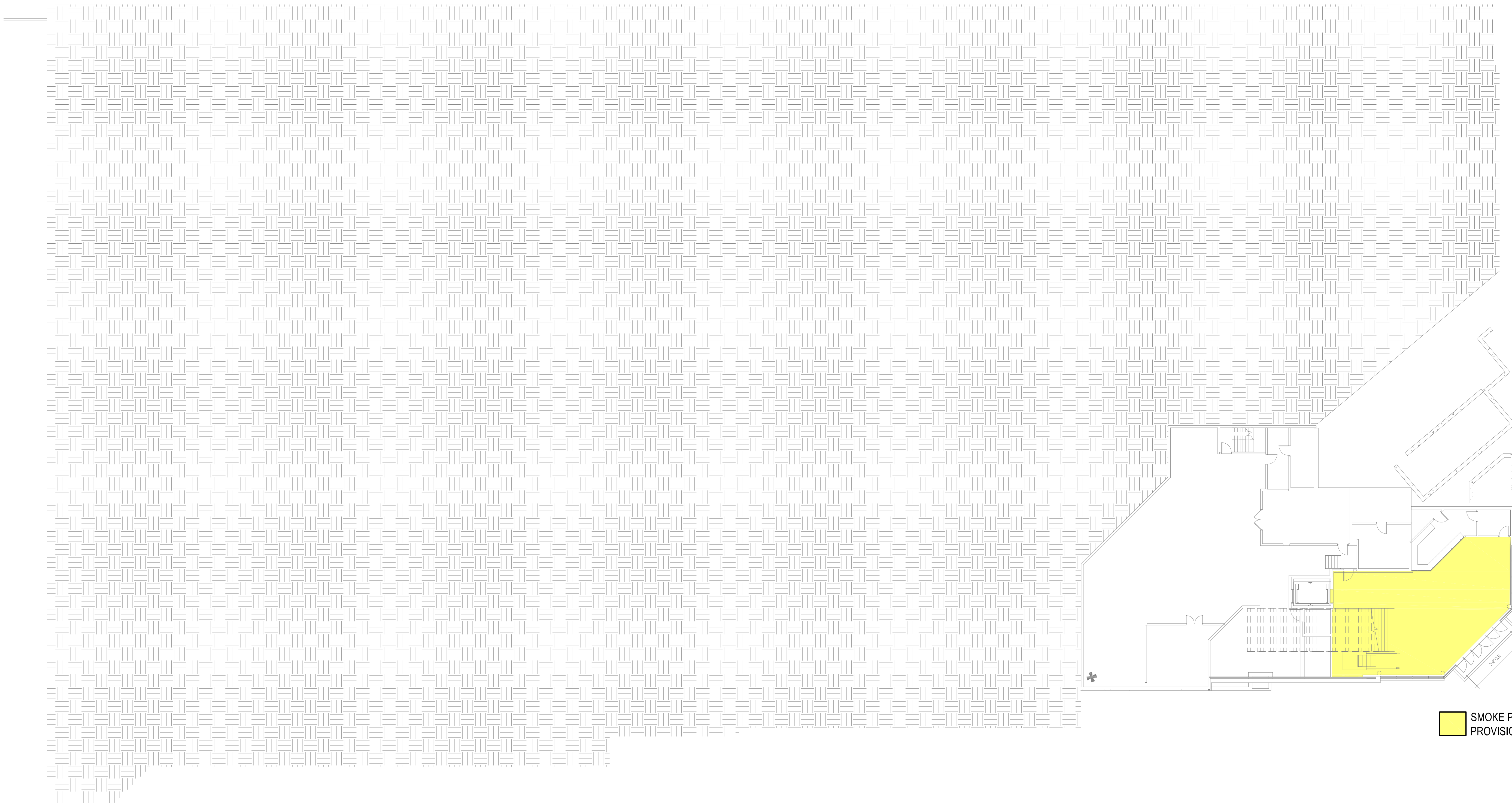
DESIGN

The smoke control system was designed using a *computational fluid dynamics* (CFD) fire model called *Fire Dynamics Simulator* (FDS). The FDS software, developed by the *National Institute of Standards and Technology* (NIST), was considered the best software for modeling the evolving distribution of smoke, fire gases, and temperature in the Arena during smoke exhaust fan operation in order to determine if tenable conditions were maintained six feet above the highest level of egress in the active smoke control zone. The parameters used for the fire modeling were based on the 2009 MUBEC and the 2009 Edition of NFPA 101.

Please see the illustrations on the following pages (outlined in Table 1.3 below) for system details:

Table 1.3
Illustrations Depicting Mechanical Smoke Control Requirements for the Cumberland County Civic Center

ILLUSTRATION	DESCRIPTION
SM.001-003	Plan views of Cumberland County Civic Center that depict: 1. Smoke protected areas.
IL.001-005	Plan views of Cumberland County Civic Center that depict: 1. Smoke control zones. 2. Proposed locations of mechanical exhaust. 3. Proposed locations of make-up air by doors on automatic openers. 4. Flow of make-up air through smoke control zones.



SMOKE PROTECTED ASSEMBLY SEATING PROVISIONS APPLIED

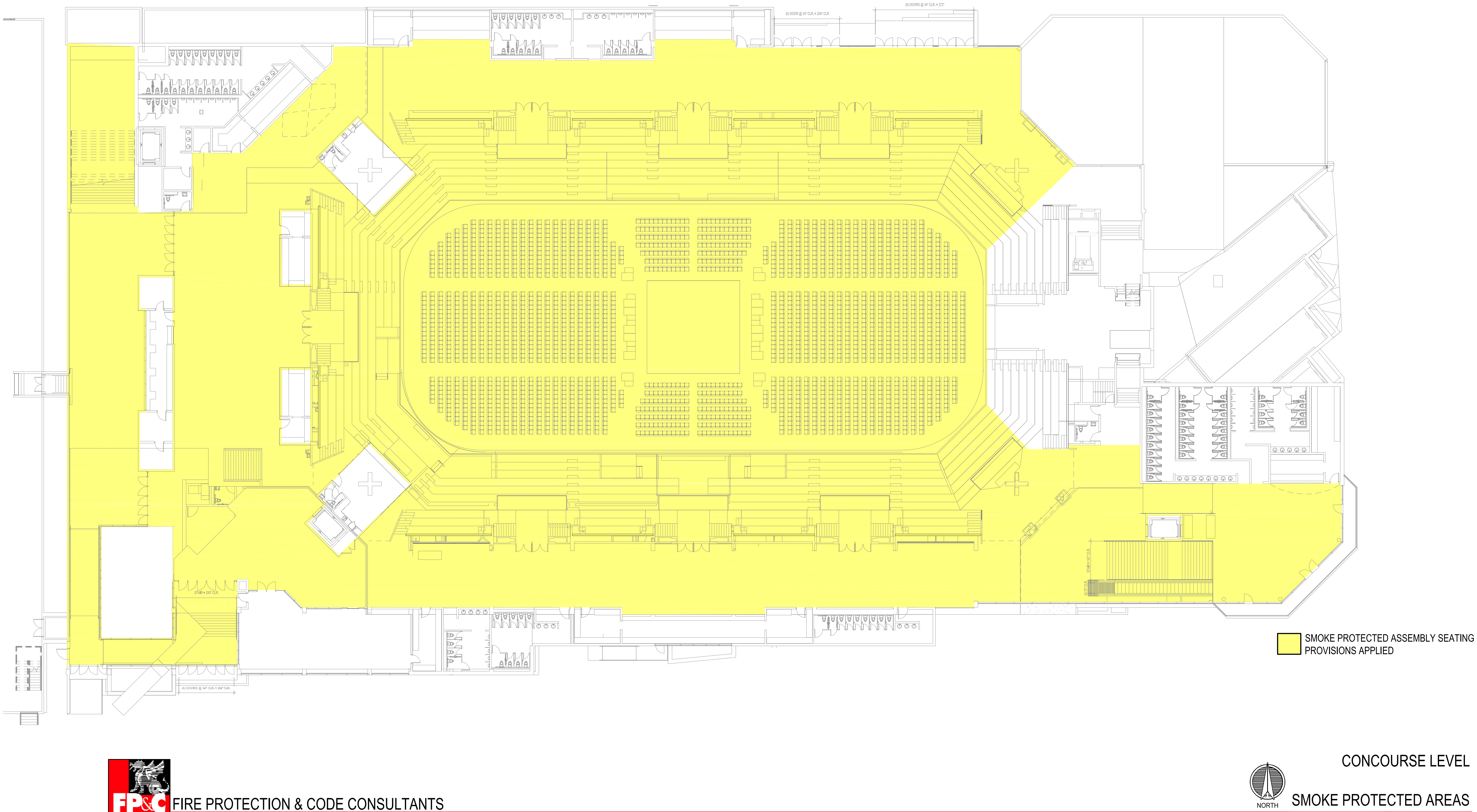
MECHANICAL LEVEL

NORTH

SMOKE PROTECTED AREAS

SM.001

FIRE PROTECTION & CODE CONSULTANTS

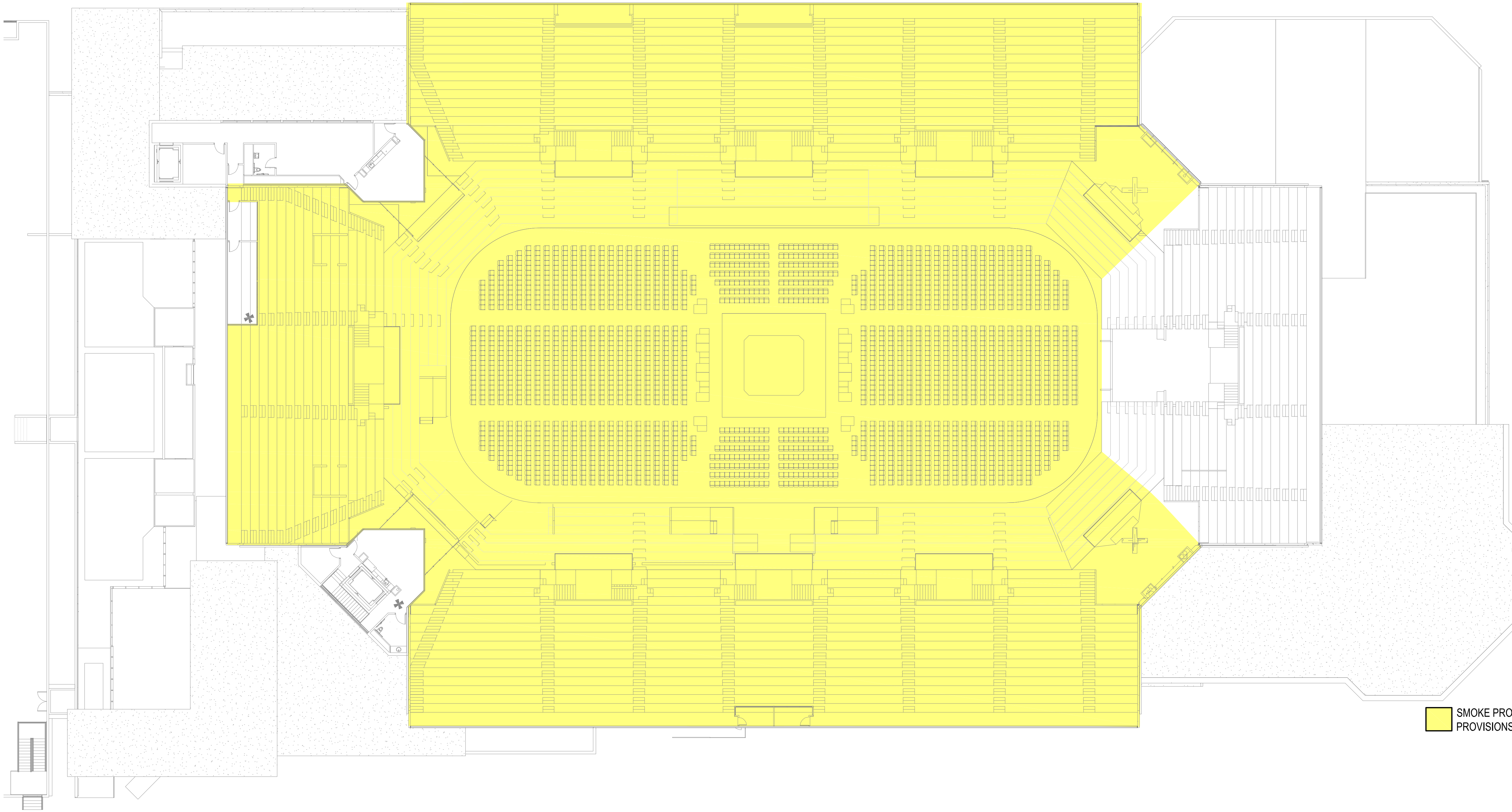


FIRE PROTECTION & CODE CONSULTANTS

CONCOURSE LEVEL

SMOKE PROTECTED AREAS

SM.020



SMOKE PROTECTED ASSEMBLY SEATING PROVISIONS APPLIED

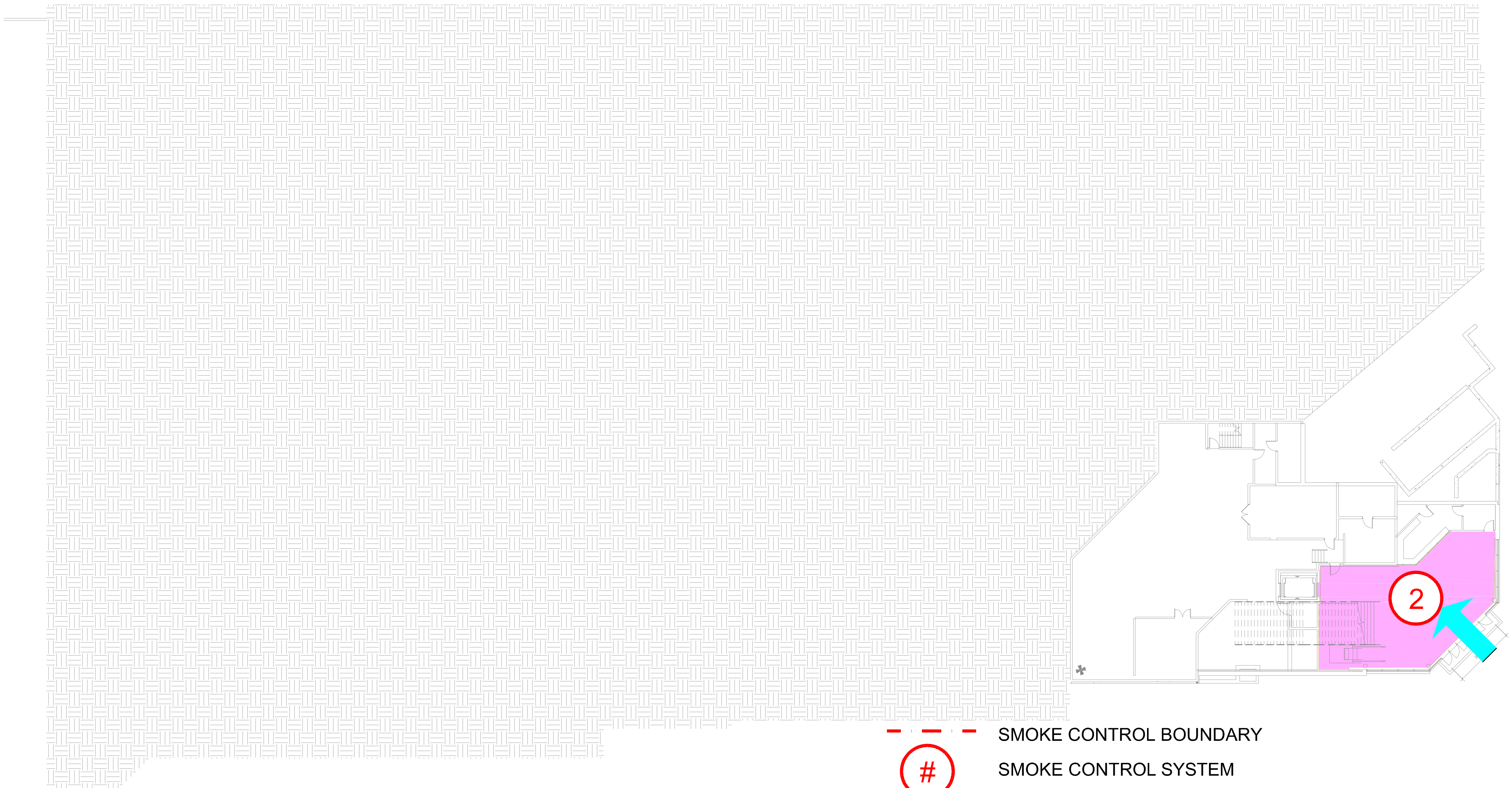
FIRE PROTECTION & CODE CONSULTANTS

UPPER SUITE LEVEL

NORTH

SMOKE PROTECTED AREAS

SM.040



SMOKE CONTROL BOUNDARY

SMOKE CONTROL SYSTEM

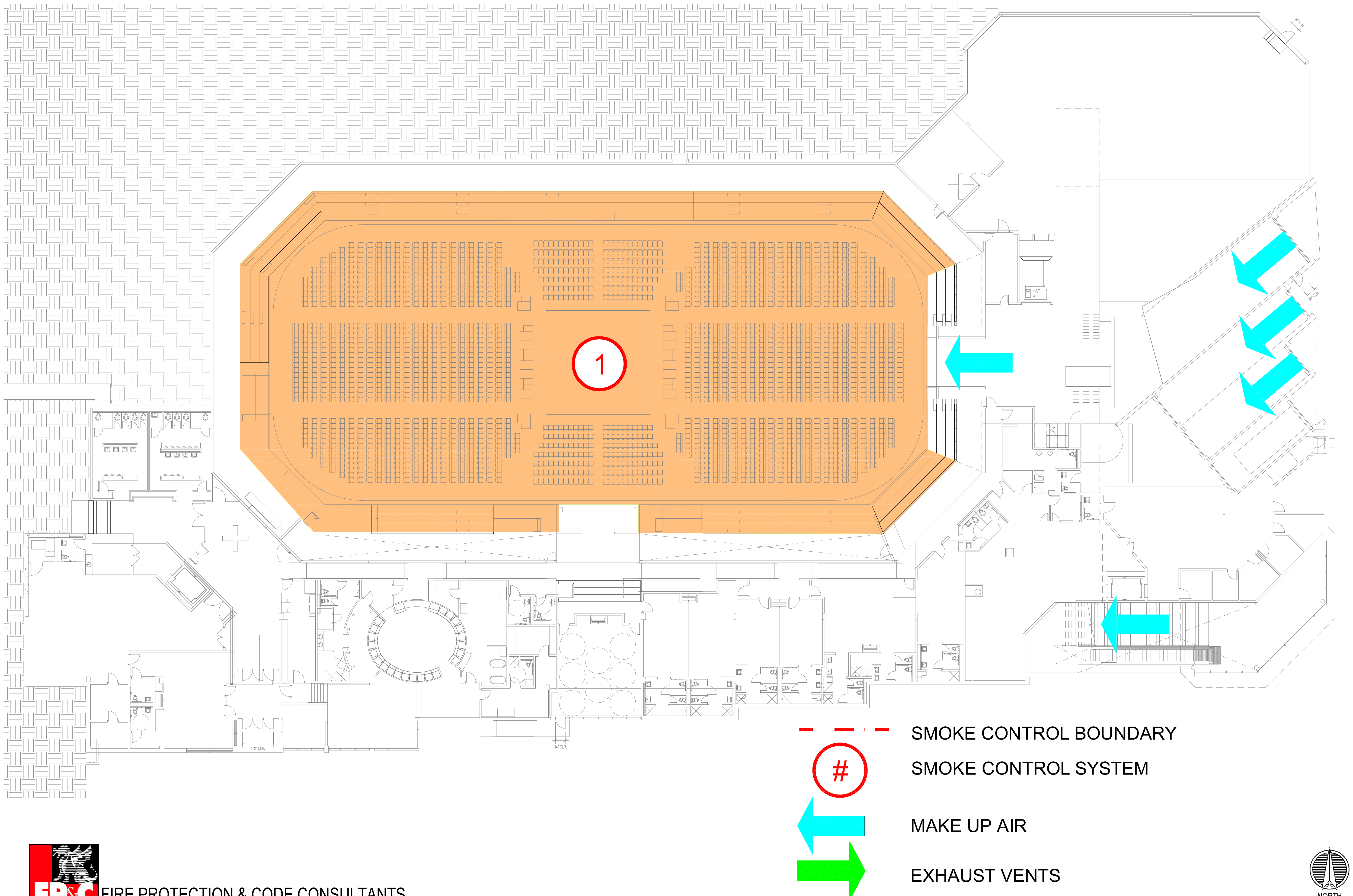
MAKE UP AIR

EXHAUST VENTS

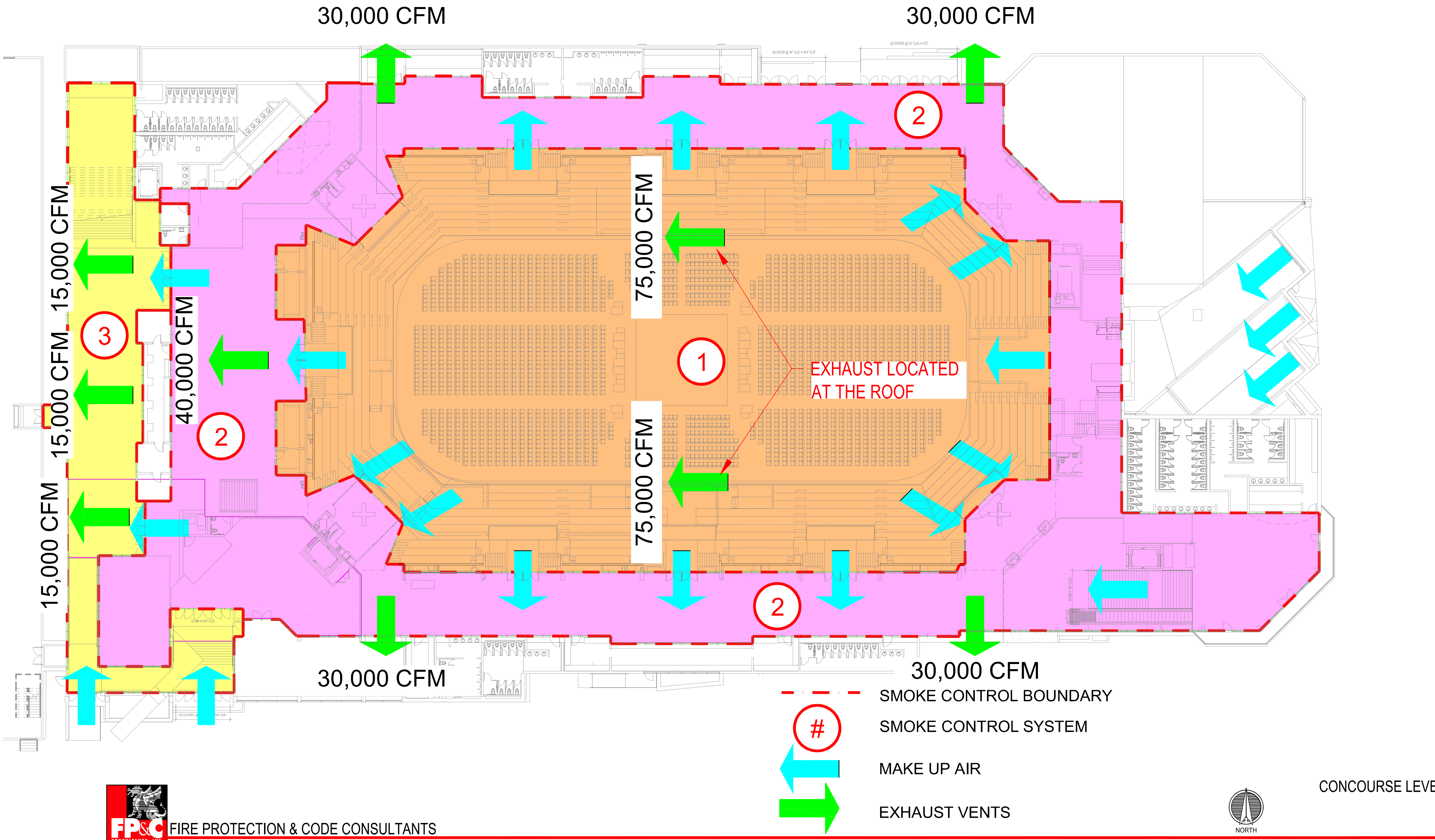
NORTH

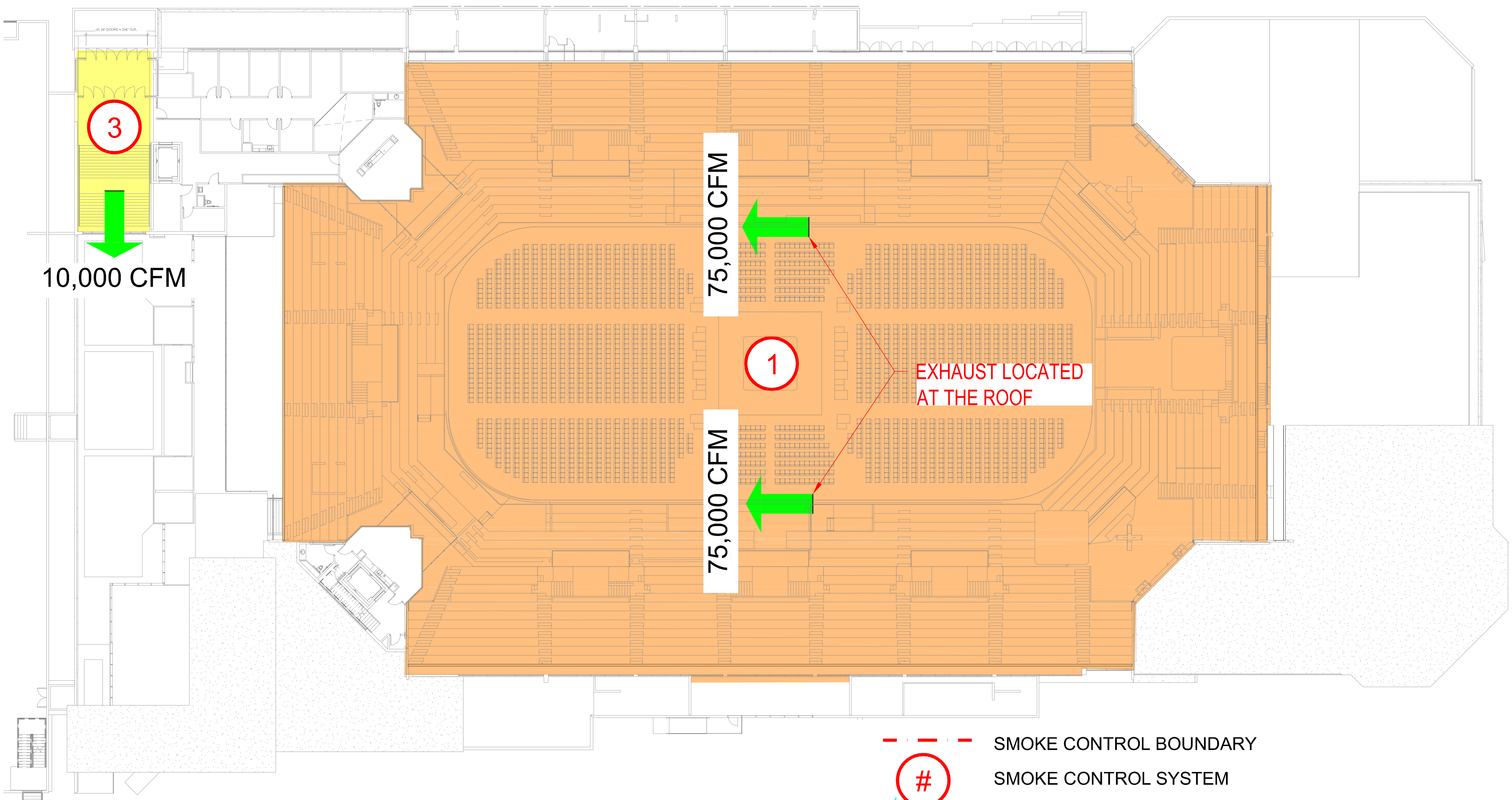
MECHANICAL LEVEL

FIRE PROTECTION & CODE CONSULTANTS


1
SMOKE CONTROL BOUNDARY
#
SMOKE CONTROL SYSTEM
MAKE UP AIR
EXHAUST VENTS
NORTH

EVENT LEVEL


30,000 CFM
30,000 CFM
15,000 CFM
15,000 CFM
15,000 CFM
40,000 CFM
75,000 CFM
75,000 CFM
1
2
2
2
3
EXHAUST LOCATED
AT THE ROOF
30,000 CFM
30,000 CFM
SMOKE CONTROL BOUNDARY
#
SMOKE CONTROL SYSTEM
MAKE UP AIR
EXHAUST VENTS
NORTH
CONCOURSE LEVEL
FIRE PROTECTION & CODE CONSULTANTS



SMOKE CONTROL BOUNDARY

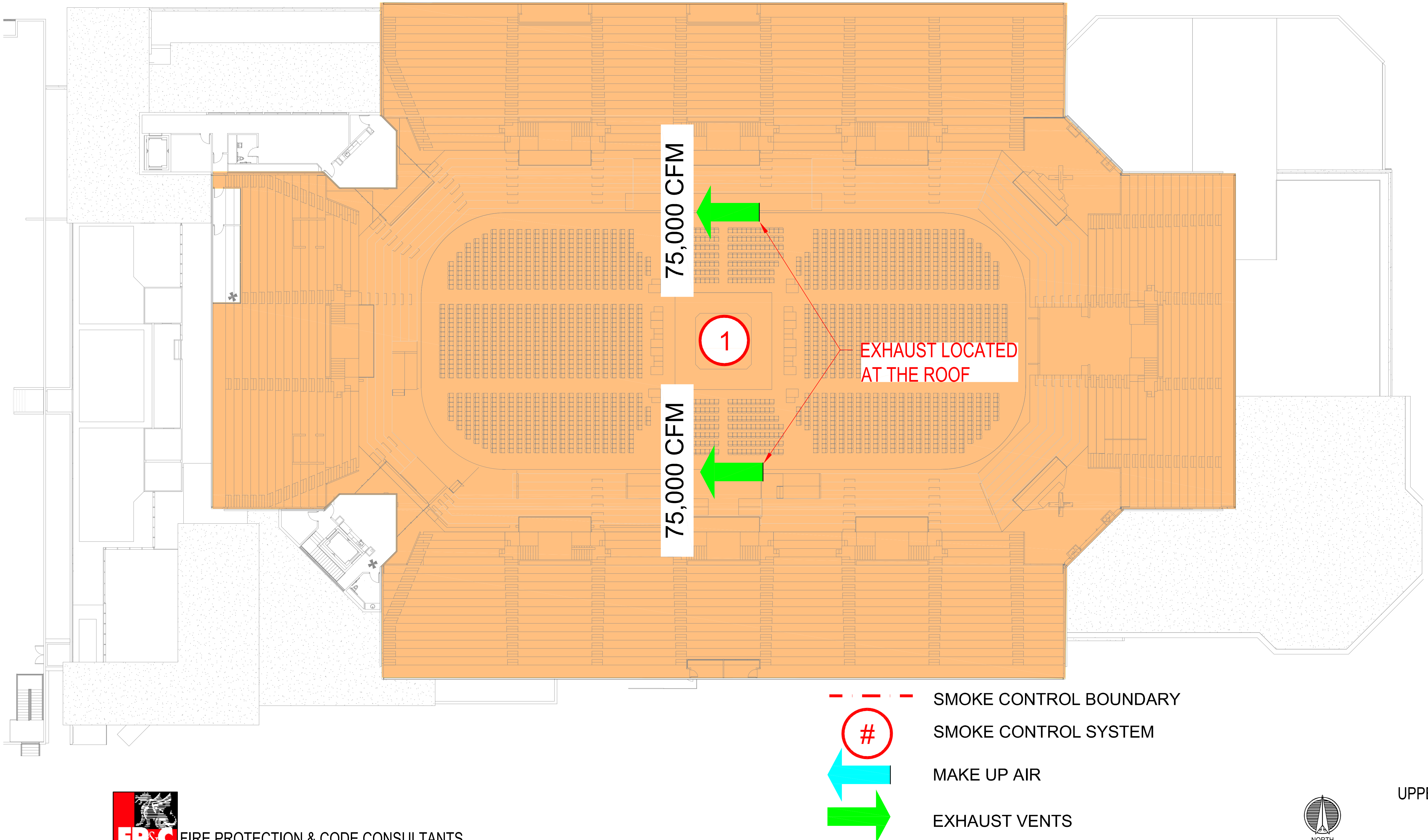
SMOKE CONTROL SYSTEM

MAKE UP AIR

EXHAUST VENTS

MID SUITES LEVEL

NORTH



UPPER SUITE LEVEL

FIRE PROTECTION & CODE CONSULTANTS

IL.005

2.0 REQUIREMENTS

The following requirements for the smoke control system in the Cumberland County Civic Center are referenced from the 2009 MUBEC that has been adopted by the State of Maine and City of Portland.

2.1 The smoke control system is required to be supplied with two sources of power per Section 909.11 of the 2009 MUBEC. The smoke control system includes all components involved in proper operation of the system to include (but are not limited to) the exhaust fans, dampers, make-up air supply points (all doors on automatic openers in this case), and alarms panels. Primary power will come from the normal building power system. Secondary power is reportedly from a standby generator. The 2008 Edition *National Electrical Code* (NFPA 70) requires standby power systems to be provided with at least 2 hours of run time (for generators powered by internal combustion engines described in Section 701.11 [B]). Note that this required standby power supply time exceeds the duration of operation for the smoke control system required by Section 909.4.6 of the 2009 MUBEC (egress time or 20 minutes, whichever is less) and thus ensures the duration of operation will protect both the means of egress for occupants as well as follow on fire fighter operations.

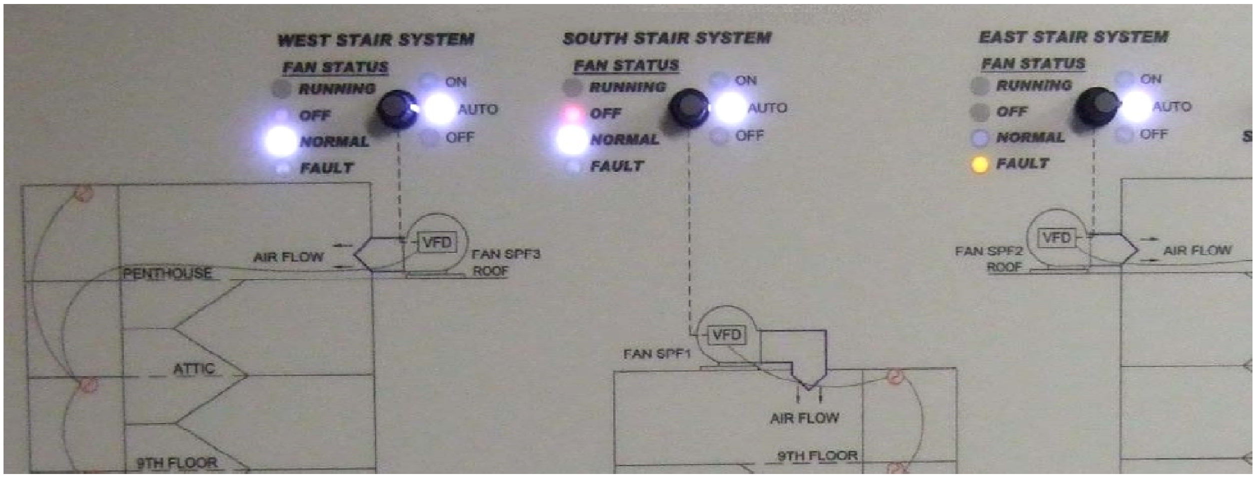
2.2 A Firefighter's Smoke Control Panel is required per Section 911.1.5 (6) of the 2009 MUBEC and must conform to the specifications set forth in Section 909.16 of the 2009 MUBEC. Section 911 of the 2009 MUBEC requires the panel to be installed in a Fire Command Center if using smoke-protected assembly seating or in an approved location adjacent to the fire alarm control panel. In general, a Firefighter's Smoke Control Panel should contain the following:

2.2.1 Manual control or override of automatic control for mechanically controlled systems.

2.2.2 Fans within the building should be clearly shown along with the direction of air flow and the relationship of components (usually on a plan or section view diagram). The intent is to allow firefighters and other emergency personnel who are not familiar with the building to quickly gain situational awareness as to the intended function of the smoke control system and if it is indeed properly functioning. The Fire Marshal and Authority Having Jurisdiction (AHJ) will have the final approval on what is displayed on the panel.

2.2.3 Status indicators are required to be provided for all smoke control equipment and comply with the status indicator guidance in Section 909.16.1 of the 2009 MUBEC. Control capability is of these components is further defined in Section 909.16.2 and 909.16.3 of the 2009 MUBEC. Figure 2.1 below provides an example of what these status indicators could look like.

Figure 2.1
Example of a Fire Fighter's Smoke Control Panel
Close Up of Status Indicators and Air Flow Indicators



2.3 All smoke control equipment shall be suitable for the intended use and suitable for the design temperatures indicated in the rational analysis (Section 3.1.4.13 of this report) in accordance with Section 909.10 of the 2009 MUBEC.

2.4 In order to be approved, the smoke control system must be tested in the presence of the AHJ to confirm that the system operates in compliance with all applicable code sections (Section 909.20.4.3 of the 2009 MUBEC).

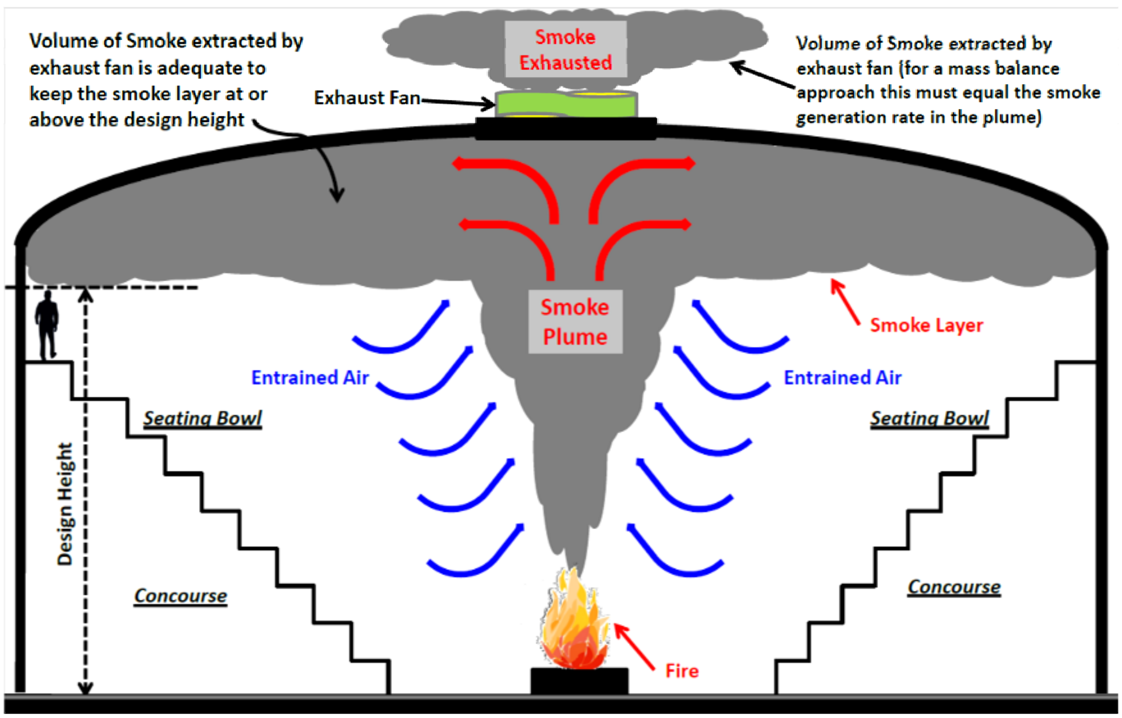
3.0 CUMBERLAND COUNTY CIVIC CENTER ARENA SMOKE CONTROL SYSTEM

3.1 RATIONAL ANALYSIS ASSUMPTIONS

A mechanical smoke control system is required in order to allow the use of smoke-protected assembly seating provisions in the Cumberland County Civic Center in accordance with Section 909.8.1 of the 2009 MUBEC and Section 12.4.2.1 (2) of the 2009 Edition of NFPA 101. The exhaust method was used for the proposed smoke control system in accordance with Section 909.8 of the 2009 MUBEC.

The exhaust method is a mass balance approach. The burning fire introduces mass (products of combustion and entrained air [which constitute smoke]) into the upper smoke layer. The exhaust system is designed to remove mass (smoke) from the smoke layer.

Figure 3.1
Example of a Smoke Control Mass Balance Approach



When the exhaust fan mass removal rate equals the mass generated by the fire, the smoke layer remains at a constant level. When the fire reduces its assumed size by consumption of the fuel package, or if it does not reach its assumed size due to inadequate fuel arrangement or automatic sprinkler activation, the smoke layer will rise above the design level and create even more favorable tenable conditions.

3.1.1 Smoke Control Zones

The Cumberland County Civic Center smoke control system is to be configured with three mechanical smoke control zones that encompass the West Lobby, the Seating Bowl, and the Main Concourse (which includes a portion of the Mechanical Level Lobby that is considered a communicating space in accordance with Section 8.6.6 of the 2009 Edition of NFPA 101). The purpose of the mechanical smoke control system in the Cumberland County Civic Center is to control the accumulation of smoke in the West Lobby, the Seating Bowl, the Main Concourse, and the Mechanical Level Lobby in order to maintain tenable conditions six feet above the highest level of egress in the active smoke control zone in order to allow Arena occupants to exit in accordance with Section 909.8.1 of the 2009 MUBEC and Section 12.4.2.1 (2) (a) of the 2009 Edition of NFPA 101. For further explanation of the tenable limits in the smoke layer, see **Appendix A** of this report.

3.1.1.1 The smoke control system for the Cumberland County Civic Center consists of mechanical exhaust fans in the following zones:

1. West Lobby Smoke Control Zone: A total of four mechanical exhaust fans were modeled in the West Lobby. Three mechanical exhaust fans were modeled at the ceiling of the West Lobby and one mechanical exhaust fan was modeled at the top of the stair that communicates with this space to the north.

2. Seating Bowl Smoke Control Zone: Two mechanical exhaust fans were modeled at the roof of the Seating Bowl.

3. Main Concourse Smoke Control Zone: A total of five mechanical exhaust fans were modeled in the Main Concourse. The north and south Main Concourses each employed two mechanical exhaust fans on the east and west ends. The west Main Concourse employed one mechanical exhaust fan.

The following methods were used to calculate and validate the smoke control system in the Cumberland County Civic Center:

3.1.1.2 The smoke exhaust fan capacities for the Arena smoke control zone were refined using a CFD model provided by NIST called the FDS.

3.1.1.3 The make-up air requirements were designed to be provided by overhead doors in the east loading dock and exterior doors on automatic openers. Make-up air will be supplied to the smoke control zones from these openings to the outside air as follows:

1. West Lobby Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will then be transferred to the Main Concourse through the openings on the northeast, southeast, and southwest ends of the Seating Bowl. Make-up air will be supplied to the West Lobby from two doors on automatic openers that connect the Main Concourse and the West Lobby (which will in turn be supplied through the Seating Bowl openings). Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

2. Seating Bowl Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

3. Main Concourse Smoke Control Zone: Make-up air will enter the Seating Bowl through the east Event Level vomitory from the loading docks. Make-up air will then be transferred to the Main Concourse through the openings on the northeast, southeast, and southwest ends of the Seating Bowl as well as from the doors on automatic openers in the vomitories. Make-up air will also be provided by doors on automatic openers on the southwest Main Concourse Level and the southeast Mechanical Level.

The effectiveness of the make-up air supplied and its affect on the smoke plume was verified using FDS.

3.1.2 Smoke Control System Operation

The Cumberland County Civic Center smoke exhaust mode is activated manually through the Fire Department Fire Fighters Control Panel (FFCP), automatically from a waterflow switch signal from the fire alarm system in the zoned automatic sprinklers, automatically from smoke detectors in the Seating Bowl smoke control zone (beam smoke detection), automatically from smoke detectors in the West Lobby smoke control zone (area smoke detection), or from smoke detectors in the Main Concourse smoke control zone (area smoke detectors at the ceiling of the Mechanical Level lobby). The total time estimated for the system to function was conservatively modeled at 90 seconds. This would allow transmission time from the waterflow switch (or smoke detector) to the fire alarm panel and from the panel to the smoke exhaust fans and make-up air sources. This also includes time for the deactivation of the Cumberland County Civic Center HVAC systems. The smoke exhaust fans in the Cumberland County Civic Center start and operate at scheduled air volume. Overhead doors on automatic openers at the east loading dock are used to provide unconditioned make-up air into the Seating Bowl which is then distributed to the rest of the Arena by doors on automatic openers in the Seating Bowl vomitories and the Lobby.

3.1.3 Maine Uniform Building and Energy Code Requirements

3.1.3.1 Stack Effect

Per Section 909.4.1 of the 2009 MUBEC the stack effect condition was considered for this smoke control system. The mechanical design must account for the worst case pressure differential (reverse stack effect conditions in the summer) that would cause the outside air to work against the exhaust fans. The following explanation and calculations are provided for the mechanical designer in order to demonstrate the potential effect of the stack effect and reverse stack effect conditions.

Any pressure differential between the interior and exterior of the building can affect the calculated required exhaust rate. Local climate temperature extremes and the relatively constant temperature of the interior of the building (70˚ F) can create pressure differentials between the interior and exterior of the building. The mechanical design must account for the worst case pressure differential (reverse stack effect conditions) that would affect the exhaust fan performance along its performance curve. This pressure differential consideration by the mechanical designer will ensure that the exhaust fan can provide the required exhaust under all stack effect and reverse stack effect scenarios.

Internal building temperatures were assumed to be consistent with normal temperature defined in Section 415.2 of the 2009 MUBEC as 70° F (21.1° C). In accordance with equation 3.22a of *Design of Smoke Management Systems* by Klote and Milke, the pressure to be overcome by the smoke exhaust system is calculated below for stack effect and reverse stack effect conditions:

$$\Delta P_{Stack} := K_s \cdot \left(\frac{1}{T_0} - \frac{1}{T_B} \right) \cdot Z$$

ΔP_{Stack} = Stack pressure differential in inches of water column

K_s = 7.64 (Coefficient)

T_0 = Outside air temperature (ºR)

T_B = Building air temperature (ºR) = 70 ºF + 460 = 530 ºR [Normal Temperature and Pressure]

Z = Height above the neutral plane (ft)

For summer conditions (reverse stack effect) conditions:

$$\Delta P_{Stack} := 7.64 \cdot \left(\frac{1}{546.8^{o}\ R} - \frac{1}{530^{o}\ R} \right) \cdot 60.67\ ft = -0.03 \text{ inches of water column}$$

ΔP_{Stack} = Stack pressure differential in inches of water column

K_S = 7.64 (Coefficient)

T_0 = 86.8 ºF + 460 = 546.8 ºR [2009 ASHRAE Fundamentals, Portland, Maine]

T_B = 70 ºF + 460 = 530 ºR [Normal Temperature and Pressure]

Z = 60.67 feet (conservative assumption - uses entire building height instead of neutral plane)

For winter conditions (stack effect) conditions:

$$\Delta P_{Stack} := 7.64 \cdot \left(\frac{1}{459.7^{o}\ R} - \frac{1}{530^{o}\ R} \right) \cdot 60.67\ ft = 0.13 \text{ inches of water column}$$

ΔP_{Stack} = Stack pressure differential in inches of water column

K_S = 7.64 (Coefficient)

T_0 = -0.3 ºF + 460 = 459.7 ºR [2009 ASHRAE Fundamentals, Portland, Maine]

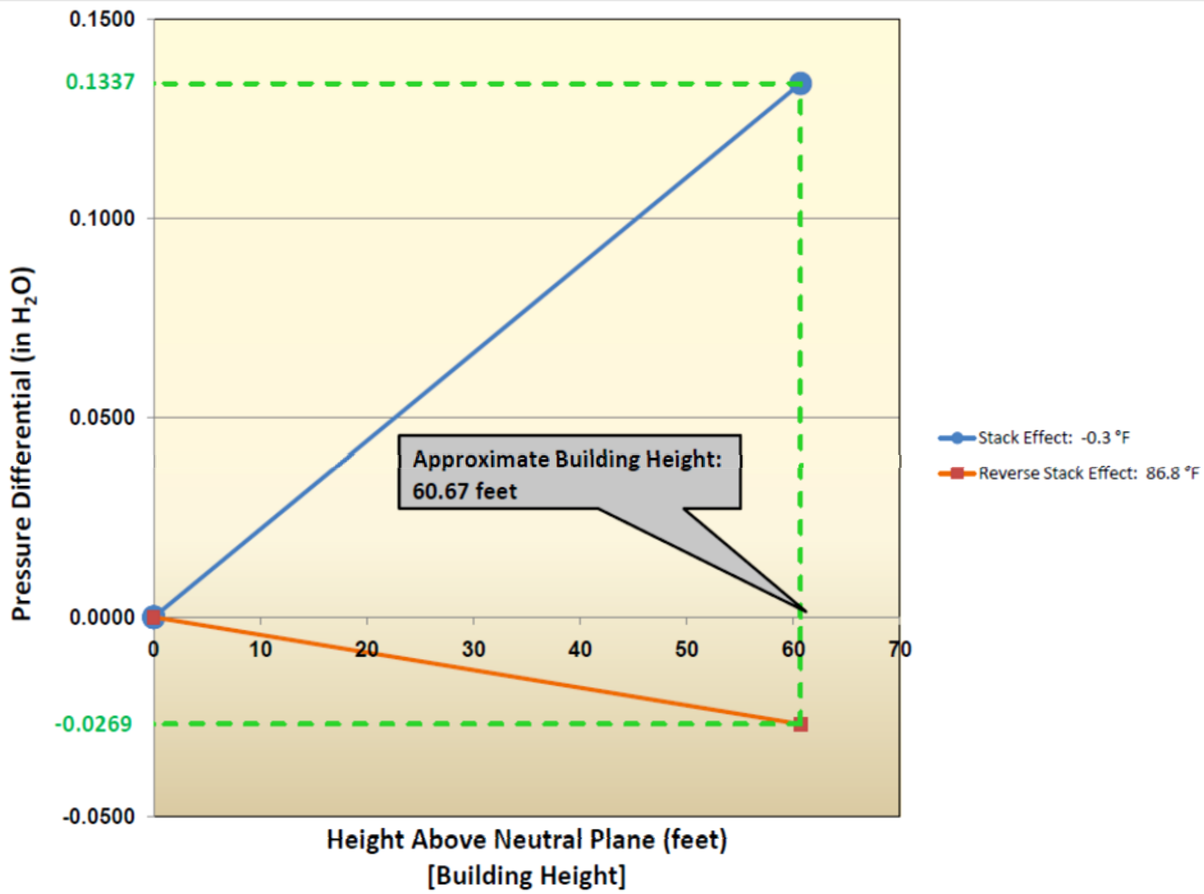
T_B = 70 ºF + 460 = 530 ºR [Normal Temperature and Pressure]

Z = 60.67 feet (conservative assumption - uses entire building height instead of neutral plane)

The graph in Figure 3.2 below illustrates the relationship between stack effect as it relates to building height and temperature differential. The values for the calculations above are highlighted on this graph.

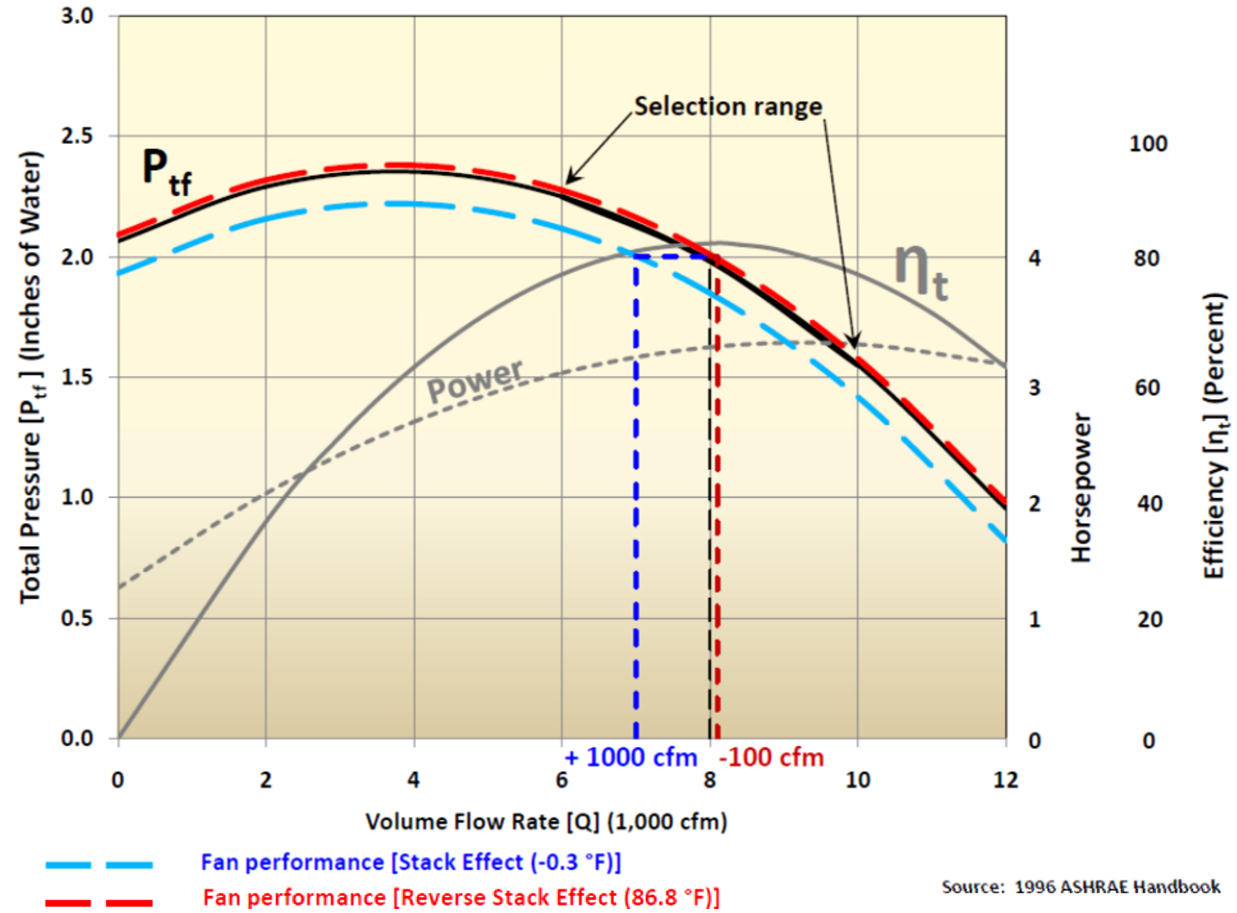
Figure 3.2

Stack Effect (2.6° F Low and 97.6° F High)



These pressure differentials are insignificant due primarily to the relatively low overall height of the Arena. The exhaust fans should be able to easily overcome these stack pressures.

Figure 3.3
Stack Effect Relationships to ASHRAE Fan Pressure Curve



The generic fan curve above shows the relationship between stack effect pressure differentials and fan performance.

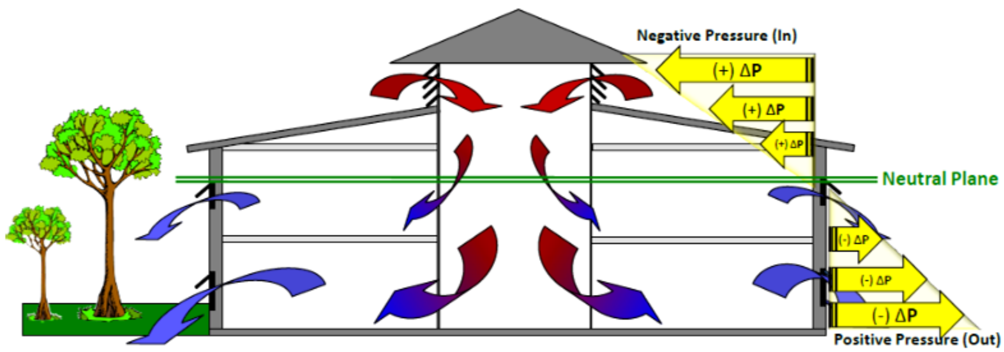
1. 7,900 cfm performance for reverse stack effect (-100 cfm from 8,000 cfm fan)

2. 9,000 cfm performance for stack effect (+1,000 cfm to 8,000 cfm fan)

As the example pressure performance curve in Figure 3.3 demonstrates, the worst case scenario occurs in the reverse stack effect condition (summer) which creates a negative pressure differential on the building that the fan must overcome in addition to the exhaust requirements in order to achieve the mass balance for the smoke control system. The pressure of the atmosphere pushing into the building (opposing exhaust during reverse stack effect conditions) at 60 feet above grade (assuming the exhaust fan was at the roof of the Cumberland County Civic Center) creates a condition where a mechanical fan rated to supply 8,000 cfm of exhaust will only be capable of providing 7,900 cfm of exhaust (according to the example pressure performance curve in Figure 3.3) and would need to provide approximately 100 cfm of additional exhaust capacity (an increase of 1.25%). In this case, these pressure differentials are insignificant and should be easily accounted for by the mechanical designer so that the recommended exhaust capacities are met.

The following diagram (Figure 3.4) illustrates the effects of the negative pressure differential on a building during the reverse stack effect condition. As demonstrated by the calculations above, the positive pressure on the building will require increased fan performance above the calculated design. In order to account for the reverse stack effect condition for the Cumberland County Civic Center, the design fires were modeled by the FDS computational fluid dynamics software using the summer conditions.

Figure 3.4
Reverse Stack Effect Diagram



3.1.3.2 Temperature Effect of Fire

Per Section 909.4.2 of the 2009 MUBEC, the temperature effect of the design fire was accounted for by the CFD fire modeling software called Fire Dynamics Simulator (FDS).

Fire Dynamics Simulator (Computational Fluid Dynamics [CFD] model)

Temperature is a key factor in the fluid dynamics equations that represent the conditions in the Cumberland County Civic Center. FDS will model the effect of the design fire's temperature by simultaneously solving the thousands of fluid dynamics equations that represent the conditions in these spaces.

The FDS software analyzes the effects of the temperature within the calculated smoke layer. As the fire grows, calculated temperature, visibility (optical density of the smoke), and carbon monoxide levels within the smoke layer and the room are analyzed. See **Appendix A** for more information on these assumed tenability limits.

The temperature of the smoke affects the quantity of exhaust required, since the hotter the smoke is, the more it expands. As it expands, its density decreases (more volume for the same mass). This affects the mass balance calculations, since an exhaust fan's ratings are in cubic feet per minute (cfm), which is a measurement of volume, not mass. As a result, the amount of exhaust required increases with the temperature of the smoke layer.

3.1.3.3 Wind Effect

Per Section 909.4.3 of the 2009 MUBEC, the effect of wind on the smoke control system was considered but was not modeled by the FDS software, as FDS does not simulate the pressure differential on the exhaust fan equipment. The wind can have an adverse affect on the function of the exhaust system since the exhaust fan is mechanically driven and will have to overcome the pressure differential created by the wind. The wind can have an adverse affect on the make-up air supplied by open doors in the worst case wind direction condition and can impede air flow into the building. The worst case wind direction condition occurs when the wind blows against the opposite side of the building from the make-up air doors, creating negative pressure relative to the building at those doors as it flows around the building.

The mean wind speed ranges from 7.1 to 11.0 mph with a 26.7 mph 0.4% extreme wind speed (Heating and Wind Design Conditions – Portland, Maine, United States from Chapter 14 of the *2009 ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers) Fundamentals Handbook)* with a general direction from the west (opposite the make-up air doors which can cause negative pressure differentials). The negative pressure differentials that are possible from these wind loads range from approximately 0.78 to 0.85 inches of water column for the mean wind speeds and can be as high as approximately 1.23 inches of water column for the extreme wind speed noted from the ASHRAE Handbook. The mechanical designer will need to provide a fan capable of supplying the required exhaust at the above negative pressure differentials relative to the building (caused by the exterior wind speeds and wind direction anticipated).

3.1.3.4 HVAC Systems

The kitchen exhaust, restroom exhaust, and HVAC systems were assumed to be off during operation of the smoke control system in order to address the effect of the HVAC systems per Section 909.4.4 of the 2009 MUBEC. There are two reasons why all exhaust systems were assumed to be off during a fire event:

1. If smoke or excessive heat is detected in a building ventilation duct system, these ducts are required to be dampered (closed off in order to terminate operation) per Section 716 of the 2009 MUBEC. It would be more conservative to assume the building ventilation system was shut down due to the presence of smoke or heat in the ventilation

ducts than to assume this would not occur.

2. It is possible that the primary source of power to the building could be lost in the event of a fire. Standby power systems are required to operate the smoke control system, not the building ventilation system. It would be more conservative to assume the building ventilation system was shut down due to loss of power than to assume this would not occur.

3.1.3.5 Climate

Per Section 909.4.5 of the 2009 MUBEC, the effect of the climate was considered along with the stack effect conditions with regards to temperature. Doors on automatic openers at the east loading docks and exterior doors will be used to provide unconditioned make-up air. There is a potential for snow or ice blockage of the make-up air and exhaust equipment in this climate that could obstruct the proper functioning of the mechanical smoke control system. It is recommended that design measures be taken to limit the effect of snow and ice blockage to the make-up air and mechanical equipment.

3.1.3.6 Duration of Operation

Per Section 909.4.6 of the 2009 MUBEC, the duration of the system operation was determined by taking the most conservative time constraint. As a result, the total required egress time value was assumed to be the 20 minute maximum required by Section 909.4.6 of the 2009 MUBEC. The 2009 Edition of NFPA 101 does not specify system duration of operation for smoke protected assembly seating.

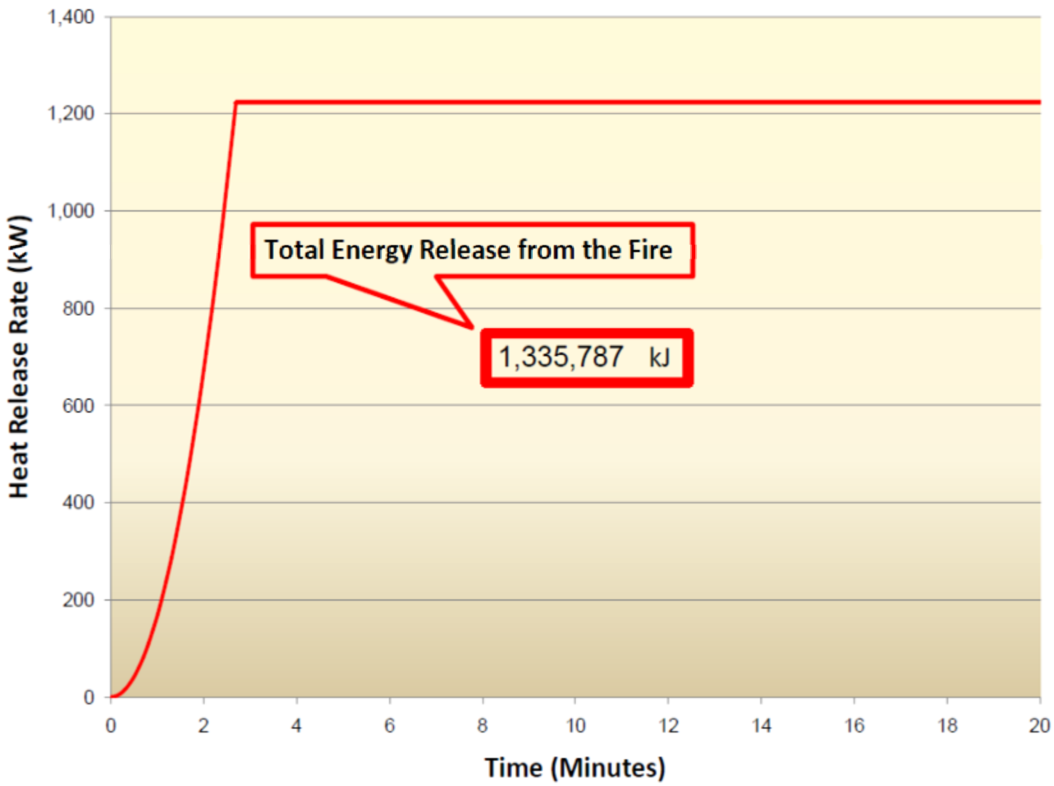
3.1.4 <u>Design Fundamentals</u>

Chapters 4 and 5 of the 2005 Edition of NFPA 92B (referenced by the 2009 MUBEC) contain a list of design criteria to aid in the design of the smoke exhaust system. The following parameters were taken into consideration when designing the Cumberland County Civic Center smoke control system.

3.1.4.1 Design Fire (2005 Edition of NFPA 92B, Section 3.3.7)

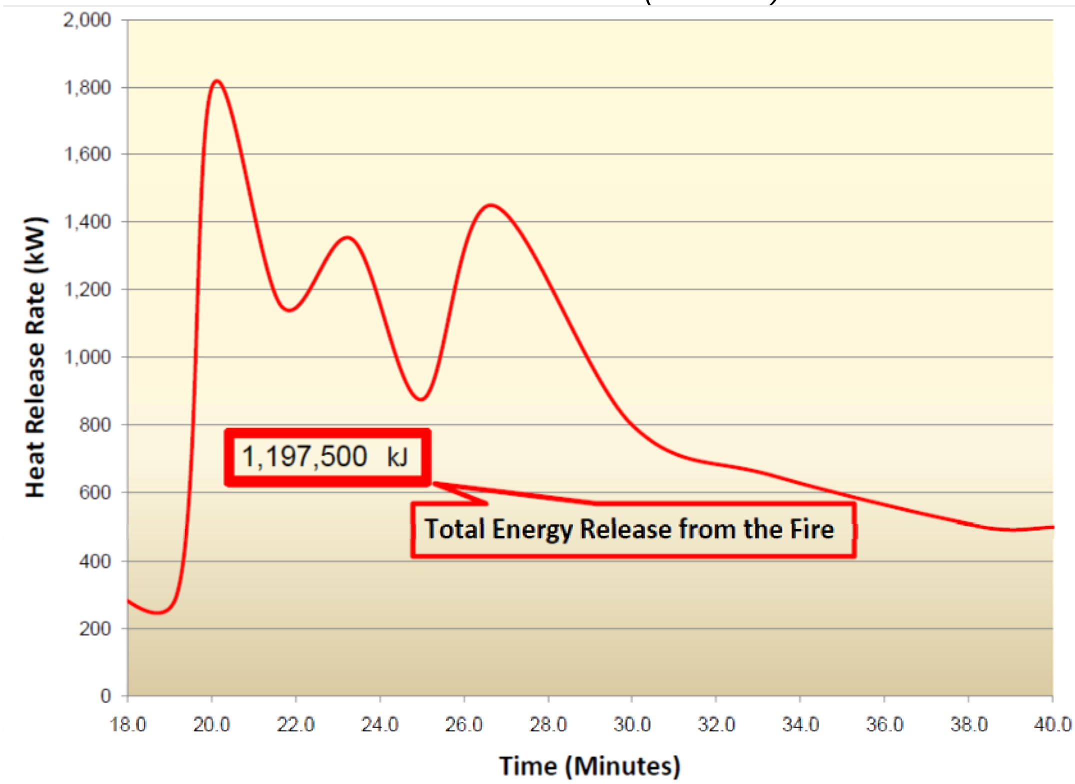
The following design fire analysis addresses the design fire requirements in Section 909.9 of the 2009 MUBEC. A fast growth fire was chosen for the fire in the smoke exhaust calculations. The smoke control zone is protected by automatic sprinklers and was assumed to be a Light Hazard occupancy with potential fuel load restrictions based on this occupancy hazard classification from the 2007 Edition of NFPA 13. The design fire was assumed to grow at the fast rate until sprinkler activation, at which time the fire size was conservatively assumed to be controlled by the automatic sprinklers and remain at a steady state heat release rate until the end of the evaluation. The steady state fire is also based on the conservative assumption that a continuous fuel load is present. In many cases, fires have a limited fuel package and the effect of automatic sprinklers can actually suppress the fire. Both of these factors can cause the fire to enter a decay phase in which reduced amounts of smoke and combustion products are produced. The simulated fires used in this evaluation do not assume that the fuel packages are consumed, that the distance between fuel packages may be so large that radiant heat is insufficient to cause ignition of adjacent fuel packages, or that the automatic sprinklers may reduce or extinguish the fire. An example of this type of fire growth model used in this analysis is shown in Figure 3.5 below.

Figure 3.5
Example of a Fast Growth, T-Squared Fire at Steady State (Design Fire 3)
Source: SFPE Handbook, 3rd Edition



1. For the design fires, it should be noted that the use of a fast growth steady state design fire is a further conservative assumption. Most fires with a limited fuel package will have an unsteady growth to a maximum heat release rate and then decay or "burn out" after the fuel package has been consumed. In most cases this unsteady growth and decay fire only reaches its maximum heat release rate for a very short period of time as shown below in Figure 3.6.

Figure 3.6
Example of an Unsteady Growth and Decay Fire
Source: NIST Fire on the Web (Kiosk Fire)



2. The unsteady growth and decay fire (Figure 3.6) transfers much less energy than a fast growth steady state heat release rate fire (Figure 3.5). By conservatively assuming a design fire that grows uniformly (fast growth T-squared) to steady state, a larger amount of energy is assumed to be released as well as a constant source of smoke, thereby providing a factor of safety versus unsteady fire growth behavior with a limited fuel package.

3. The total energy transferred by a fire can be determined from the graphs in Figure 3.5 and Figure 3.6 by determining the area under the heat release rate curve. The heat release rate is displayed in kilowatts (kW) in these graphs which is a measure of power (the energy or work done over some unit of time). A kilowatt (kW) is a kilojoule (energy) per second (unit of time). This area under the heat release rate curve will be the product of kilowatts (kilojoules per second) and time (seconds) and results in kilojoules (energy) transferred by the fire at a particular heat release rate over the time period. For the fast growth steady state fire in Figure 3.5 this is a fairly simple task – the area under the heat release rate curve is almost rectangular. For the unsteady growth and decay fire, the exercise in determining the area under the curve in Figure 3.6 is achieved using the

trapezoidal rule or some other method of estimating the integral (area under the curve).

4. In the comparison between the fires in Figure 3.5 and Figure 3.6, approximately 1.1 times the energy (1,335,787 kJ vs. 1,197,500 kJ) is transferred in the fast growth steady state fire versus the unsteady growth and decay fire.

5. NIST via its *Fire on the Web* website has provided data for numerous fire test scenarios (including the kiosk fire represented by Figure 3.6). The following images from the NIST website provide an example of what a kiosk fire would look like. The three images provide an image of the initial test condition, an image of the kiosk burning at its maximum heat release rate, and an image of the burning kiosk as the fire nears the end of its decay.

Figure 3.7
Example of an Unsteady Growth and Decay Fire
*Source: NIST Fire on the Web (*Kiosk *Fire)*
Initial Condition [0-20 minutes in Figure 3.6 above]

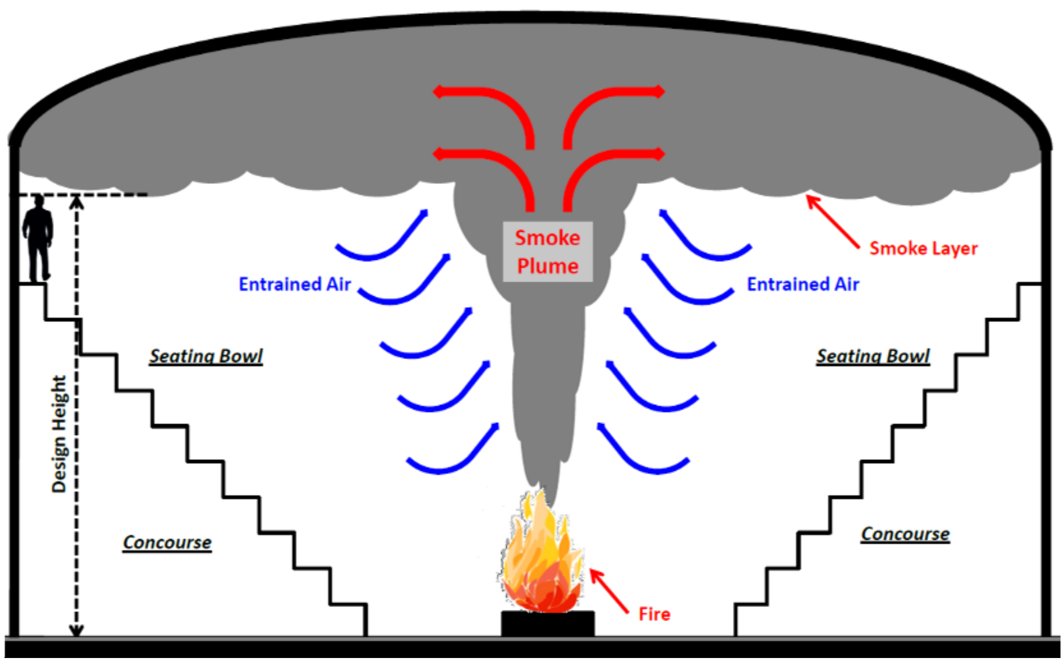
Figure 3.8
Example of an Unsteady Growth and Decay Fire
*Source: NIST Fire on the Web (*Kiosk *Fire)*
Peak Fire Growth (Maximum Heat Release Rate) [20-28 minutes in Figure 3.6 above]

Figure 3.9
Example of an Unsteady Growth and Decay Fire
*Source: NIST Fire on the Web (*Kiosk *Fire)*
Fire Decay Phase [28-40 minutes in Figure 3.6 above]

6. Five design fire scenarios were used for the Cumberland County Civic Center analysis. Two design fires were modeled on the Main Concourse in order to properly size the smoke control system for that long and narrow space.

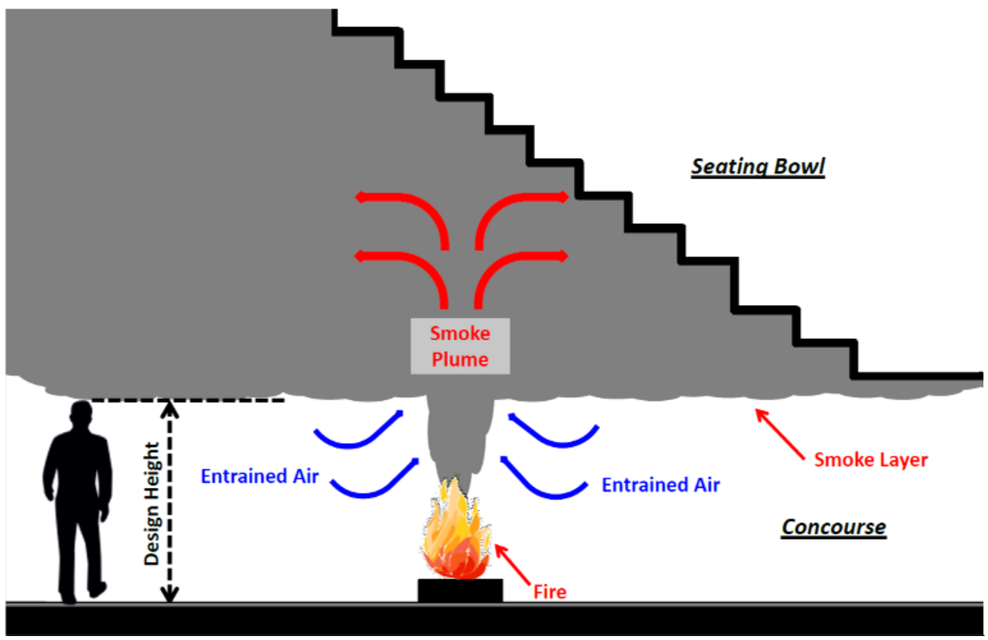
6.1 Design Fire 1 consists of a fast growth T-squared fire located on the Event Level floor in the Seating Bowl. The expected fuel load in this space could consist of a performance stage or vehicles which can be modeled using the fast growth T-squared fire growth rateT-squared. This fire was not assumed to be sprinkler limited. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. See Figure 3.10 below for an illustration of this type of design fire.

Figure 3.10
Axisymmetric Smoke Plume Diagram



6.2 Design Fire 2 consists of a fast growth T-squared fire located on the floor of the Main Concourse near the southeast end. The expected fuel load in this space could consist of kiosks filled with merchandise which can be modeled using the fast growth T-squared fire growth rateT-squared. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. See Figure 3.11 below for an illustration of this type of design fire.

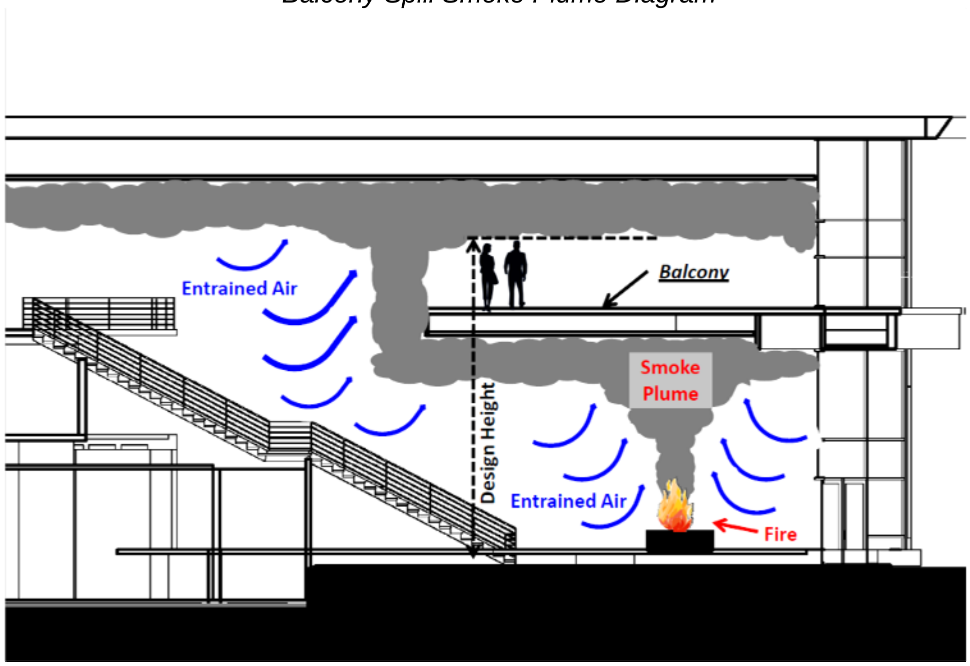
Figure 3.11
Axisymmetric Smoke Plume Diagram



6.3 Design Fire 3 consists of a fast growth T-squared fire located on the floor of the Main Concourse on the west end. The expected fuel load in this space could consist of kiosks filled with merchandise which can be modeled using the fast growth T-squared fire growth rateT-squared. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume.

6.4 Design Fire 4 consists of a fast growth T-squared fire located on the Mechanical Level in the communicating space that connects to the Main Concourse by an open stair. The expected fuel load in this space could consist of kiosks filled with merchandise which can be modeled using the fast growth T-squared fire growth rateT-squared. The fire was located under the ceiling on the east side of the space away from the stair in order to create a balcony spill smoke plume. The greater amount of smoke generation possible by a balcony spill plume results because the maximum amount of air can be entrained into the smoke plume as it spills from under the ceiling of the Mechanical Level into the Main Concourse. Even though the greatest smoke volume is generated by this fire scenario, the smoke produced by it is more diluted by the large amounts of air entrained than that produced by the axisymmetric smoke plume from Design Fires 1-3. This fire was assumed to be sprinkler limited based on the calculations performed by the Fire Dynamics Simulator (FDS) software. See Figure 3.12 below for an illustration of this type of design fire.

Figure 3.12
Balcony Spill Smoke Plume Diagram



6.5 Design Fire 5 consists of a fast growth T-squared fire located on the floor of the Lobby on the west end of the Main Concourse. The expected fuel load in this space could consist of kiosks filled with merchandise or furniture which can be modeled using the fast growth T-squared fire growth rateT-squared. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. This design fire scenario creates a balcony spill plume scenario that affects the stairs that are open directly to the north of the lobby.

3.1.4.2 Height and Area (2005 Edition of NFPA 92B, Section 4.2.1)

The Cumberland County Civic Center Seating Bowl has a sloped ceiling with a maximum floor to ceiling height of approximately 60 feet. A fire directly under the highest portion of the ceiling produces the worst case smoke generation scenario as the axisymmetric smoke plume from a fire on the Event Level floor in this open area would be able to entrain the maximum amount of air as it rises to the ceiling.

The Cumberland County Civic Center Main Concourse has a sloped ceiling with a maximum floor to ceiling height of approximately 20 feet. A fire directly under the highest portion of the ceiling produces the worst case smoke generation scenario as the axisymmetric smoke plume from a fire on the Main Concourse floor in this open area would be able to entrain the maximum amount of air as it rises to the ceiling.

The balcony spill plume fire that results from a fire on the Mechanical Level (which forms a communicating space with the Main Concourse), though the 2005 Edition of NFPA 92B calculations estimate that it creates the maximum amount of smoke, will produce a smoke plume that is far more diluted than the axisymmetric plume. All scenarios were modeled using the Fire FDS for proper fan sizing and analysis of the conditions within the Arena during a fire.

The Cumberland County Civic Center West Lobby has a flat ceiling with a maximum floor to ceiling height of approximately 10 feet. A fire on the floor directly under the ceiling produces the worst case smoke generation scenario as the axisymmetric smoke plume from a fire on the Main Concourse floor in this open area would be able to entrain the maximum amount of air as it rises to the ceiling. Additionally this space creates a balcony spill plume as well that affects the stairs to the north.

3.1.4.3 Design Approach (2005 Edition of NFPA 92B, Section 4.3)

The 2005 Edition of NFPA 92B, Section 4.3 requires the design approach for a smoke management system to be a method listed in Section 4.3. The exhaust method was chosen in accordance with Section 909.8 of the 2009 MUBEC. In order to comply with the Section 909.8.1 of the 2009 MUBEC, the smoke management system has been designed so that tenable conditions are maintained six feet above the highest level of egress access in the active smoke control zone. This approach was used to maintain the smoke layer at tenable limits for a period of 20 minutes or 1.5 times the calculated egress time, whichever is less (Section 909.4.6 of the 2009 MUBEC). The most conservative maximum duration of 20 minutes was chosen. The 2009 Edition of NFPA 101 does not specify system duration of operation for smoke protected assembly seating.

3.1.4.4 Design Considerations (2005 Edition of NFPA 92B, Section 4.2.1)

The plan area of the Cumberland County Civic Center Seating Bowl is approximately 62,561 square feet. The plan area of the Main Concourse (including Mechanical Level) is approximately 29,075 square feet. The plan area of the West Lobby is approximately 6,052 square feet. This floor area configuration was accounted for by the FDS computational fluid dynamics fire model.

3.1.4.5 Occupancies (2005 Edition of NFPA 92B, Section 4.2.1)

The area utilizing smoke control in Cumberland County Civic Center is a Assembly use group (Group A-4) occupancy.

3.1.4.6 Egress Routes (2005 Edition of NFPA 92B, Section 4.2.1)

Smoke-protected assembly seating provisions (as described in Section 1025.6.2.1 of the 2009 MUBEC and Section 12.4.2.1 (2) (a) of the 2009 Edition of NFPA 101) are utilized in the Cumberland County Civic Center. The smoke management system has been designed so that tenable conditions are maintained six feet above the highest level of egress access in the active smoke control zone.

3.1.4.7 Areas of Refuge (2005 Edition of NFPA 92B, Section 4.2.1)

The Cumberland County Civic Center does not require any areas of refuge and none have been incorporated into the design. The 2009 MUBEC and ADA (American Disabilities Act) consider a fully sprinklered building as providing an adequate level of safety without areas of refuge.

3.1.4.8 Smoke Development Analysis (2005 Edition of NFPA 92B, Section 4.3)

The smoke development analysis of the design approach chosen from the 2005 Edition of NFPA 92B, Section 4.3 is required to be justified using one of the following methods: algebraic calculations, CFD models, compartment fire models, scale modeling, or zone modeling. To satisfy this requirement, the Design Team has selected to use the FDS, CFD model provided by NIST, for the smoke development analysis.

3.1.4.9 Minimum Smoke Layer Depth (2005 Edition of NFPA 92B, Section 4.4.1.1)

The Design Team has selected a height at the minimum design depth of the smoke layer based on the requirements in the 2009 MUBEC. As part of the engineering analysis, the Design Team is designing the smoke exhaust system to maintain the smoke layer at tenable limits at least six feet above the highest surface used for egress in the active smoke control zone (to comply with the Section 909.8.1 of the 2009 MUBEC and Section 12.4.2.1 (2) (a) of the 2009 Edition of NFPA 101).

3.1.4.10 Smoke Travel to Communicating Spaces (2005 Edition of NFPA 92B, Section 4.4.2)

1. The design of the Cumberland County Civic Center will allow smoke from one of the adjacent, non-smoke control zone adjoining spaces to spill into the large volume space of the smoke control zones (Seating Bowl, Main Concourse, or West Lobby). The Design Team has utilized the techniques allowed by the 2005 Edition of NFPA 92B, Section 4.4.2.1 and designed the exhaust system to keep the smoke six (6) feet above the highest level of egress in the active smoke control zone. The smoke generated from fires in adjoining, non-smoke control zone spaces that infiltrates into the neighboring smoke control zone was determined to be significantly less than the smoke generated by a fire in one of the smoke control zones.

2. The design of the Cumberland County Civic Center would normally allow smoke from a fire in one smoke control zone of the Arena to migrate into other smoke control zones. The purpose of the smoke control system is to maintain the smoke layer at tenable limits at least six feet above the highest surface used for egress in the active smoke control zone (to comply with the Section 909.8.1 of the 2009 MUBEC and Section 12.4.2.1 (2) (a) of the 2009 Edition of NFPA 101). The Design Team has utilized the techniques allowed by the 2005 Edition of NFPA 92B, Section 4.4.2 and designed the exhaust system to keep the smoke six feet above the highest level of egress in the active smoke control zone. The smoke generated from fires in adjoining, smoke control zone spaces that infiltrates into the neighboring smoke control zone was determined to be significantly less than the smoke generated by a fire in one of the smoke control zones.

3.1.4.11 System Startup (2005 Edition of NFPA 92B, Section 4.5.2)

The smoke management system is required to achieve full operation prior to the smoke levels reaching the design smoke conditions.

To evaluate the time it takes for the smoke exhaust system to become operational, the Design Team has considered the following design factors from the 2005 Edition of NFPA 92B, Section 4.5.2.2.

1. Time for detection of a fire incident in the Cumberland County Civic Center can be estimated from the time for sprinkler activation or smoke detector activation. The beam detectors were essential for proper system operation for a fire in the open on the Event Level floor in the Seating Bowl (axisymmetric Design Fire Scenario 1) as a

sprinkler-limited fire was not assumed. The area detectors were essential for proper system operation for a fire on the Mechanical Level Lobby (balcony spill plume Design Scenario Fire 4) and in the West Lobby (axisymmetric Design Fire Scenario 5). Automatic sprinklers were the primary method of system activation for Design Fire Scenario 2 and Design Fire Scenario 3 in the Main Concourse. This time to activation can be estimated using the FDS software. Detailed information on the detection parameters is provided in Section 3.2 of this report.

Table 3.1
Fire Scenario Estimated Sprinkler Activation Times

Fire Scenario	Ceiling Height (Feet)	Estimated Activation Time (Seconds)
1 – Seating Bowl Axisymmetric Plume	60.7	514.4
2 – South Main Concourse Axisymmetric Plume	26.5	133.3
3 – West Main Concourse Axisymmetric Plume	26.5	154.7
4 – Lower Level Balcony Spill Plume	34.5	157.6
5 – West Lobby Axisymmetric Plume	10	130.6

Table 3.2
Fire Scenario Estimated Smoke Detector Activation Times

Fire Scenario	Ceiling Height (Feet)	Estimated Activation Time (Seconds)
1 – Seating Bowl Axisymmetric Plume	60.7	51.2
2 – South Main Concourse Axisymmetric Plume	26.5	***No Smoke Detectors Used***
3 – West Main Concourse Axisymmetric Plume	26.5	***No Smoke Detectors Used***
4 – Lower Level Balcony Spill Plume	34.5	38.4
5 – West Lobby Axisymmetric Plume	10	37.4

2. Response times for the smoke control system activated by automatic sprinkler waterflow switch or automatic smoke detectors were assumed to be the following (and are assumed to run simultaneously):

   2.1 For the make-up air, a total of 90 seconds from the time of detection (automatic sprinkler or beam smoke detector activation) until the systems providing make-up air were actuated. This accounts for the transmission time between the water flow switch (or smoke detector) and the alarm panel (60 seconds) and then transmission time to the make-up air systems (10 seconds).

2.1.1 The Cumberland County Civic Center will be provided with make-up air via overhead doors on automatic openers on the east loading dock and exterior doors (see illustrations IL.002 through IL.003 shown previously in the report).

2.2 For the mechanical exhaust, a total of 90 seconds from the time of detection (automatic sprinkler activation or smoke detector activation) until the smoke control exhaust fans are operational. This accounts for the transmission time between the water flow switch (or smoke detector) and the alarm panel (60 seconds), transmission time to the fans (10 seconds), and exhaust fan ramp-up time (20 seconds).

3. For manual activation, a total of 60 seconds was assumed for the activation of the make-up air and mechanical smoke exhaust systems from the time of manual activation from the Firefighter's smoke control panel per Section 909.17 of the 2009 MUBEC.

3.1.4.12 Make-Up Air (2005 Edition of NFPA 92B, Section 4.6)

Make-up air for the smoke control system will be supplied through natural ventilation provided by overhead doors in the loading dock on the east end of the building and exterior doors that were modeled to open automatically upon system actuation. Make-up air will travel from the loading dock through the Seating Bowl and into other areas of the building and into the building from the exterior doors on the southeast and southwest. The illustrations outlined in Table 1.2 below represent the make-up air supply plan.

According to the NFPA Handbook (20th Edition, Volume 2, pages 18-54), CFD models like the FDS can realistically simulate air (and smoke) flow up to Mach 0.3 (20,000 feet per minute). The FDS software can simulate plugholing (as normally calculated with NFPA 92B algebraic equations) and model the affects of air flows over 200 feet per minute into the smoke control zone towards the design fire with the subsequent effect on the quantity of smoke produced (the limiting assumption of the NFPA 92B algebraic equations).

3.1.4.13 Operating Conditions (2005 Edition of NFPA 92B)

The smoke management system components are required (2005 Edition of NFPA 92B, Section 4.7) to be capable of continuous use at the maximum temperature expected over the design interval time.

The FDS simulations were used to estimate the temperature at the exhaust vents in the Cumberland County Civic Center smoke control zone for the Design Fire scenarios. The Cumberland County Civic Center is provided with automatic sprinklers as part of the FDS simulations. Temperatures at the exhaust vents were calculated using thermocouple slice files.

Table 3.3

Fire Scenario Maximum Exhaust Equipment Temperatures

FIRE SCENARIO	MAXIMUM EXHAUST VENT TEMPERATURE
1 – Seating Bowl Axisymmetric Plume	110° F [1]
2 – South Main Concourse Axisymmetric Plume	80° F [1]
3 – West Main Concourse Axisymmetric Plume	95° F [1]
4 – Lower Level Balcony Spill Plume	123° F [2]
5 – West Lobby Axisymmetric Plume	98° F [1]

[1] These temperatures are estimated based on slice file measurements recorded in the FDS software at the exhaust vents and not on the temperatures at the sprinklers (165°F). The lower temperatures result from the ceiling jet of the smoke plume traveling across the ceiling to the exhaust vents and cooling from the presence of automatic sprinklers.

[2] These temperatures were estimated using the same methods noted in Footnote 1 above. The lower temperatures that result are from the balcony spill plume from the Mechanical Level lobby that entrains more air and has more time to cool as the smoke plume travels to the ceiling to the exhaust vents.

3.2 SMOKE EXHAUST MODELING

For the Design Fire Scenarios a CFD model was determined to be the best approach to model the conditions in the Cumberland County Civic Center due to the complex floor geometry relationships in the Arena. Tenability criteria, which are based upon temperature, visibility (optical density of the smoke), and gas concentrations, are examined as the benchmark of acceptability for the results of the computational fluid dynamics fire model in accordance with the guidance in Section A.3.3.8 of the 2005 Edition of NFPA 92B.

The smoke exhaust system and the automatic sprinkler system in the Cumberland County Civic Center smoke control zones were modeled using the FDS, a program developed by NIST. The FDS software can calculate the evolving distribution of smoke, fire gases, and temperature during a fire by solving numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The FDS package includes NIST's Smokeview program, which visualizes with colored, three-dimensional animations, the results of the FDS simulation of a specific fire's temperatures, various gas concentrations, and growth and movement of smoke layers across multi-room structures. A further discussion of the FDS software is provided in **Appendix A** of this report.

3.2.1 FDS Model Scenarios and Assumptions

The following scenarios were used to model the conditions within the Arena.

Table 3.4

Cumberland County Civic Center Smoke Control Zone FDS Fire Simulation Scenarios

FIRE SCENARIO	DESCRIPTION
Design Fire 1	Non-Sprinkler Limited Fast Growth T-Squared Fire 10,000 kilowatts (kW) [9,487 Btu/sec] Axisymmetric Plume
Design Fire 2	Sprinkler Limited Fast Growth T-Squared Kiosk Fire 834 kilowatts (kW) [791 Btu/sec] Axisymmetric Plume
Design Fire 3	Sprinkler Limited Fast Growth T-Squared Kiosk Fire 1,122 kilowatts (kW) [1,065 Btu/sec] Axisymmetric Plume
Design Fire 4	Sprinkler Limited Fast Growth T-Squared Kiosk Fire 1,165 kilowatts (kW) [1,105 Btu /sec] Balcony Spill Plume
Design Fire 5	Sprinkler Limited Fast Growth T-Squared Sofa/Kiosk Fire 793 kilowatts (kW) [752 Btu/sec] Axisymmetric Plume

The starting temperature for the interior space of the Cumberland County Civic Center in the design fire scenario was assumed to be 70°F as it was assumed that this is a conditioned space.

The assumptions listed in Table 3.5 were used to construct the FDS model for smoke exhaust analysis.

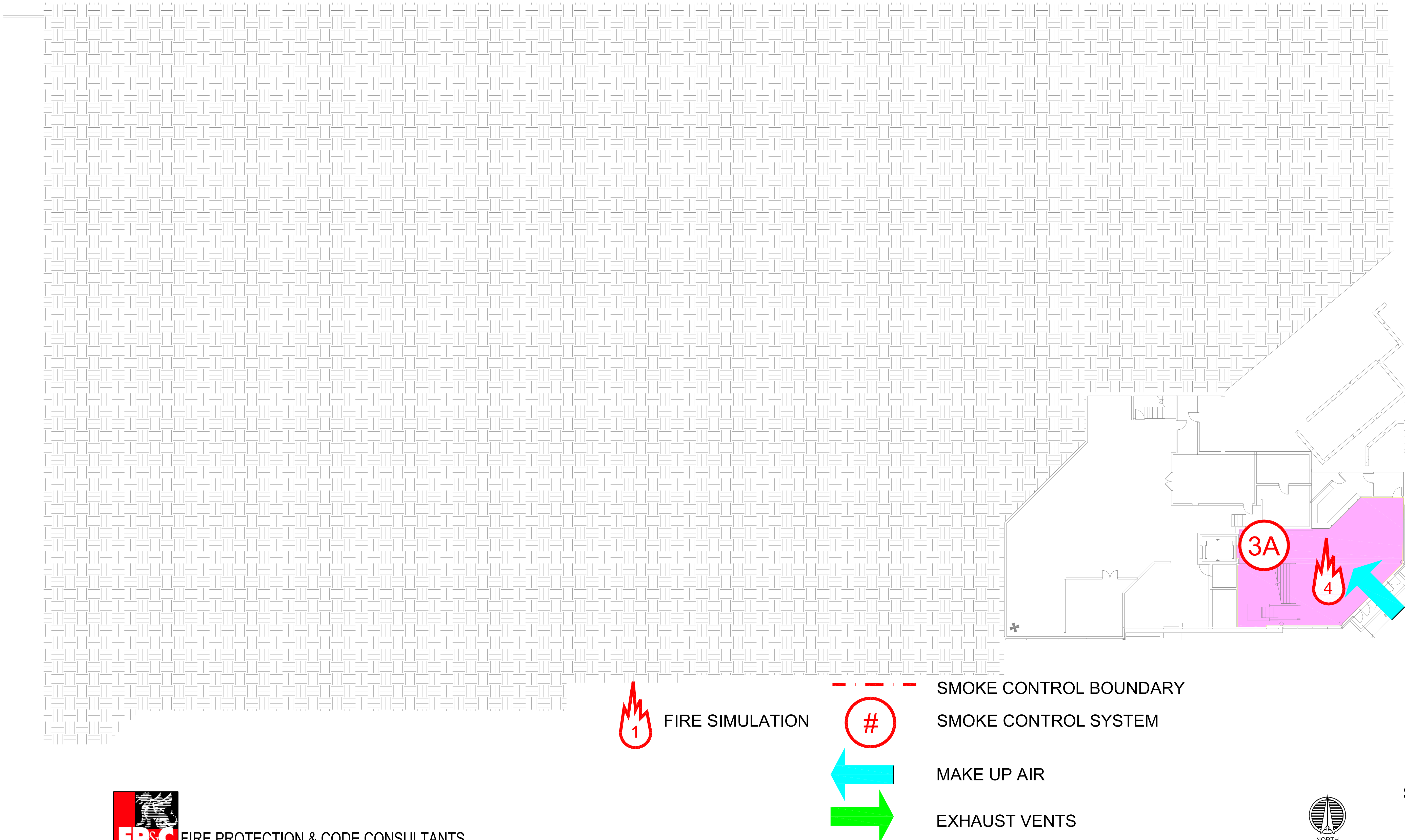
Table 3.5

Cumberland County Civic Center Smoke Control Zone FDS Model Assumptions

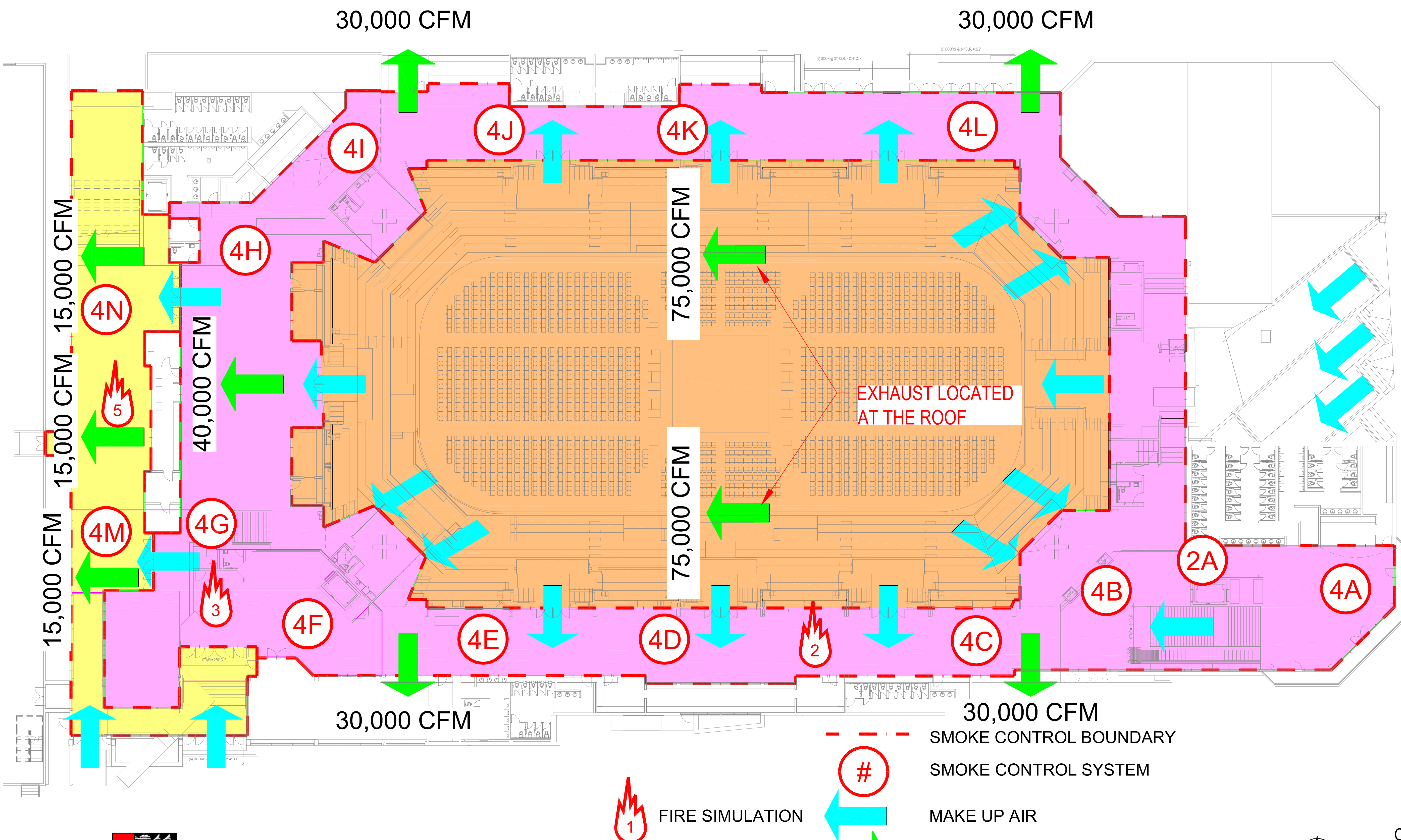
PARAMETER	PARAMETER VALUE	NOTES
Simulation Time	1,200 seconds (20 minutes)	Per 2009 MUBEC Section 909.4.6
Internal Temperature	70°F	Normal Temperature and Pressure
External Temperature Wind Speed/Direction	86.8°F Not modeled (See 3.1.3.3)	Section 3.1.3 of this report: *2009 ASHRAE Fundamentals*, Chapter 14 for Portland, ME
Ceiling Material	Steel / Gypsum Board	Existing Construction
Exterior Wall Material	Concrete, Normal Weight	Existing Construction
Interior Wall Material	Concrete, Normal Weight	Existing Construction
Floor Material	Concrete, Normal Weight	Existing Construction
Initial Fire Characteristics • Design Fire 1 • Design Fires 2-5	Max HRRPUA[1] / Growth Rate • 75 BTU/s-ft^2 / Fast, T-Squared • 75 BTU/s-ft^2 / Fast, T-Squared	Per Section 3.1.4.1 of this report: • The fire size was based on a 9,487 BTU/s [10 MW] vehicle fire • The fire size was based on a 4,743 BTU/s [5 MW] kiosk fire
Revised Fire Characteristics: • Design Fire 1 • Design Fire 2 • Design Fire 3 • Design Fire 4 • Design Fire 5	Max HRR / Growth Rate • 9,487 BTU/second / Fast Fire • 791 BTU/second / Fast Fire • 1,065 BTU/second / Fast Fire • 1,105 BTU/second / Fast Fire • 752 BTU/second / Fast Fire	Sprinkler activation time • 514.4 seconds • 133.3 seconds • 154.7 seconds • 157.6 seconds • 130.6 seconds
Smoke Detector Activation: • Design Fire 1 • Design Fire 4 • Design Fire 5	• Activation Time: 51.2 sec • Activation Time: 38.4 sec • Activation Time: 37.4 sec	• Beam Smoke Detectors • Area Smoke Detectors • Area Smoke Detectors
Sprinkler Flow Rate	0.1 Gallons/minute/square foot 225 square feet x 0.1 gpm/square foot= 22.5 gpm 22.5 gpm = 85.17 liters/minute	2007 Edition of NFPA 13, Figure 11.2.3.1.1 Area based on sprinkler spacing (15 feet x 15 feet)
Automatic Sprinkler	RTI: 50 ft ½•s ½ Activation Temperature: 165°F Spacing: 15 feet x 15 feet	NFPA Handbook, 19th Ed. p 10-253 2007 Edition of NFPA 13, Table 6.2.5.1 2007 Edition of NFPA 13, Table 8.8.2.1.2
Smoke Detector	Obscuration: 1.66%/foot Beam Detector Spacing: 30 feet Obscuration: 4 % Smoke Detector Spacing: 30 feet	Typical max obscuration (50%) 2007 Edition of NFPA 72, Section 11.5.1.3.1 UL 268, Gray Smoke 2007 Edition of NFPA 72, Section 11.5.1.3.1

[1] The heat release rate per unit area (HRRPUA) determines the floor area or footprint of the design fire. A HRRPUA of 75 BTU/s-ft^2 is used for all design fires. This value is more conservative than the 50 BTU/s-ft^2 recommended by Section A5.2.1 of the 2005Edition of NFPA 92B for mercantile spaces as it results in a larger fire for the same fire area.

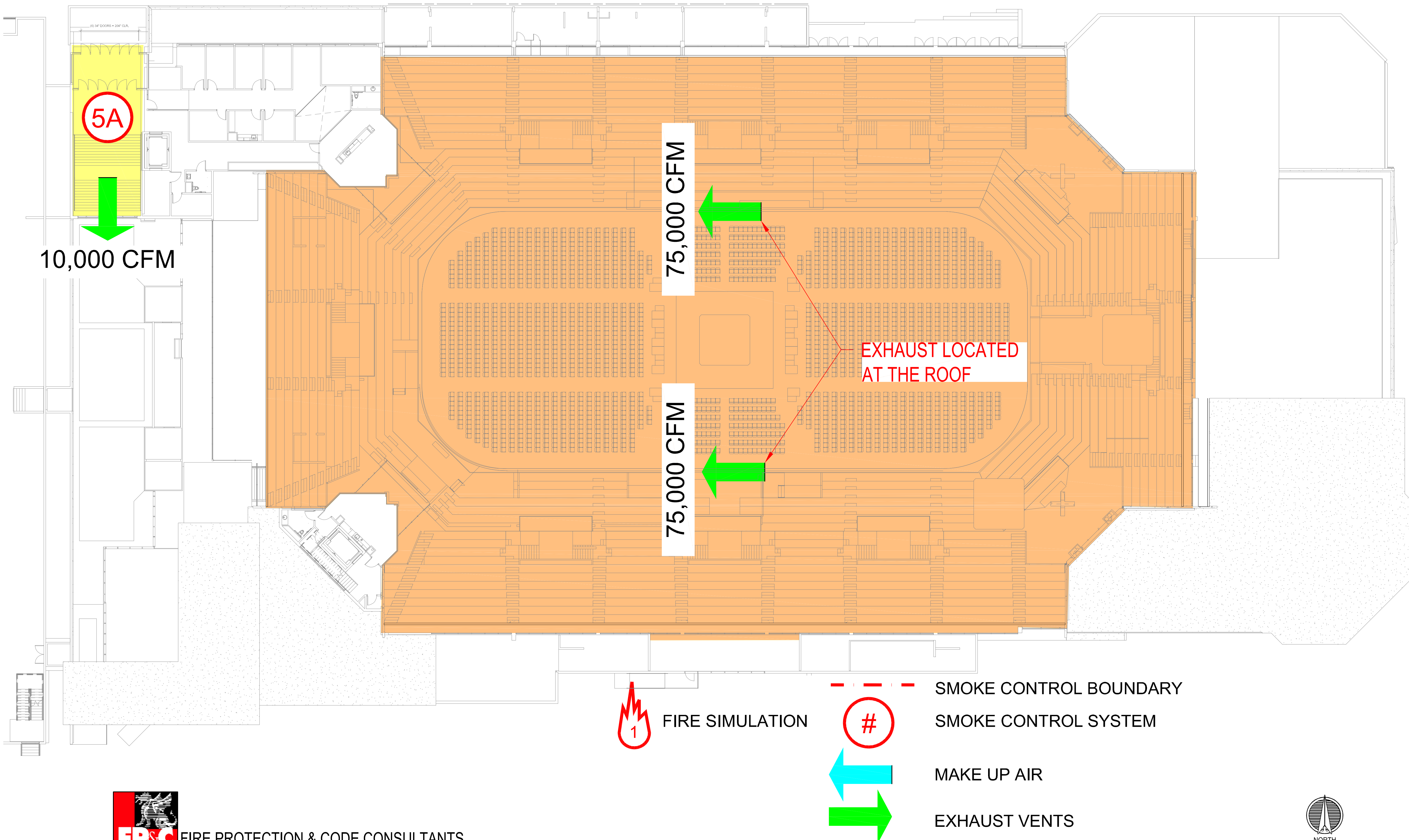
Illustrations SI.001 through SI.004 on the following pages detail the Design Fire Scenarios modeled in the Arena using the FDS.



SOUTH EAST LOBBY



CONCOURSE LEVEL

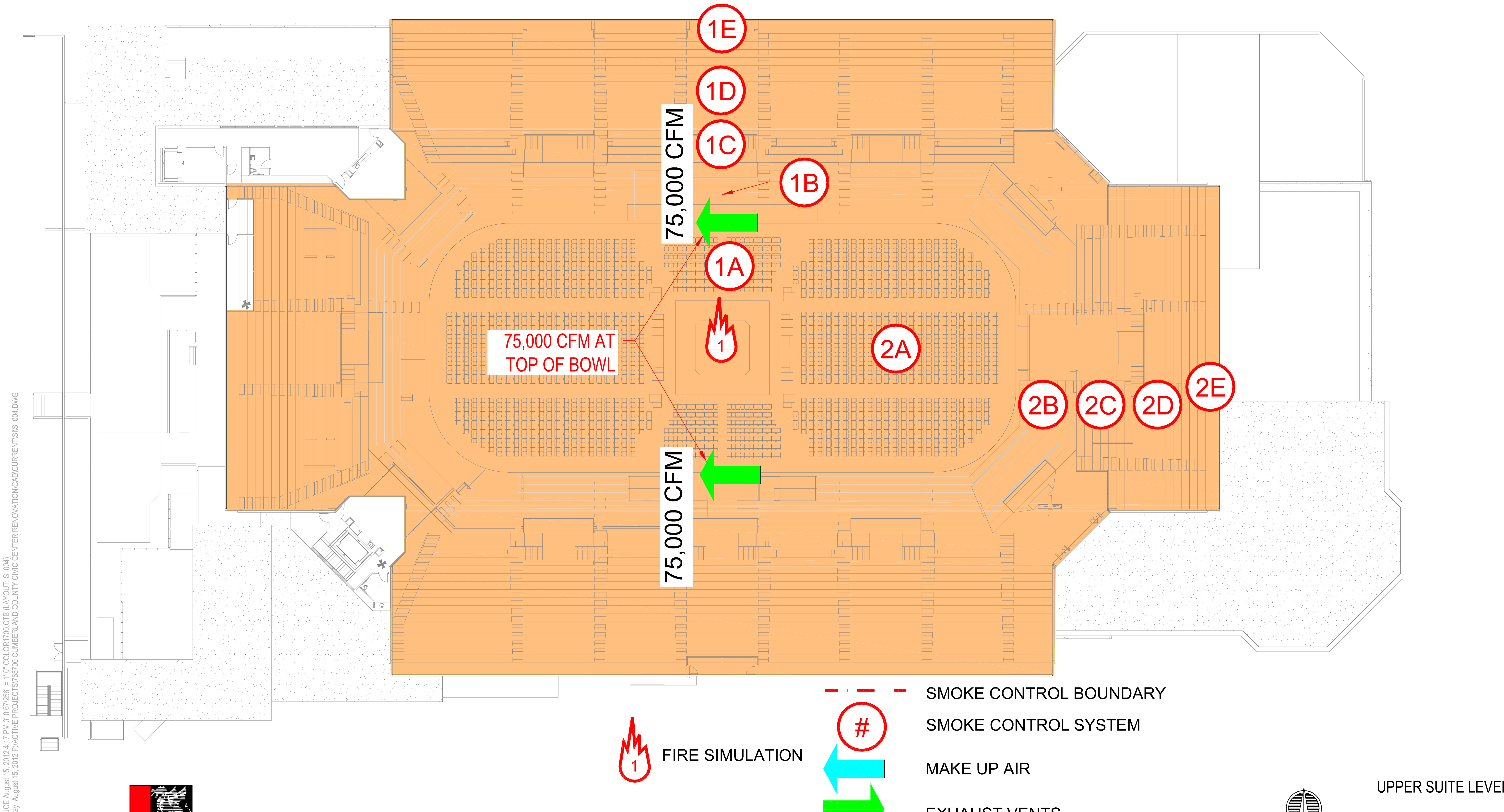


MID SUITES LEVEL

FIRE PROTECTION & CODE CONSULTANTS

SI.003

PLOT: RICHARD BRUCE August 15, 2012 4:17 PM 3'-0 67/256" = 1'-0" COLOR1700.CTB (LAYOUT: SI.003)
RICHARDB Wednesday, August 15, 2012 P:\ACTIVE PROJECTS\765700 CUMBERLAND COUNTY CIVIC CENTER RENOVATION\CAD\CURRENT\SI\SI.003.DWG


1E
1D
1C
1B
1A
75,000 CFM
75,000 CFM AT
TOP OF BOWL
1
2A
2B
2C
2D
2E
75,000 CFM
SMOKE CONTROL BOUNDARY
#
SMOKE CONTROL SYSTEM
1
FIRE SIMULATION
MAKE UP AIR
EXHAUST VENTS
NORTH
UPPER SUITE LEVEL

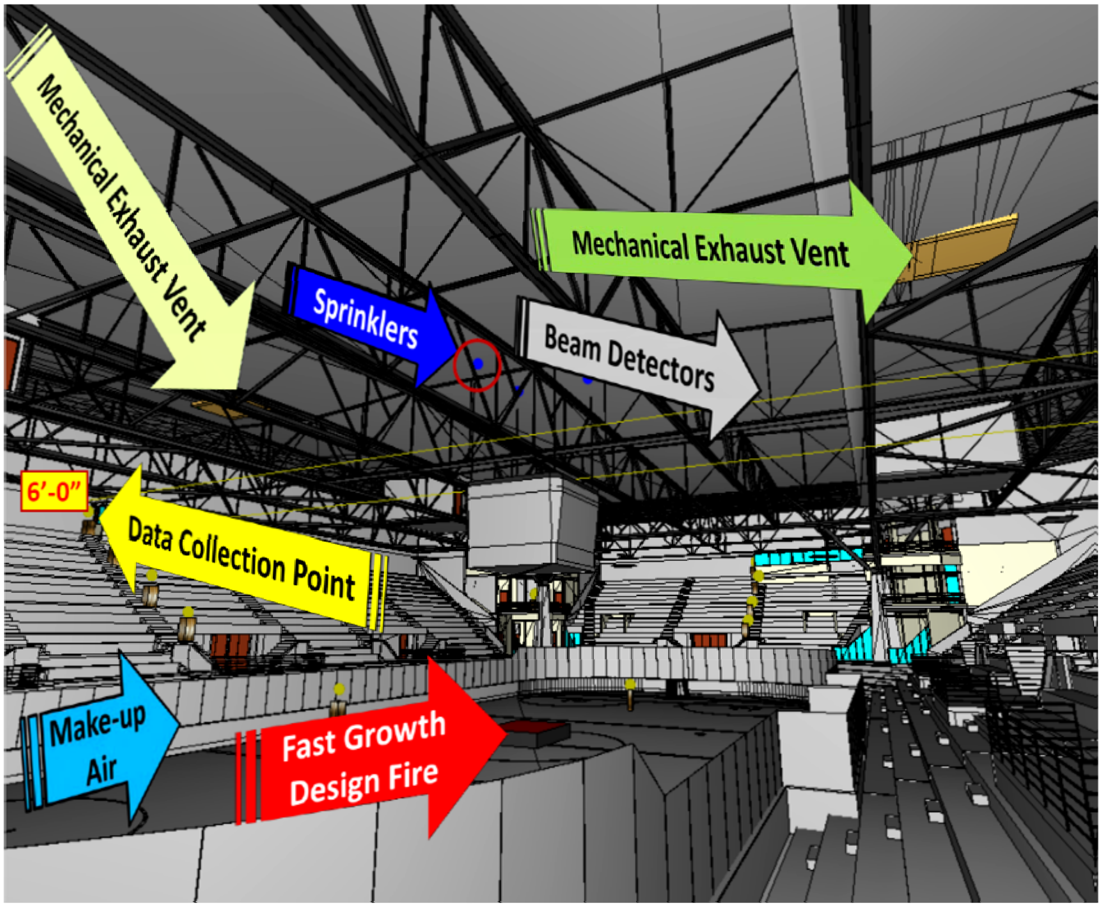
3.3 FDS MODEL RESULTS

The images and graphs on the following pages present the results of the smoke exhaust system for the following fire scenarios:

3.3.1 Design Fire Scenario 1

Design Fire 1 consists of a fast growth T-squared fire located on the Event Level floor in the Seating Bowl. The expected fuel load in this space could consist of a performance stage or vehicles which typically burn slower than the fast growth T-squared rate based on test data. This fire was not assumed to be sprinkler limited. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. The axisymmetric smoke plume provides the most concentrated smoke and was therefore the worst case scenario for sizing the exhaust fans in the Seating Bowl of the Arena. This scenario also modeled the worst-case external conditions of reverse stack effect conditions (summer high temperature) per Section 3.1.4.1 of this Report.

Figure 3.13
Illustration Depicting Lower Level of the Cumberland County Civic Center for Design Fire 1



Note the following from the image above:

1. The location of the design fire.

2. The mechanical exhaust vent locations (75,000 cfm each vent with two vents located in the roof). Temperature data was recorded at these vents.

3 The location of the tenability data collection points. These data collectors took measurements at six feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

4. The locations of the beam smoke detectors and automatic sprinklers are depicted. The depicted locations of these devices were meant to be representative locations used for fire and smoke modeling purposes and do not represent required locations.

5. The location of the make-up air provided by the east Event Level vomitory that connects to the loading docks on the east end of the building.

Figure 3.14
Design Fire 1
Heat Release Rate

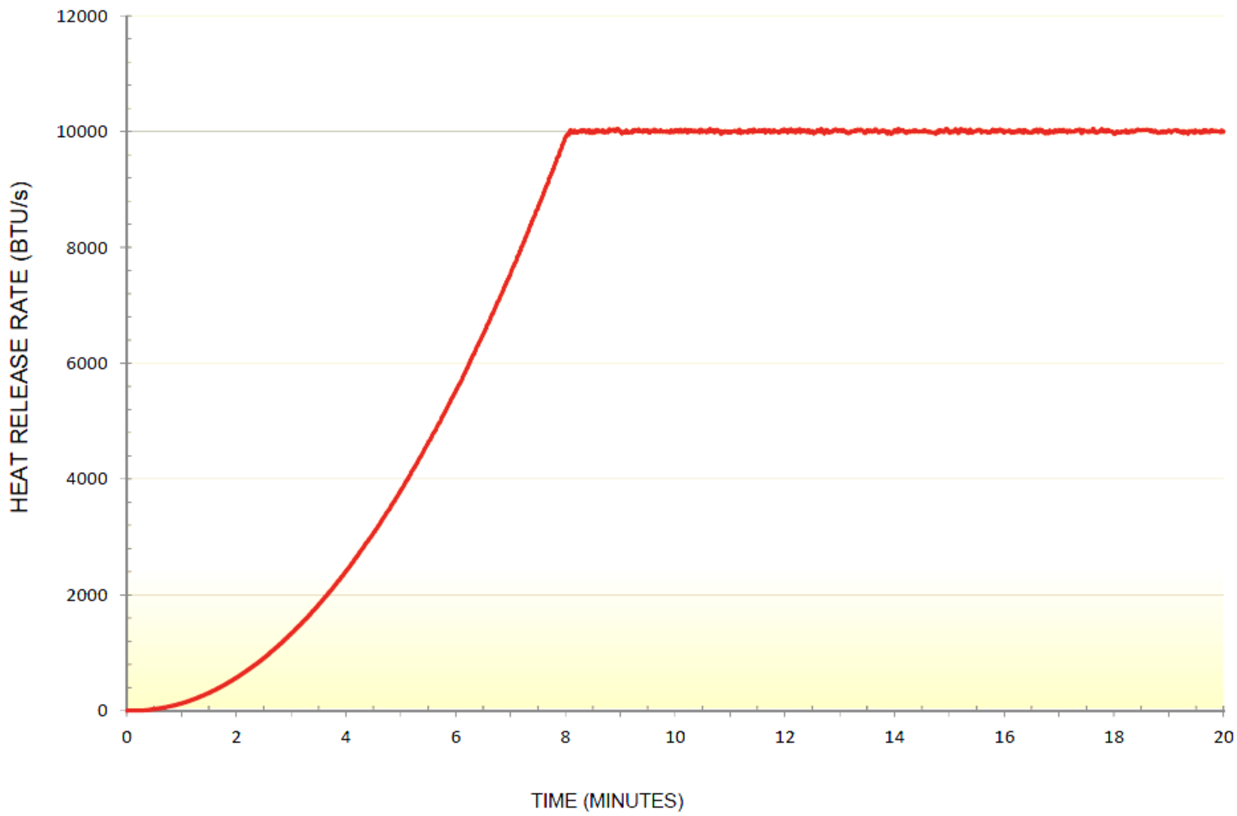
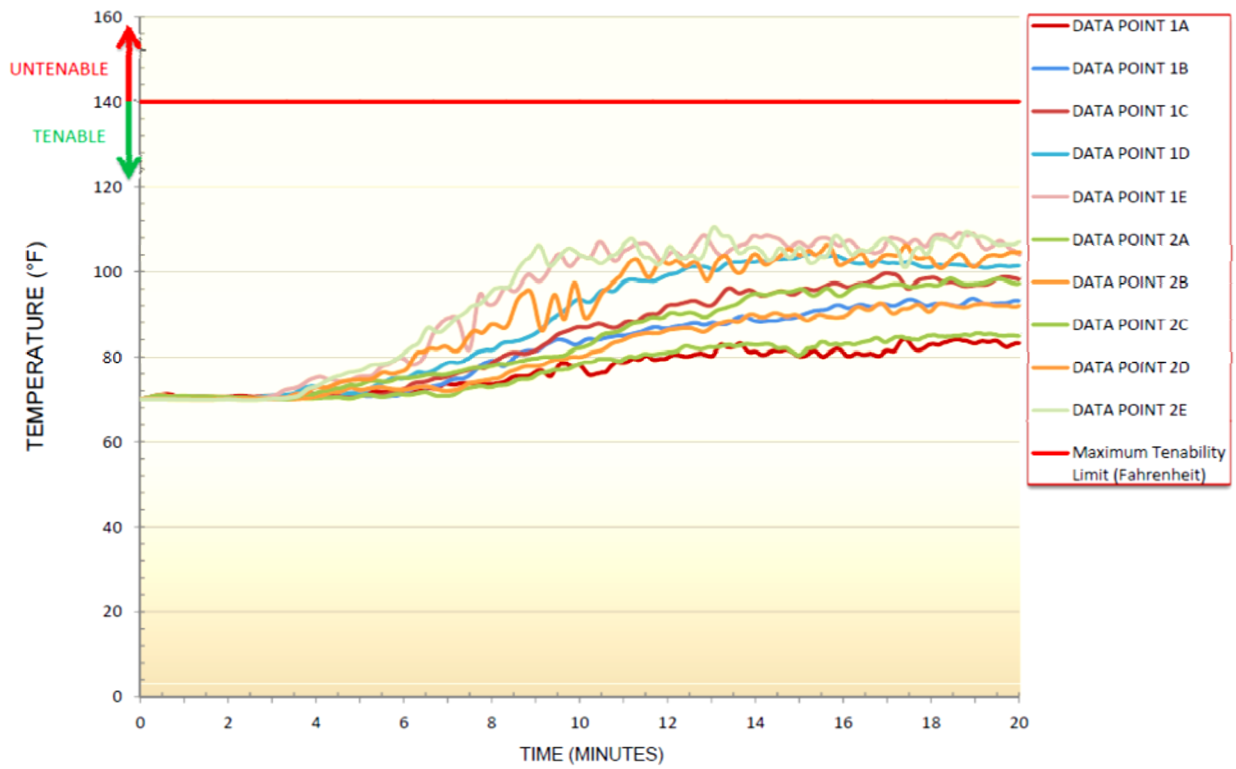
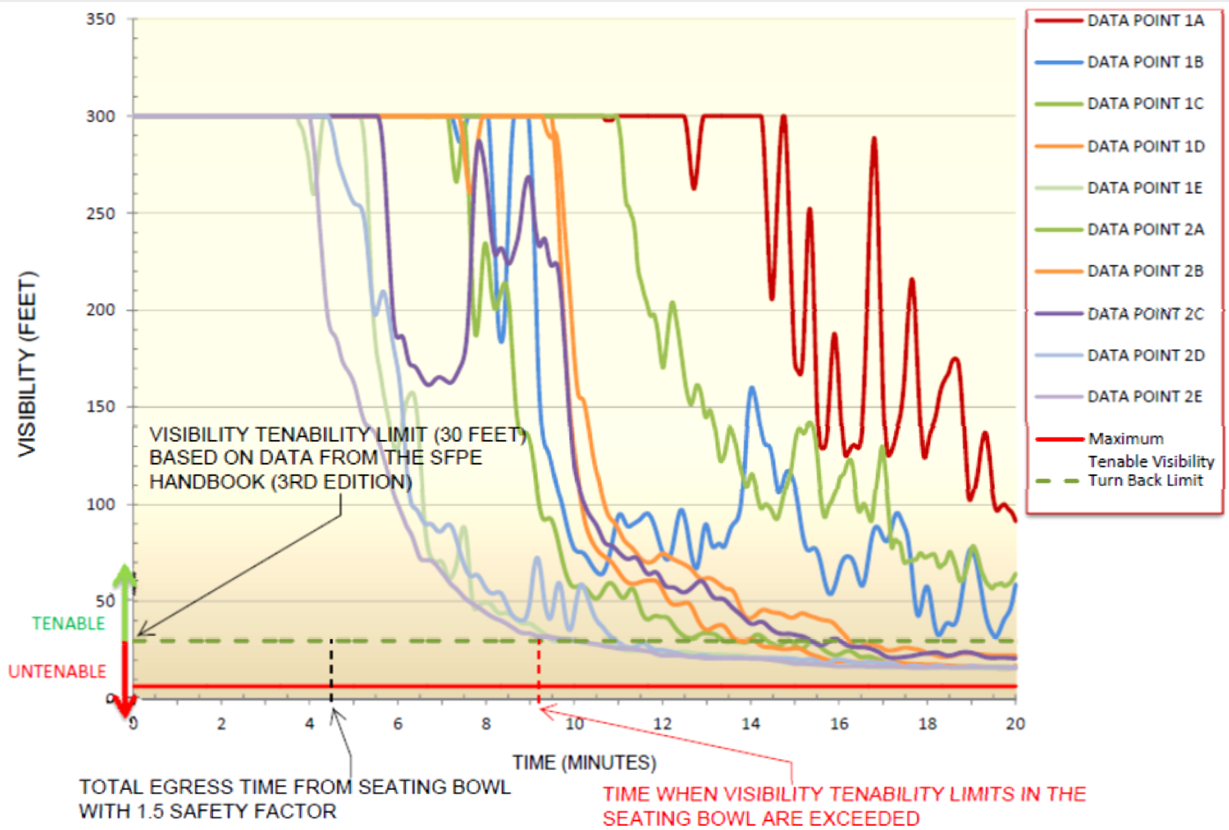


Figure 3.15
Design Fire 1
Temperature Measurements at Tenability Data Collection Points
(Six Feet Elevation)



Temperature levels are maintained within tenable limits during the simulation.

Figure 3.16
Design Fire 1
Visibility Measurements at Tenability Data Collection Points 1E and 2E
(Six Feet Elevation)



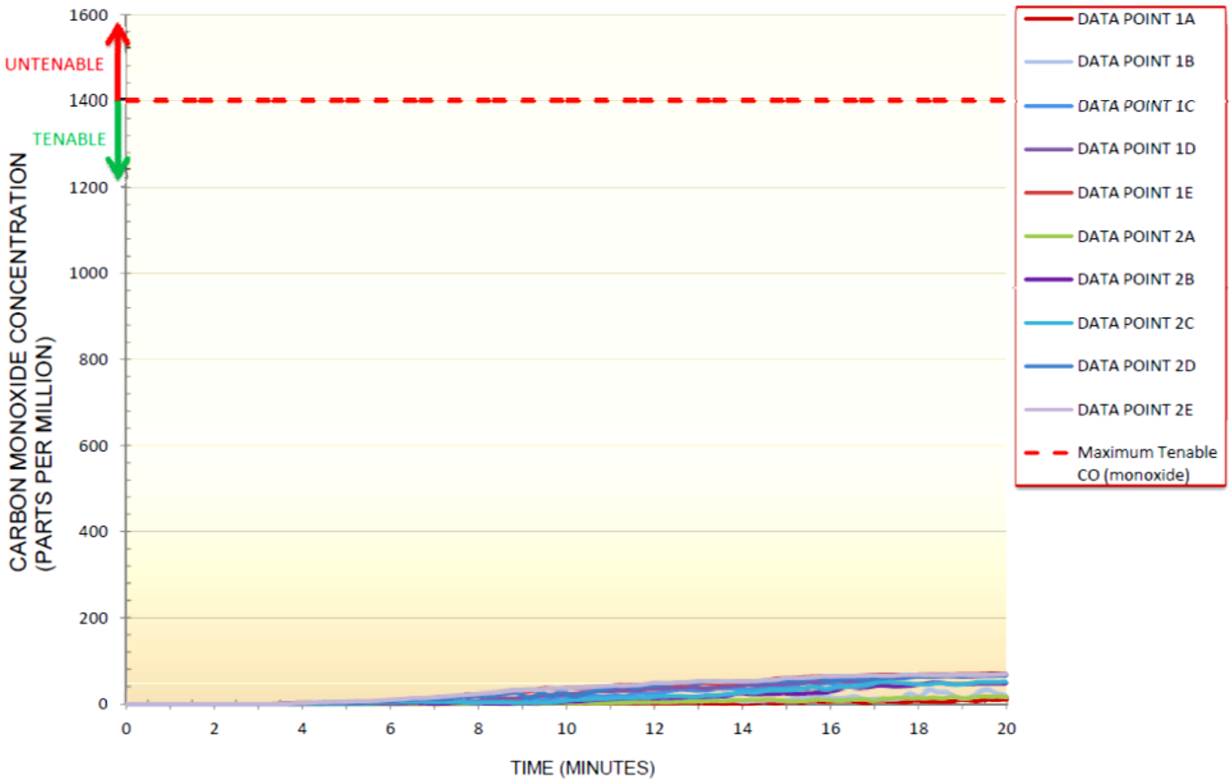
Visibility levels are maintained within tenable limits during the simulation for the duration of the required egress time (with a 1.5 safety factor). Since the total egress time multiplied by the 1.5 safety factor (4.5 minutes) is less than the time it takes for the visibility at data points 1E and 2E (six feet above the highest seats in the Seating Bowl) to drop below 30 feet (9.1 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six feet above the highest seats in the Seating Bowl in accordance with Section 909.8 of the 2009 MUBEC. Please see **Appendix B** for a further explanation of these calculations.

Figure 3.17

Design Fire 1

Carbon Monoxide Concentration Measurements at Tenability Data Collection Points

(Six Feet Elevation)



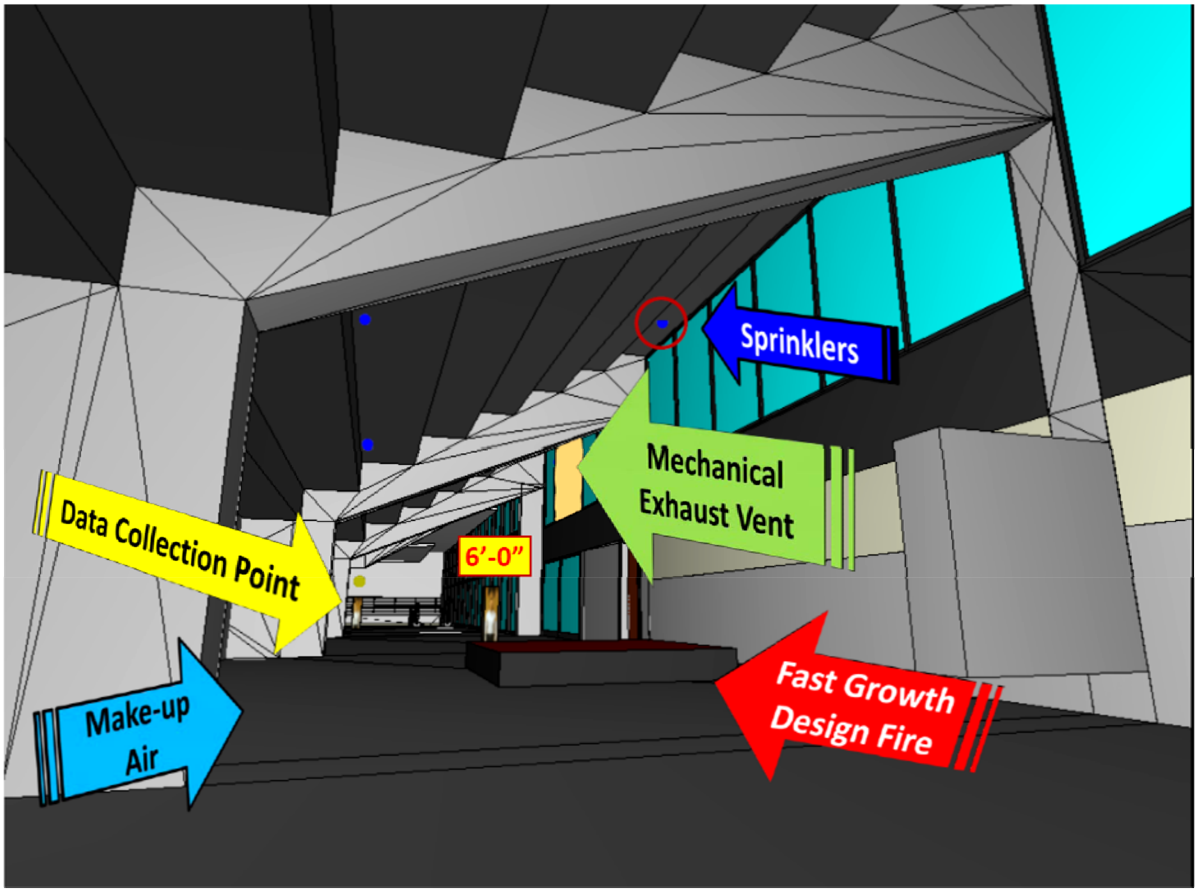
Carbon monoxide levels are maintained within tenable limits floors during the simulation.

3.3.2 Design Fire Scenario 2

Design Fire 2 consists of a fast growth T-squared fire located on the floor of the Main Concourse near the southeast end. The expected fuel load in this space could consist of kiosks filled with merchandise which typically burn slower than the fast growth T-squared rate based on test data. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. The axisymmetric smoke plume provides the most concentrated smoke and was therefore the worst case scenario for sizing the exhaust fans on the Main Concourse of the Arena. The smoke control system in the Main Concourse was designed to primarily activate by automatic sprinkler activation. This scenario also modeled the worst-case external conditions of reverse stack effect conditions (summer high temperature) per Section 3.1.4.1 of this Report.

Figure 3.18

Illustration Depicting Lower Level of the Cumberland County Civic Center for Design Fire 2



Note the following from the image above:

1. The location of the design fire.

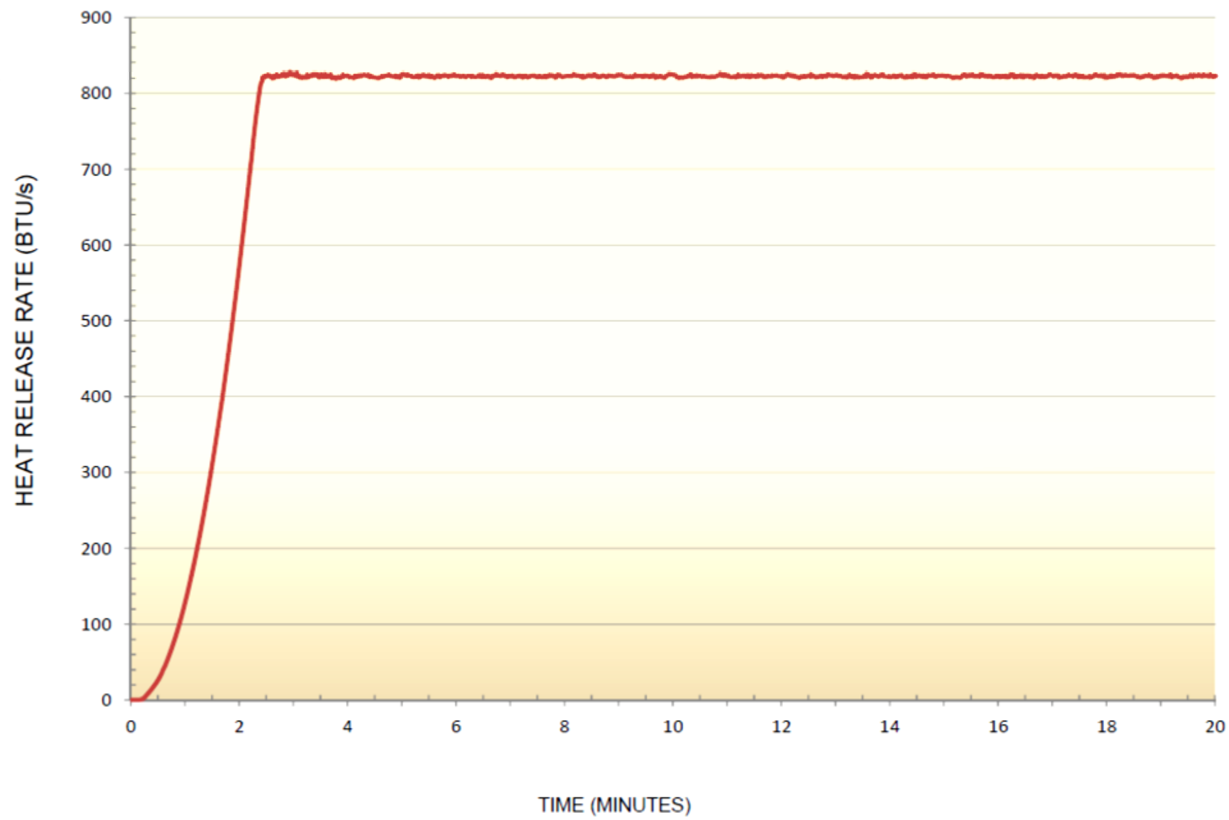
2. The mechanical exhaust vent locations (30,000 cfm each vent with two vents located in the wall of the Main Concourse). Temperature data was recorded at these vents.

3 The location of the tenability data collection points. These data collectors took measurements at six feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

4. The locations of the automatic sprinklers are depicted. The depicted locations of these devices were meant to be representative locations used for fire and smoke modeling purposes and do not represent required locations.

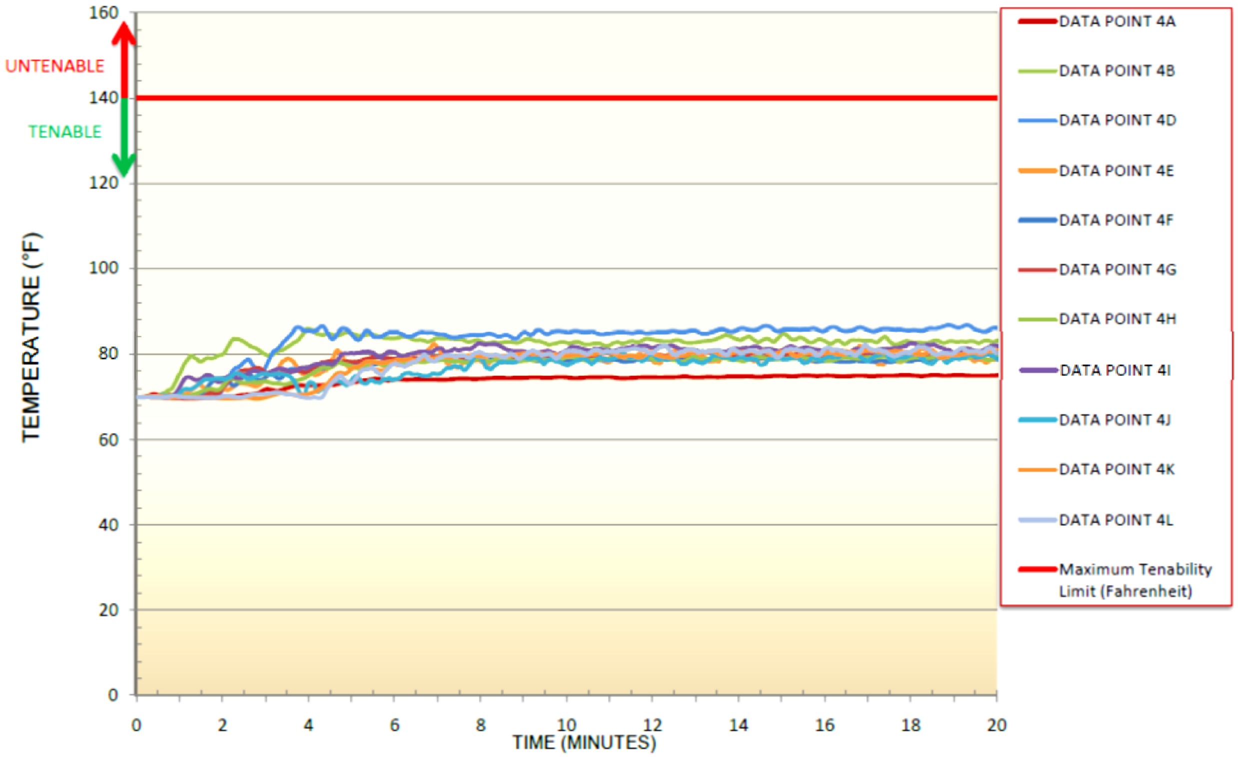
5. The location of the make-up air provided by the vomitories to the Seating Bowl (supplied from loading docks on the east end of the building).

Figure 3.19
Design Fire 2
Heat Release Rate



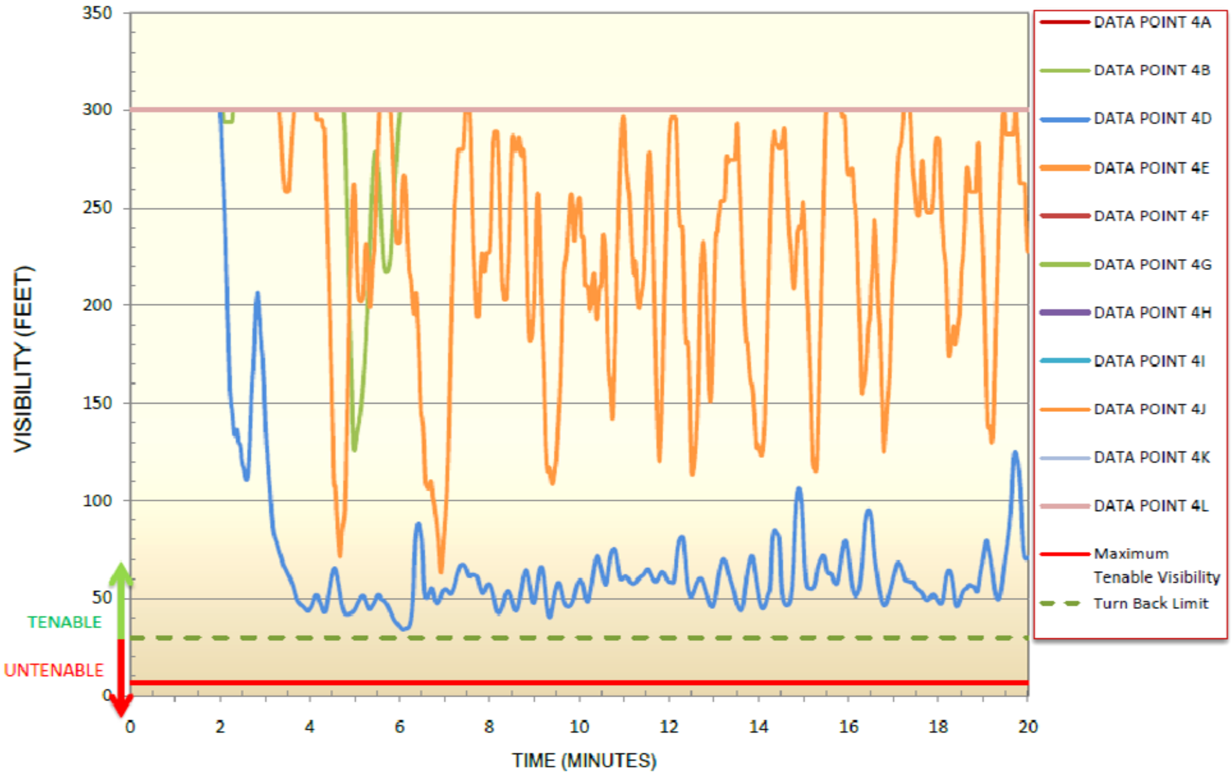
Note that the sprinkler activation temperature (165°F) is reached at approximately two minutes (133 seconds) and corresponds to the point at which the design fire is controlled at a steady state heat release rate (HRR). This activation time of 133 seconds was used with the fast growth T-squared (time in seconds) fire growth model.

Figure 3.20
Design Fire 2
Temperature Measurements at Tenability Data Collection Points
(Six (6) Feet Elevation)



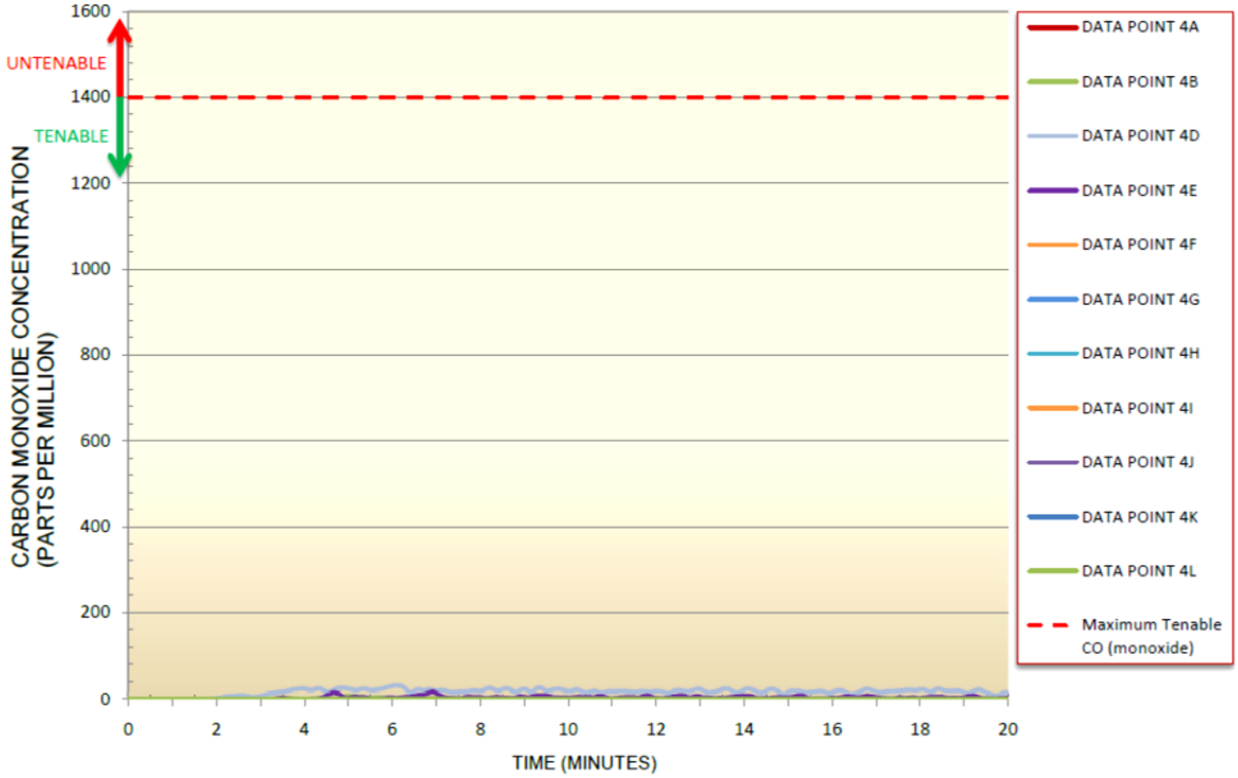
Temperature levels are maintained within tenable limits during the simulation.

Figure 3.21
Design Fire 2
Visibility Measurements at Tenability Data Collection Points
(Six Feet Elevation)



Visibility levels are maintained within tenable limits during the simulation.

Figure 3.22
Design Fire 2
Carbon Monoxide Concentration Measurements at Tenability Data Collection Points
(Six Feet Elevation)



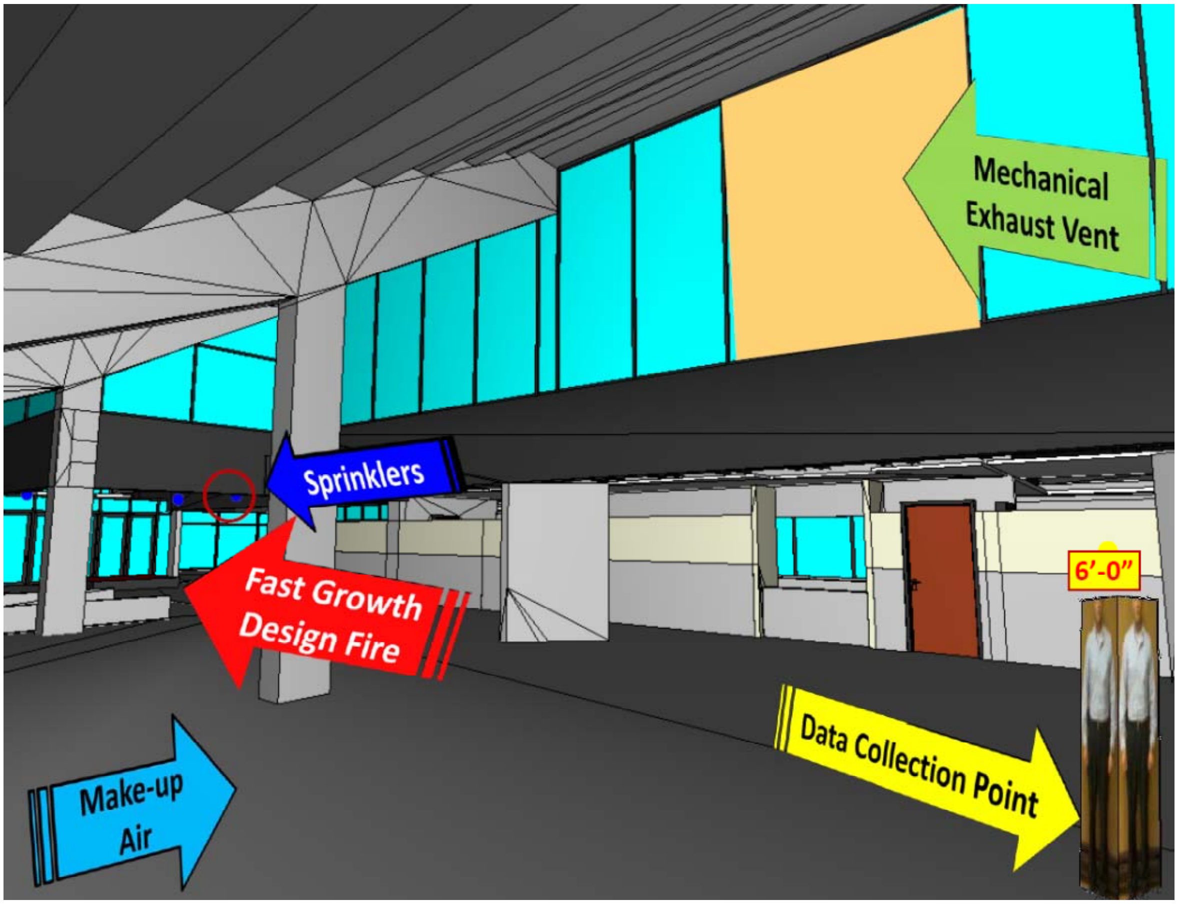
Carbon monoxide levels are maintained within tenable limits during the simulation.

3.3.3 Design Fire Scenario 3

Design Fire 3 consists of a fast growth T-squared fire located on the floor of the Main Concourse on the west end. The expected fuel load in this space could consist of kiosks filled with merchandise which typically burn slower than the fast growth T-squared rate based on test data. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. The axisymmetric smoke plume provides the most concentrated smoke and was therefore the worst case scenario for sizing the exhaust fans on the Main Concourse of the Arena. The smoke control system in the Main Concourse was designed to primarily activate by automatic sprinkler activation. This scenario also modeled the worst-case external conditions of reverse stack effect conditions (summer high temperature) per Section 3.1.4.1 of this report.

Figure 3.23

Illustration Depicting Lower Level of the Cumberland County Civic Center for Design Fire 3



Note the following from the image above:

1. The location of the design fire.

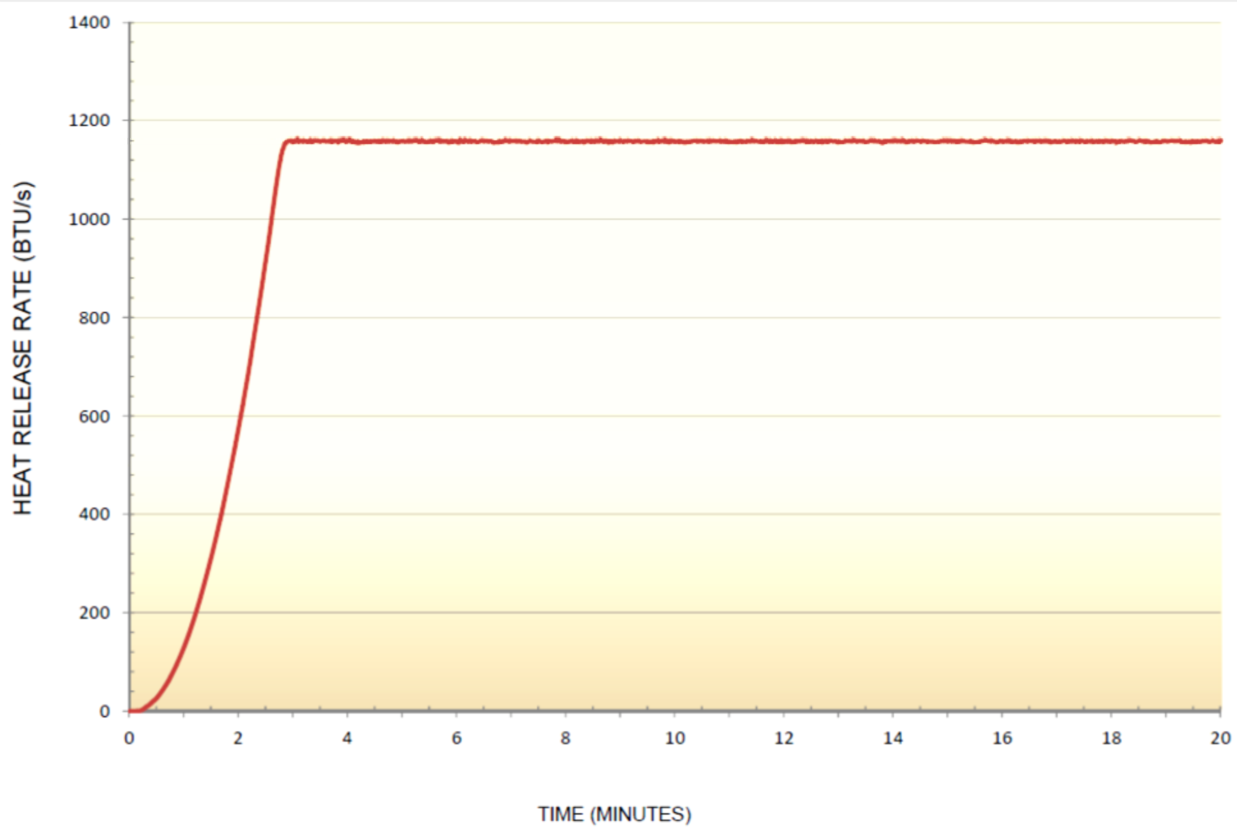
2. The mechanical exhaust vent locations (30,000 cfm each vent with two vents located in the wall of the Main Concourse). Temperature data was recorded at these vents.

3 The location of the tenability data collection points. These data collectors took measurements at six feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

4. The locations of the automatic sprinklers are depicted. The depicted locations of these devices were meant to be representative locations used for fire and smoke modeling purposes and do not represent required locations.

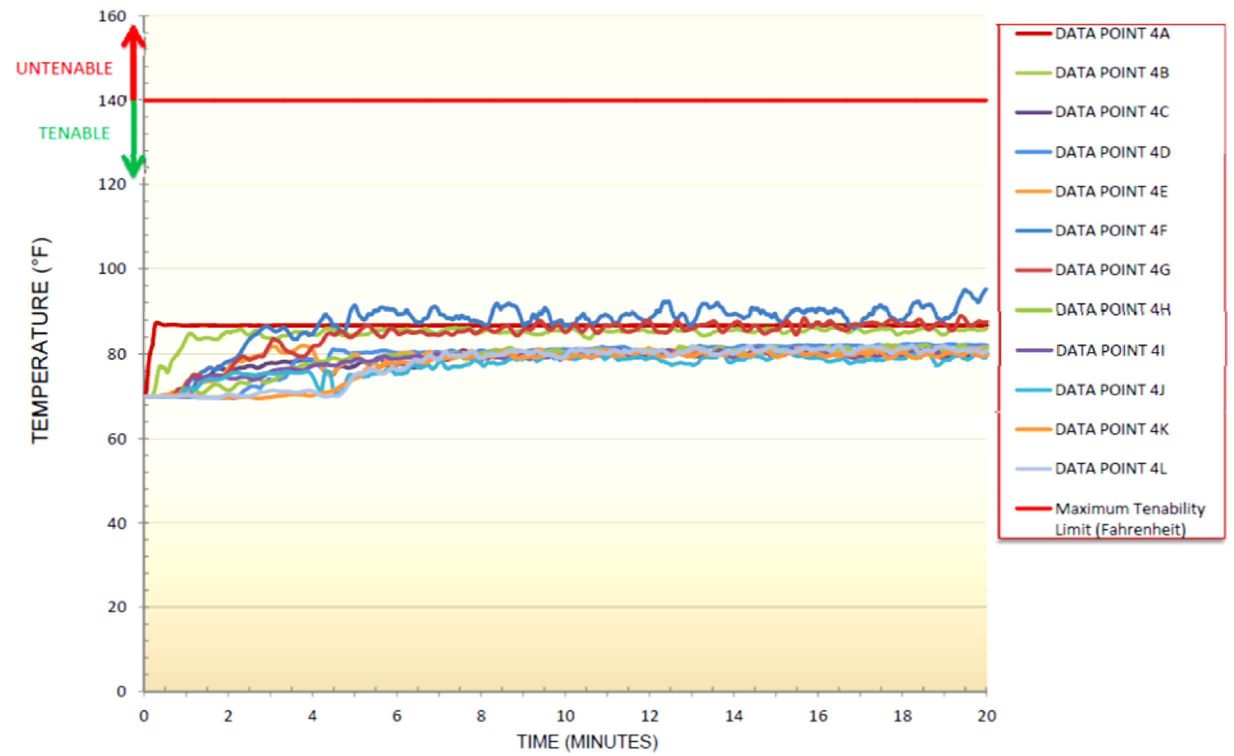
5. The location of the make-up air provided by the vomitories to the Seating Bowl (supplied from loading docks on the east end of the building).

Figure 3.24
Design Fire 3
Heat Release Rate



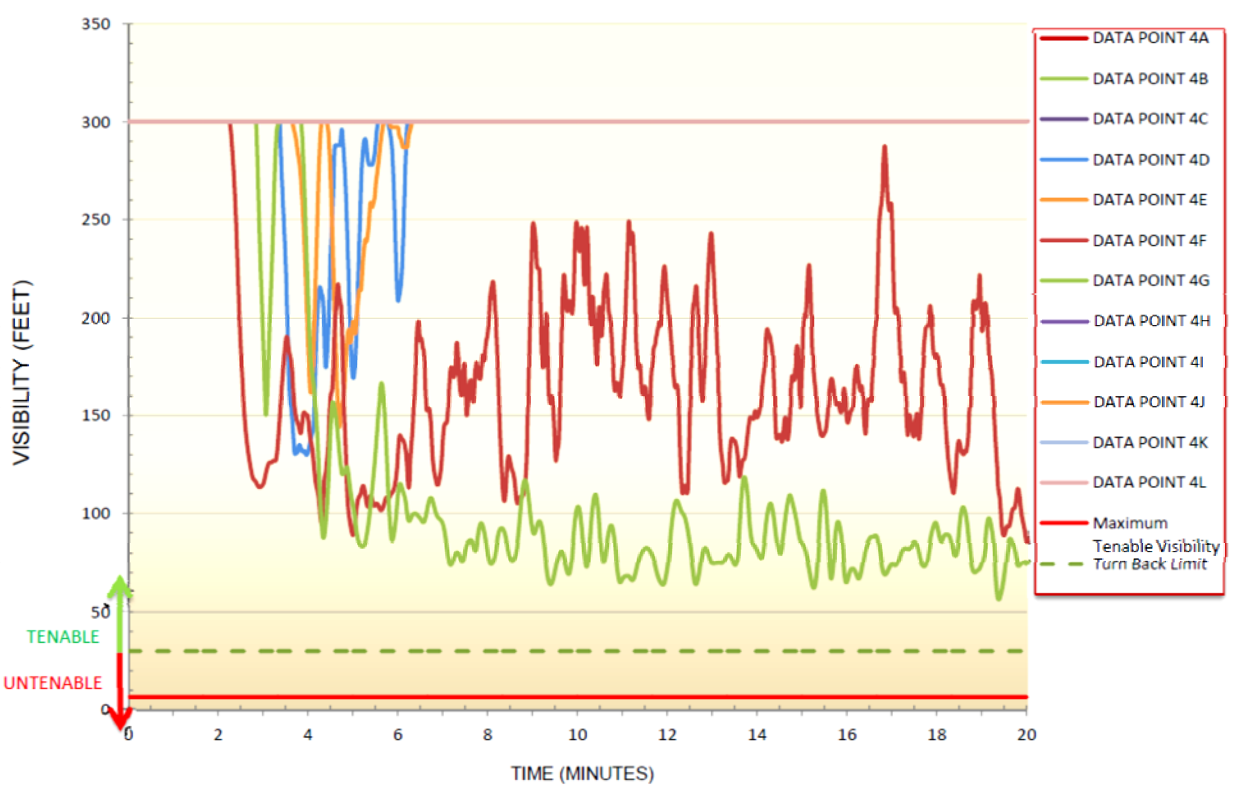
Note that the sprinkler activation temperature (165°F) is reached at approximately two and a half minutes (155 seconds) and corresponds to the point at which the design fire is controlled at a steady state heat release rate (HRR). This activation time of 155 seconds was used with the fast growth T-squared (time in seconds) fire growth model.

Figure 3.25
Design Fire 3
Temperature Measurements at Tenability Data Collection Points
(Six Feet Elevation)



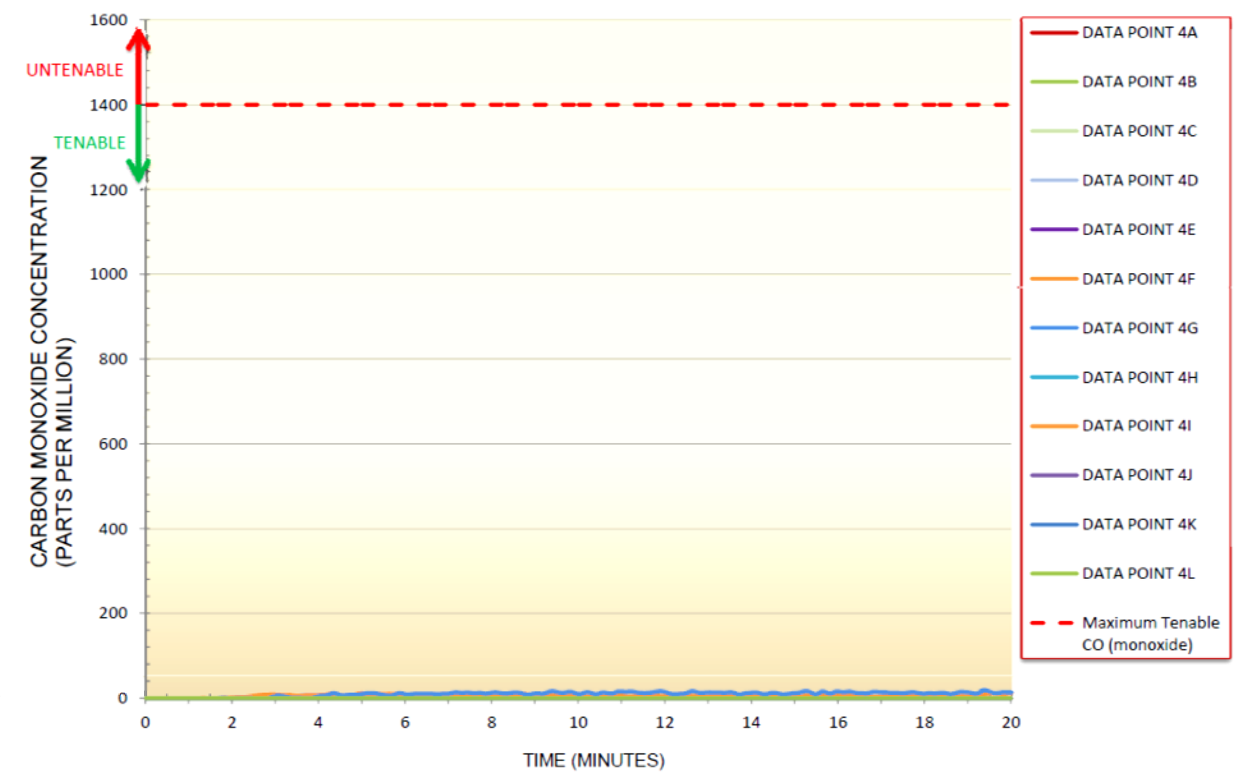
Temperature levels are maintained within tenable limits during the simulation.

Figure 3.26
Design Fire 3
Visibility Measurements at Tenability Data Collection Points
(Six Feet Elevation)



Visibility levels are maintained within tenable limits during the simulation.

Figure 3.27
Design Fire 3
Carbon Monoxide Concentration Measurements at Tenability Data Collection Points
(Six Feet Elevation)



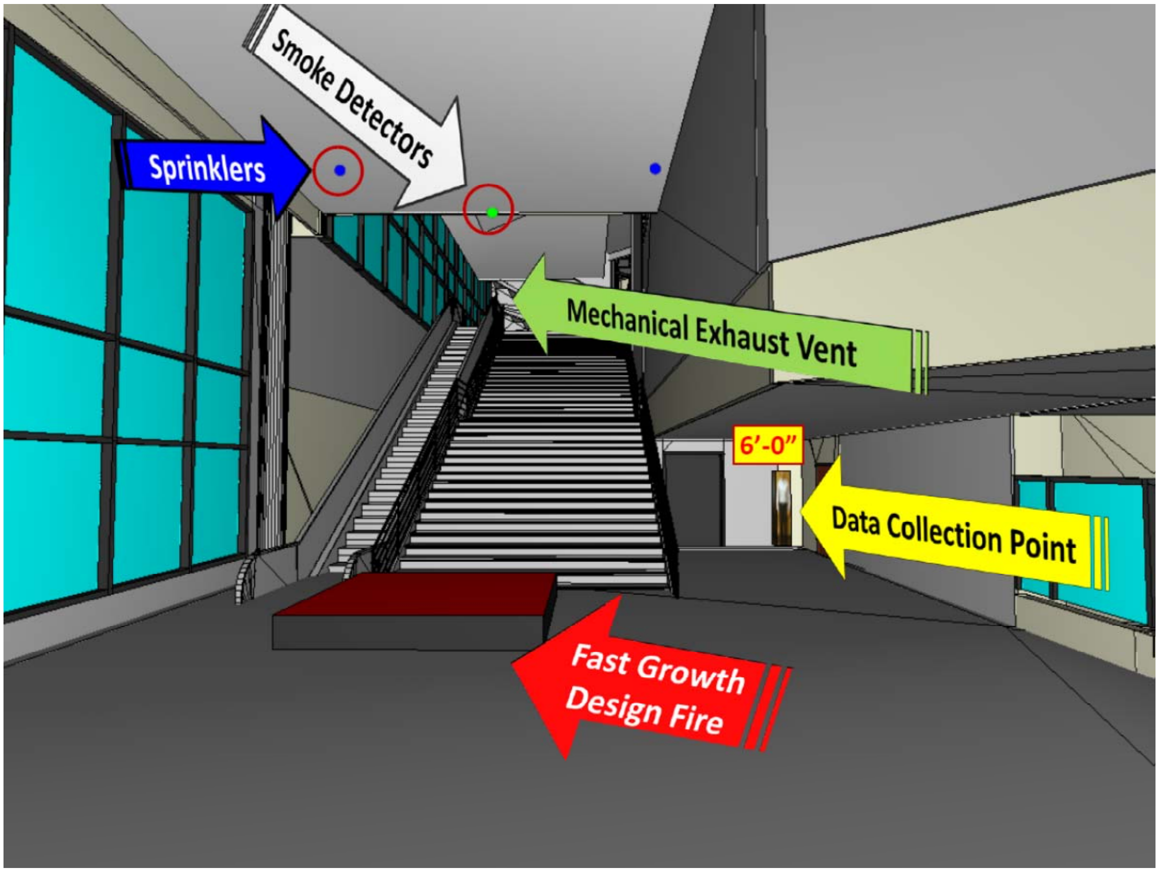
Carbon monoxide levels are maintained within tenable limits during the simulation.

3.3.4 Design Fire Scenario 4

Design Fire 4 consists of a fast growth T-squared fire located on the Mechanical Level in the communicating space that connects to the Main Concourse by an open stair. The expected fuel load in this space could consist of kiosks filled with merchandise which typically burn slower than the fast growth T-squared rate based on test data. The fire was located under the ceiling on the east side of the space away from the stair in order to create a balcony spill smoke plume. The greater amount of smoke generation possible by a balcony spill plume results because the maximum amount of air can be entrained into the smoke plume as it spills from under the ceiling of the Mechanical Level into the Main Concourse. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This scenario modeled the balcony spill smoke plume which provides the greatest smoke generation rate. The smoke generated by a balcony spill plume tends to be diluted compared to that of an axisymmetric plume (Design Fires 2-3) and thus this simulation was performed as a check on the ability of the smoke control system on the Main Concourse to maintain tenable conditions in this type of design fire scenario. The smoke control system for a fire on the Mechanical Level was designed to primarily activate by smoke detectors for faster response time that allows for a more efficient exhaust system. This simulation proves that the exhaust fans sized for on the axisymmetric plume from Design Fires 2-3 (Main Concourse) should be sufficient to handle a balcony spill plume. This scenario also modeled the worst-case external conditions of reverse stack effect conditions (summer high temperature) per Section 3.1.4.1 of this report.

Figure 3.28

Illustration Depicting Lower Level of the Cumberland County Civic Center for Design Fire 4



Note the following from the image above:

1. The location of the design fire.

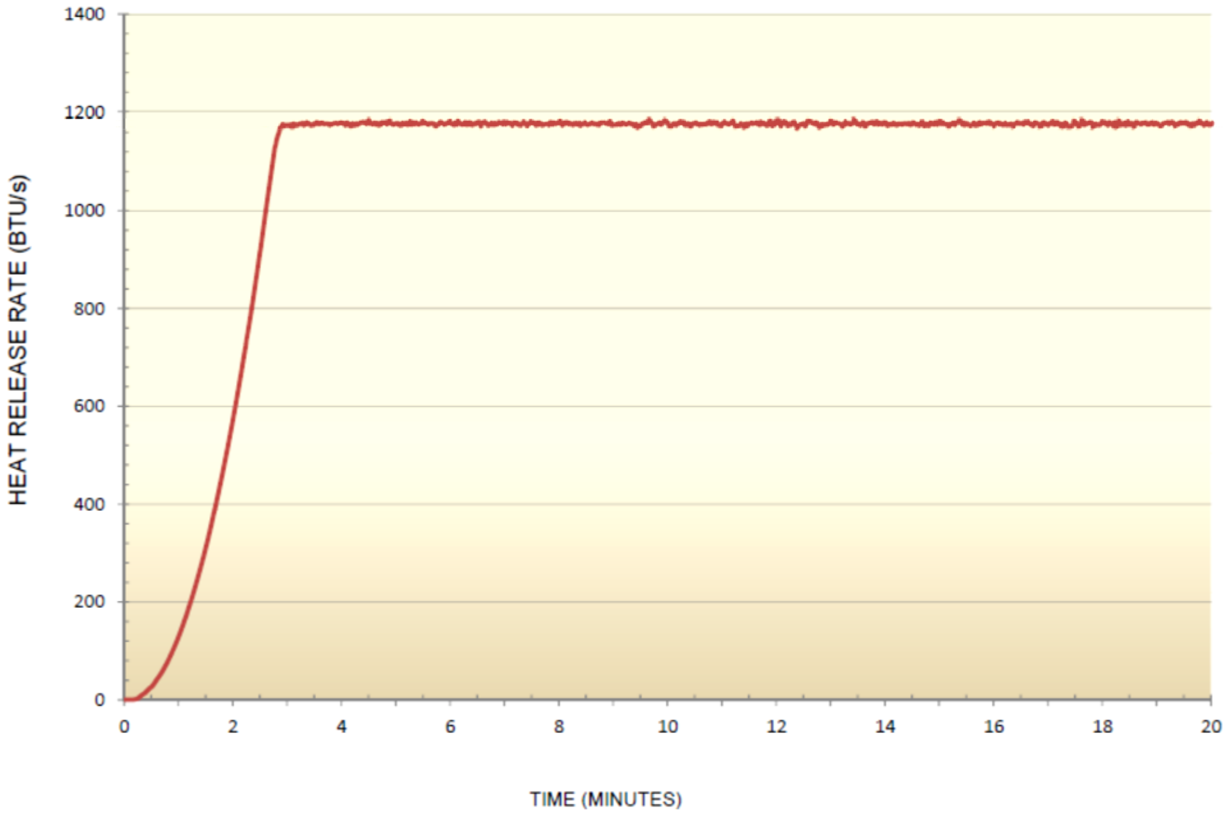
2. The mechanical exhaust vent locations. These are the same vents used for Design Fire Scenario 2 and Design Fire Scenario 3 (30,000 cfm each vent with two vents located in the wall of the Main Concourse). Temperature data was recorded at these vents.

3 The location of the tenability data collection points. These data collectors took measurements at six (6) feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

4. The locations of the area smoke detectors and automatic sprinklers are depicted. The depicted locations of these devices were meant to be representative locations used for fire and smoke modeling purposes and do not represent required locations.

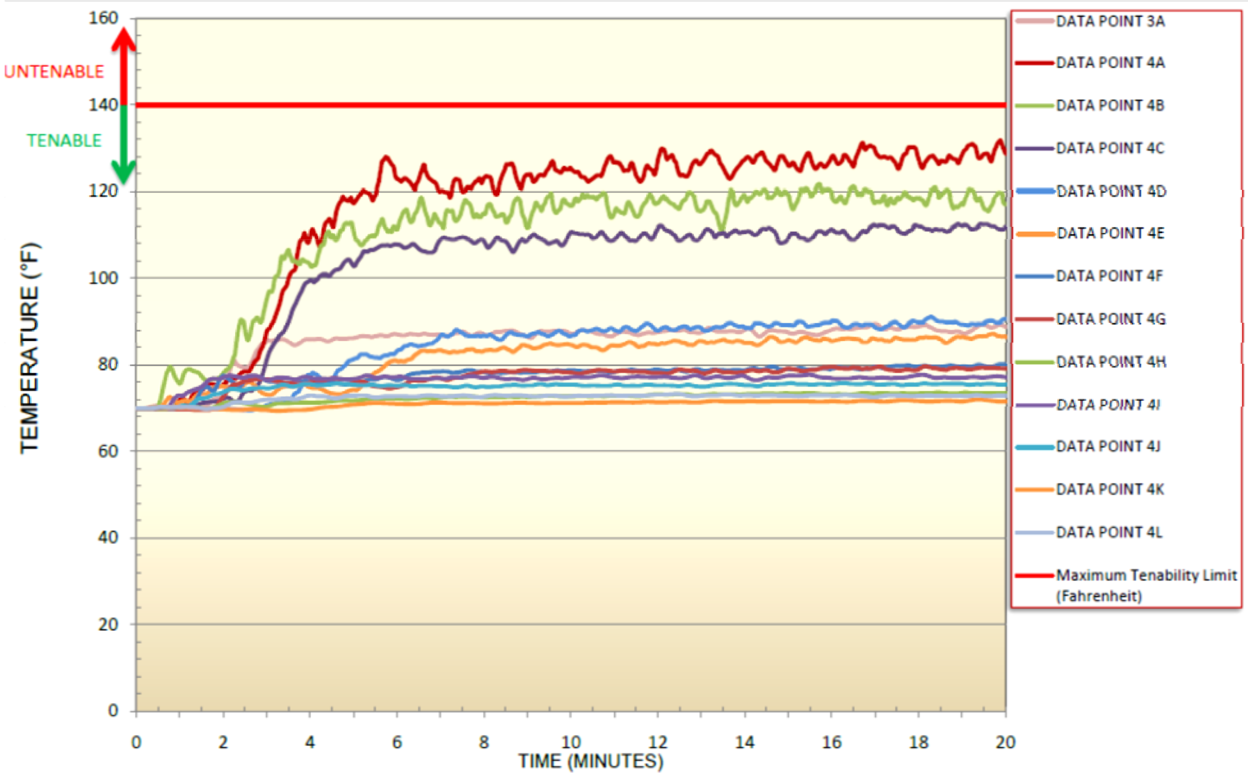
5. The location of the make-up air is not shown. Make-up air is provided by the vomitories to the Seating Bowl (supplied from loading docks on the east end of the building).

Figure 3.29
Design Fire 4
Heat Release Rate



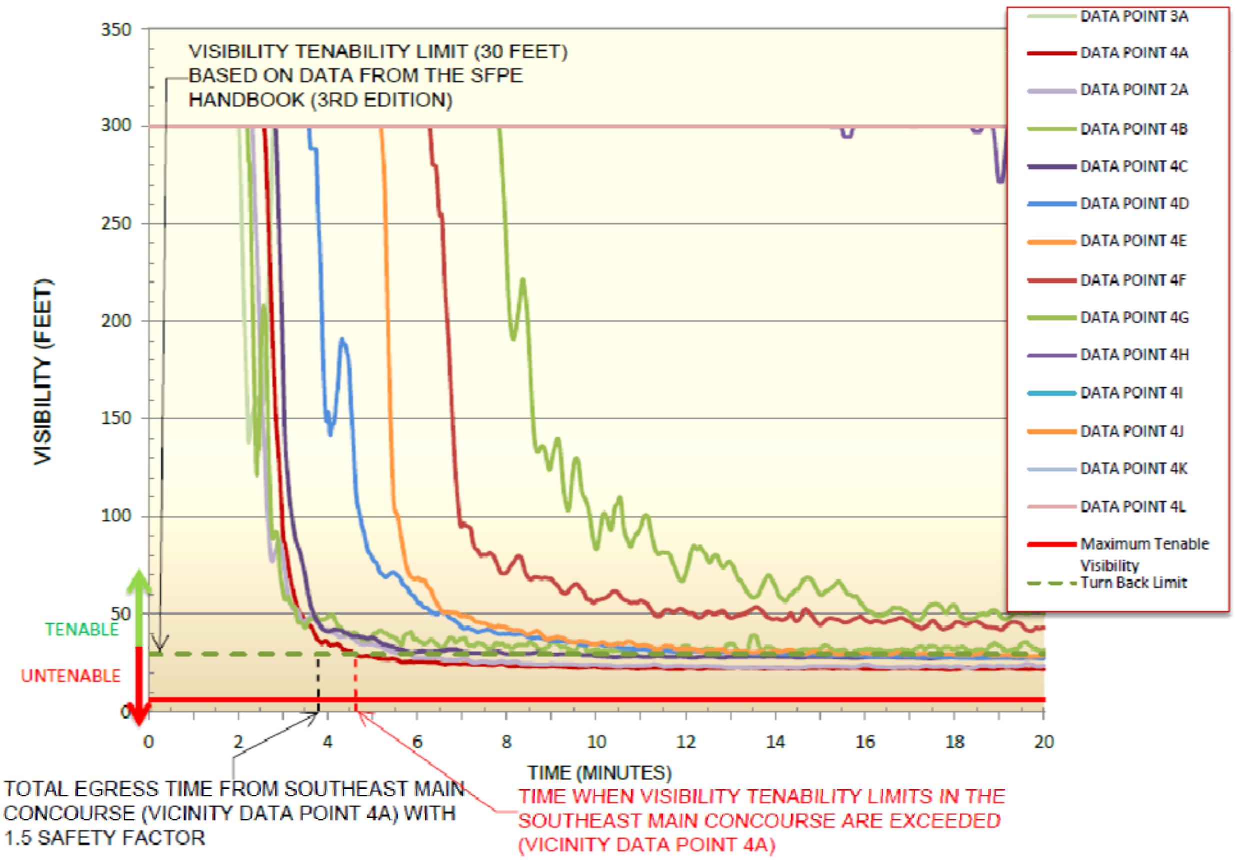
Note that the sprinkler activation temperature (165°F) is reached at approximately two and a half minutes (158 seconds) and corresponds to the point at which the design fire is controlled at a steady state heat release rate (HRR). This activation time of 158 seconds was used with the fast growth T-squared (time in seconds) fire growth model.

Figure 3.30
Design Fire 4
Temperature Measurements at Tenability Data Collection Points
(Six Feet Elevation)



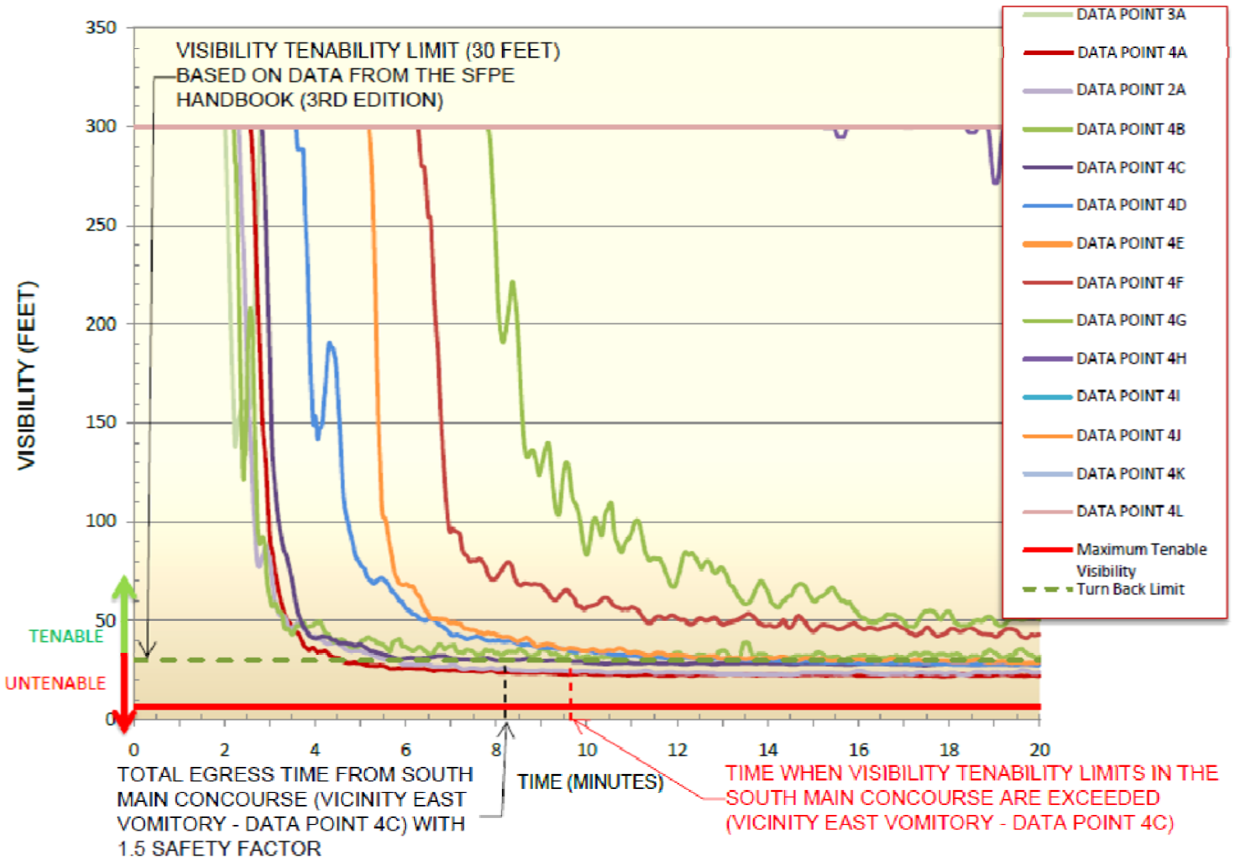
Temperature levels are maintained within tenable limits during the simulation.

Figure 3.31a
Design Fire 4
Visibility Measurements at Tenability Data Collection Point 4A
(Six Feet Elevation)



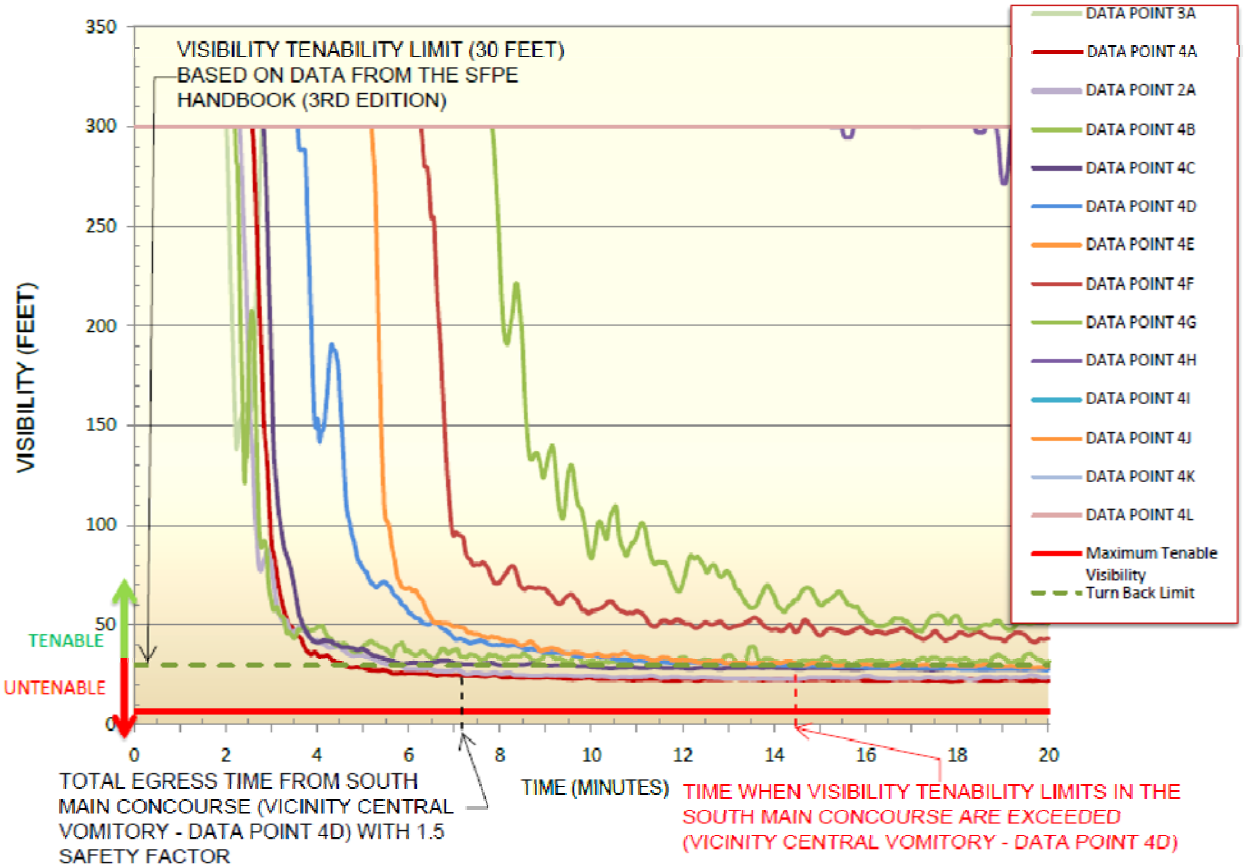
Visibility levels are maintained within tenable limits on the Main Concourse during the simulation for the duration of the required egress time (with a 1.5 safety factor). Since the total egress time multiplied by the 1.5 safety factor (3.9 minutes) is less than the time it takes for the visibility at the southeast corner of the Main Concourse in the vicinity of Data Point 4A to drop below 30 feet (4.6 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC. Please see Section 6.1 of **Appendix B** for a further explanation of these calculations for the southeast Main Concourse.

Figure 3.31b
Design Fire 4
Visibility Measurements at Tenability Data Collection Point 4C
(Six Feet Elevation)



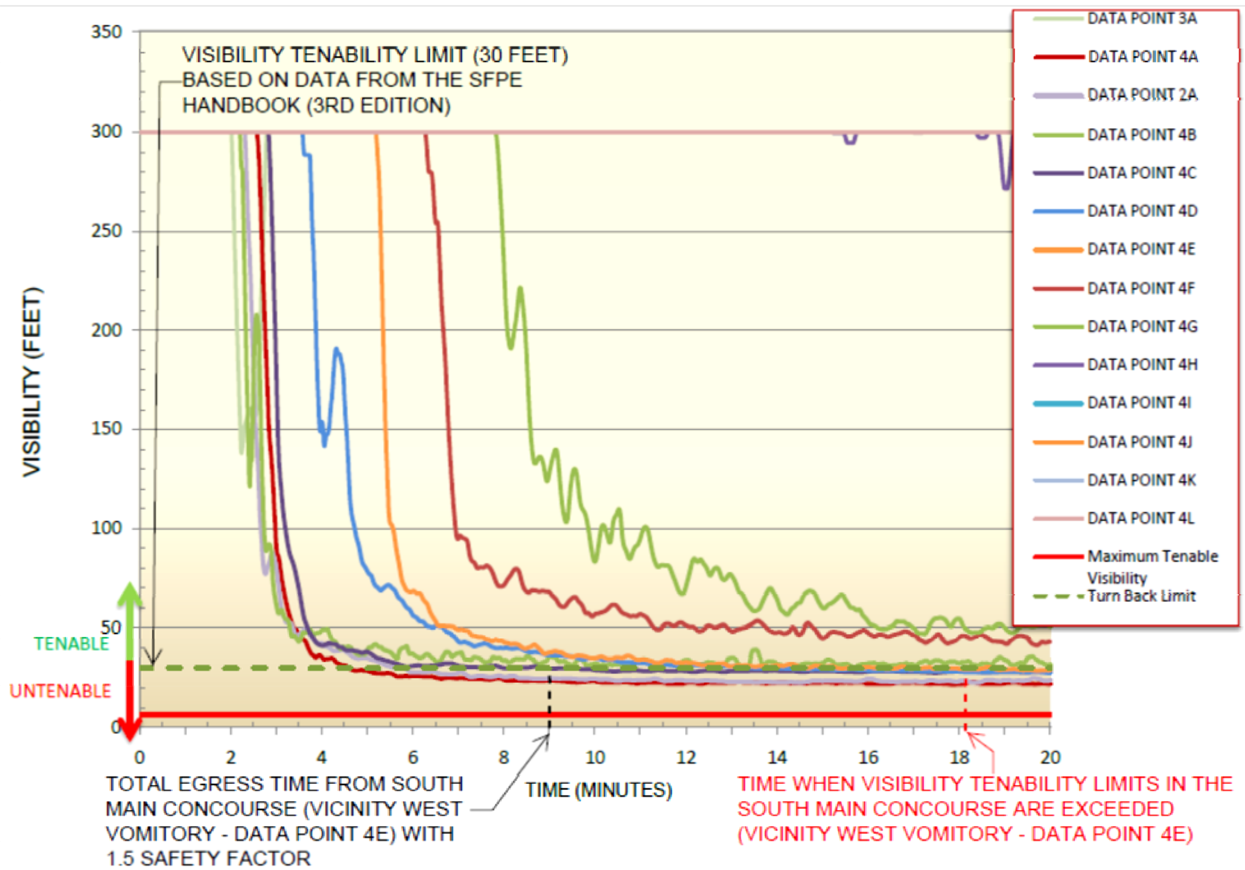
Visibility levels are maintained within tenable limits on the Mechanical Level during the simulation for the duration of the required egress time (with a 1.5 safety factor). Since the total egress time multiplied by the 1.5 safety factor for the East vomitory (8.3 minutes) is less than the time it takes for the visibility on the south Main Concourse in the vicinity of Data Point 4C to drop below 30 feet (9.7 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six (6) feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC. Please see Section 6.2.1 of **Appendix B** for a further explanation of these calculations for the East Vomitory.

Figure 3.31c
Design Fire 4
Visibility Measurements at Tenability Data Collection Point 4D
(Six Feet Elevation)



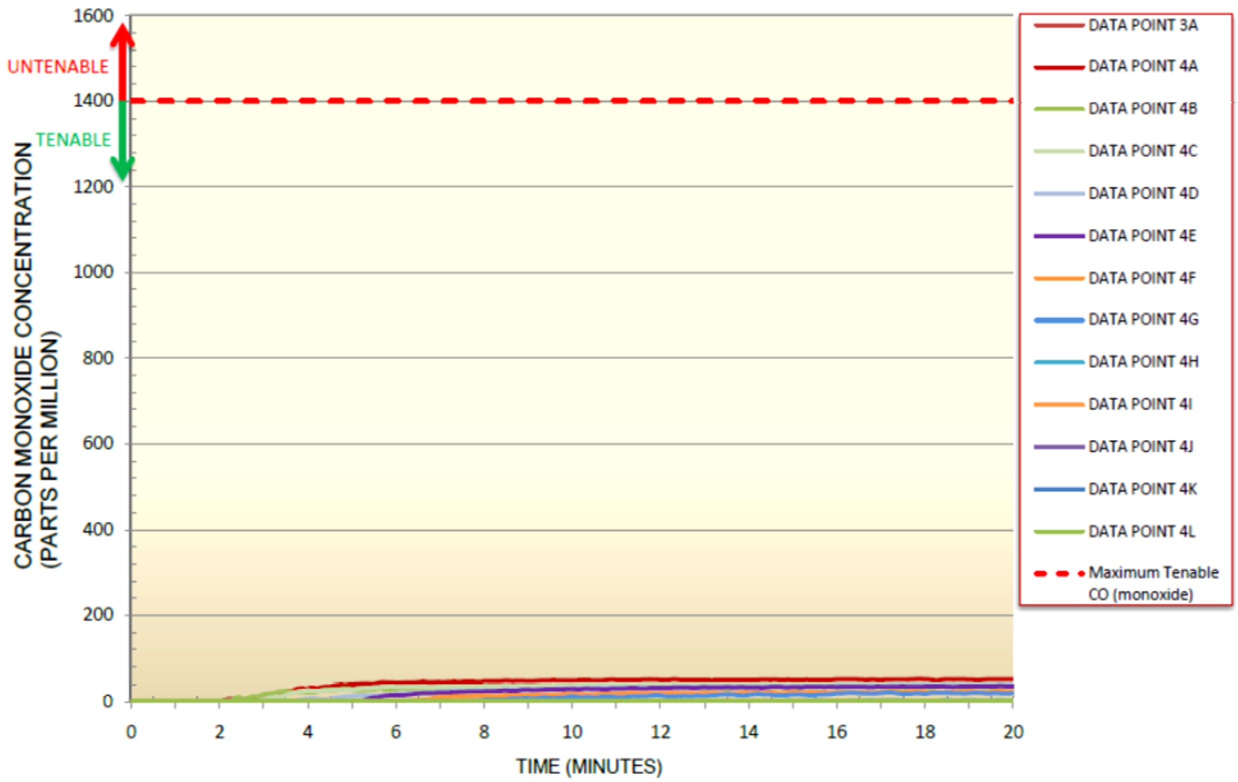
Visibility levels are maintained within tenable limits on the Mechanical Level during the simulation for the duration of the required egress time (with a 1.5 safety factor). Since the total egress time multiplied by the 1.5 safety factor for the Central vomitory (7.2 minutes) is less than the time it takes for the visibility on the south Main Concourse in the vicinity of Data Point 4D to drop below 30 feet (14.5 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC. Please see Section 6.2.2 of **Appendix B** for a further explanation of these calculations for the Central Vomitory.

Figure 3.31d
Design Fire 4
Visibility Measurements at Tenability Data Collection Point 4E
(Six Feet Elevation)



Visibility levels are maintained within tenable limits on the Mechanical Level during the simulation for the duration of the required egress time (with a 1.5 safety factor). Since the total egress time multiplied by the 1.5 safety factor for the West vomitory (9.0 minutes) is less than the time it takes for the visibility on the south Main Concourse in the vicinity of Data Point 4E to drop below 30 feet (18.1 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC. Please see Section 6.2.3 of **Appendix B** for a further explanation of these calculations for the West Vomitory.

Figure 3.32
Design Fire 4
Carbon Monoxide Concentration Measurements at Tenability Data Collection Points
(Six Feet Elevation)



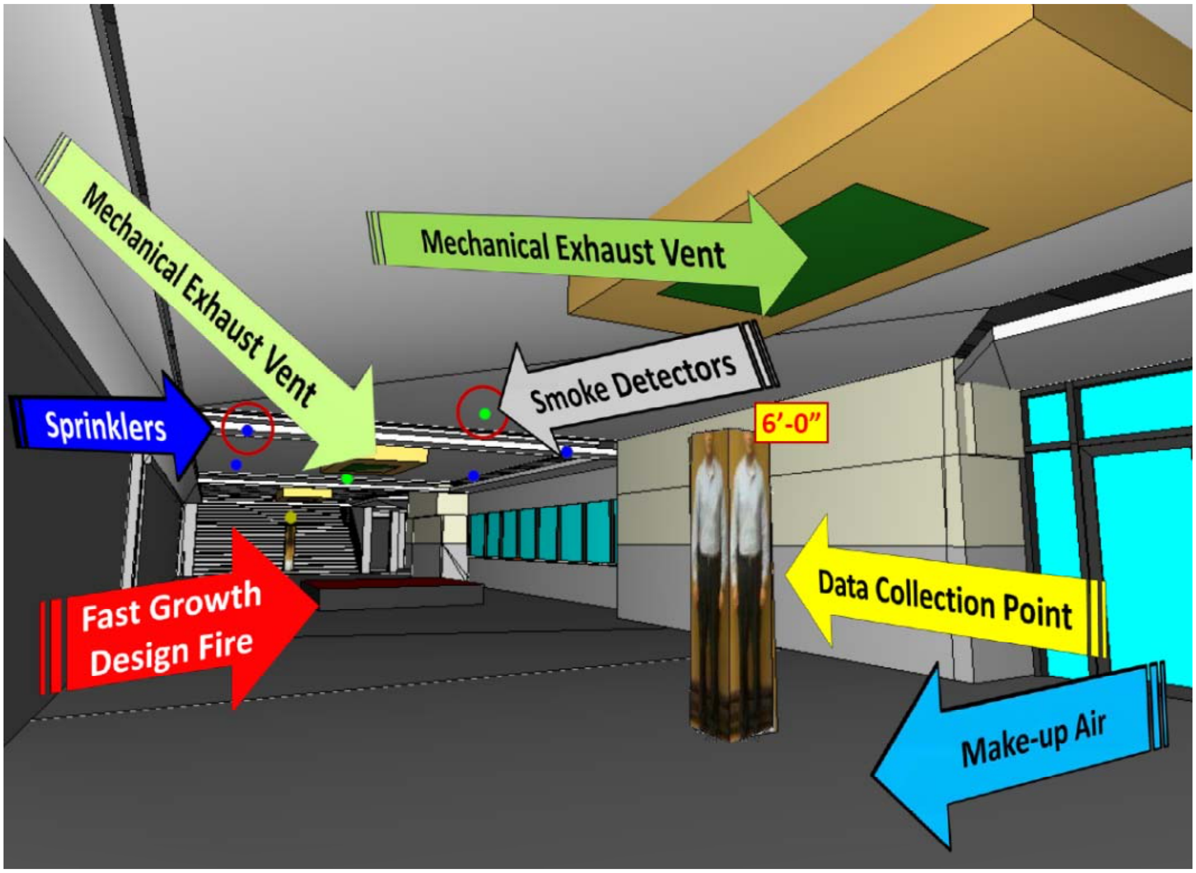
Carbon monoxide levels are maintained within tenable limits during the simulation.

3.3.5 Design Fire Scenario 5

Design Fire 5 consists of a fast growth T-squared fire located on the floor of the West Lobby on the west end of the Main Concourse. The expected fuel load in this space could consist of kiosks filled with merchandise or furniture which typically burn slower than the fast growth T-squared rate based on test data. This fire was assumed to be sprinkler limited based on the calculations performed by the FDS software. This configuration creates an axisymmetric smoke plume and the fire located away from any walls produces the largest amount of concentrated smoke for this smoke plume model as the maximum amount of air can be entrained into the smoke plume. The axisymmetric smoke plume provides the most concentrated smoke and was therefore the worst case scenario for sizing the exhaust fans on the floor of the Lobby on the west end of the Main Concourse. This design fire scenario also creates a balcony spill plume scenario that affects the stairs that are open directly to the north of the lobby. The smoke control system in the West Lobby was designed to primarily activate by smoke detectors for faster response time that allows for a more efficient exhaust system. This scenario also modeled the worst-case external conditions of reverse stack effect conditions (summer high temperature) per Section 3.1.4.1 of this report.

Figure 3.33

Illustration Depicting Lower Level of the West Lobby of the Cumberland County Civic Center for Design Fire 5



Note the following from the image above:

1. The location of the design fire.

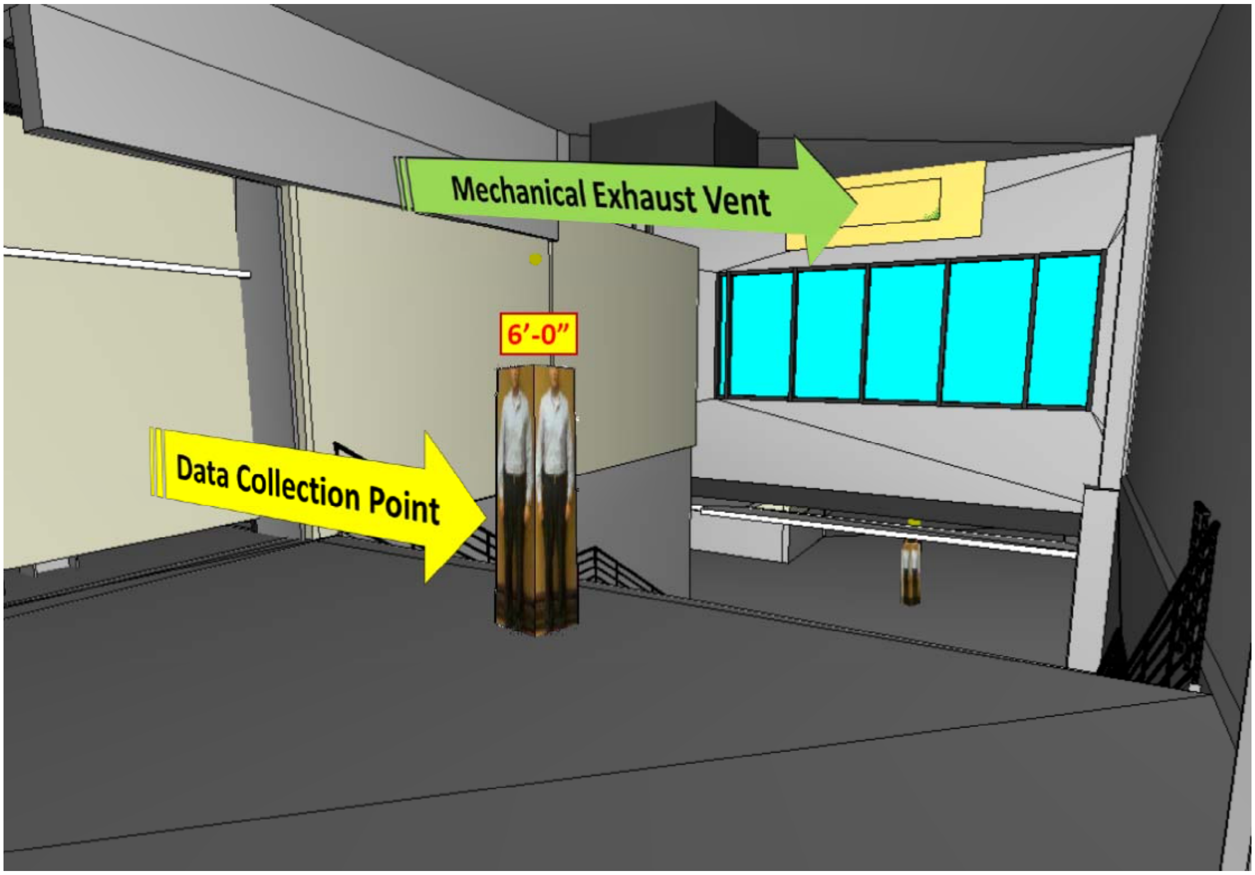
2. The mechanical exhaust vent locations are shown (15,000 cfm each vent with three vents located in the ceiling of the Lobby). Temperature data was recorded at these vents.

3 The location of the tenability data collection points. These data collectors took measurements at six feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

4. The locations of the area smoke detectors and automatic sprinklers are depicted. The depicted locations of these devices were meant to be representative locations used for fire and smoke modeling purposes and do not represent required locations.

5. The location of the make-up air is shown. Make-up air is provided by the doors that connect to the Main Concourse (supplied from loading docks on the east end of the building).

Figure 3.34
Illustration Depicting Top Stair in Northeast Corner of the Cumberland County Civic Center for Design Fire 5

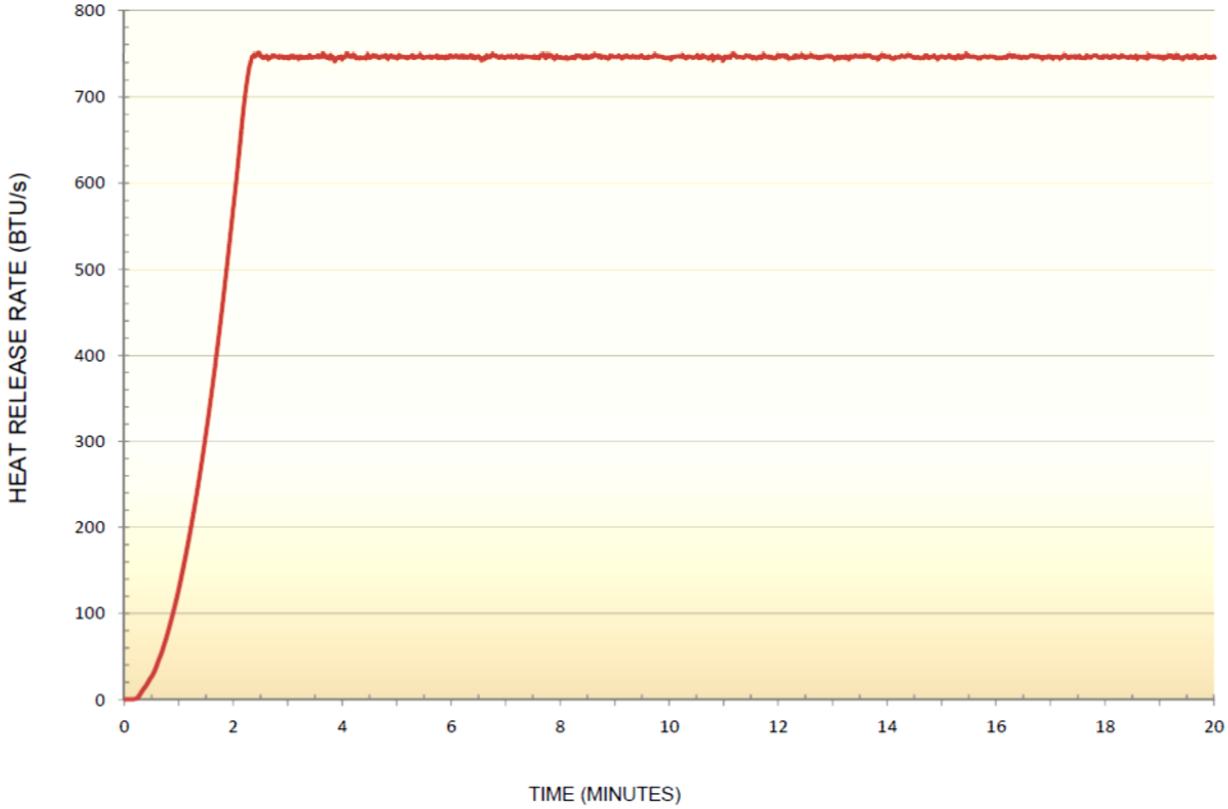


Note the following from the image above:

1. The mechanical exhaust vent location are shown (10,000 cfm vent located in the stair connected to the West Lobby). Temperature data was recorded at this vent.

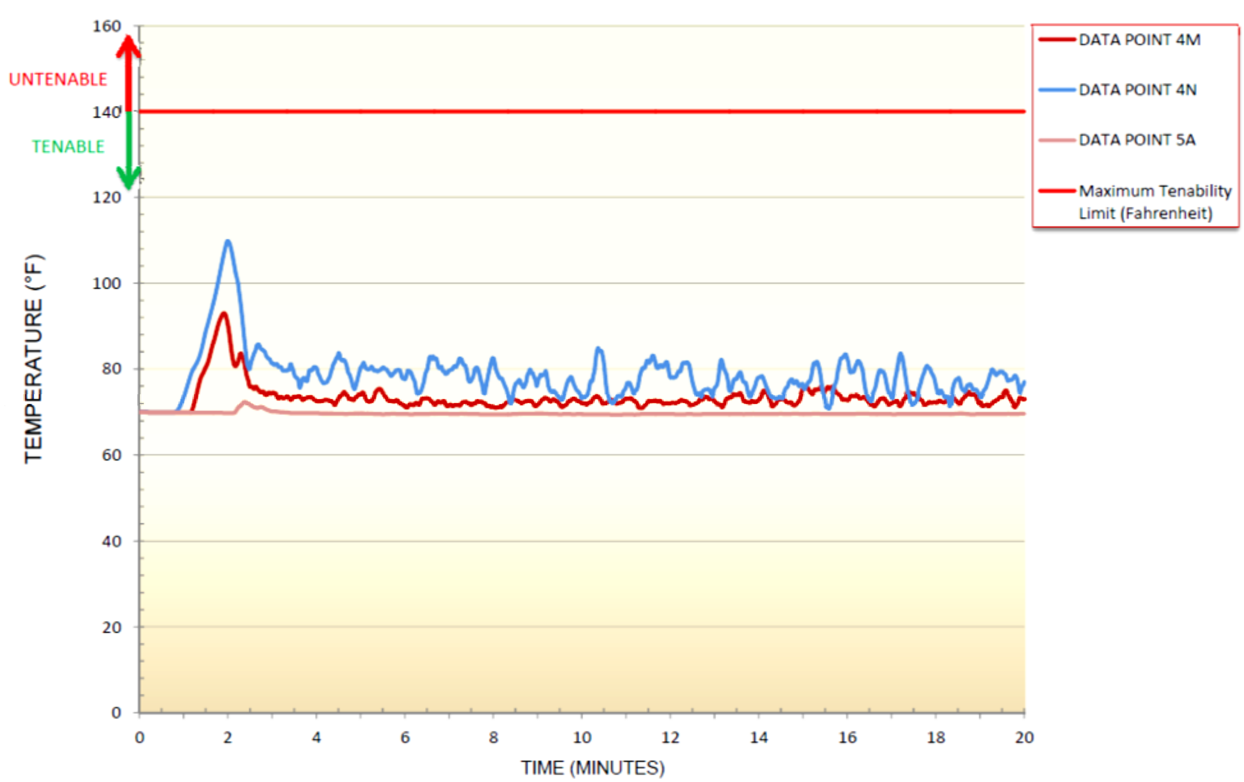
2. The location of the tenability data collection point in the stair. This data collector took measurements at six (6) feet above the floor for temperature, visibility, and carbon monoxide concentration. See the SI.001 through SI.004 illustrations on the previous pages for additional information.

Figure 3.35
Design Fire 5
Heat Release Rate



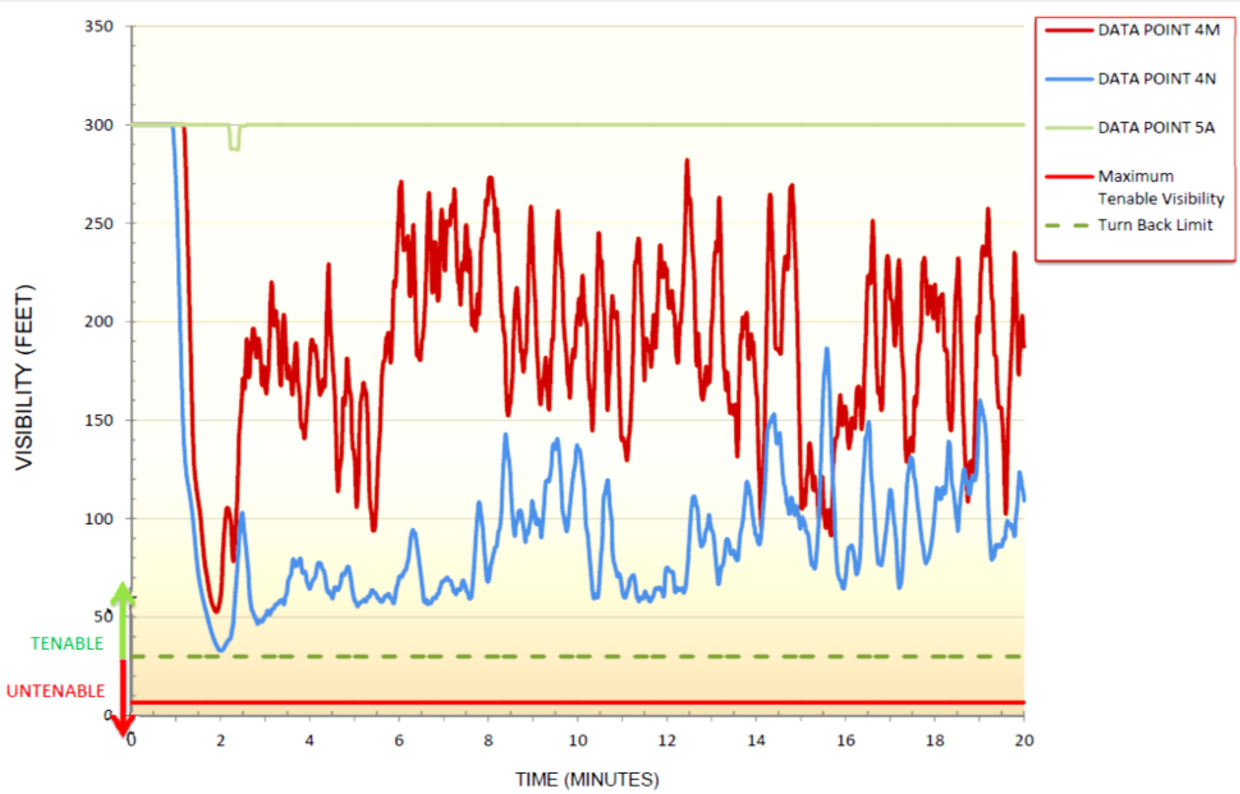
Note that the sprinkler activation temperature (165°F) is reached at approximately two minutes (131 seconds) and corresponds to the point at which the design fire is controlled at a steady state heat release rate (HRR). This activation time of 131 seconds was used with the fast growth T-squared (time in seconds) fire growth model.

Figure 3.36
Design Fire 5
Temperature Measurements at Tenability Data Collection Points
(Six Feet Elevation)



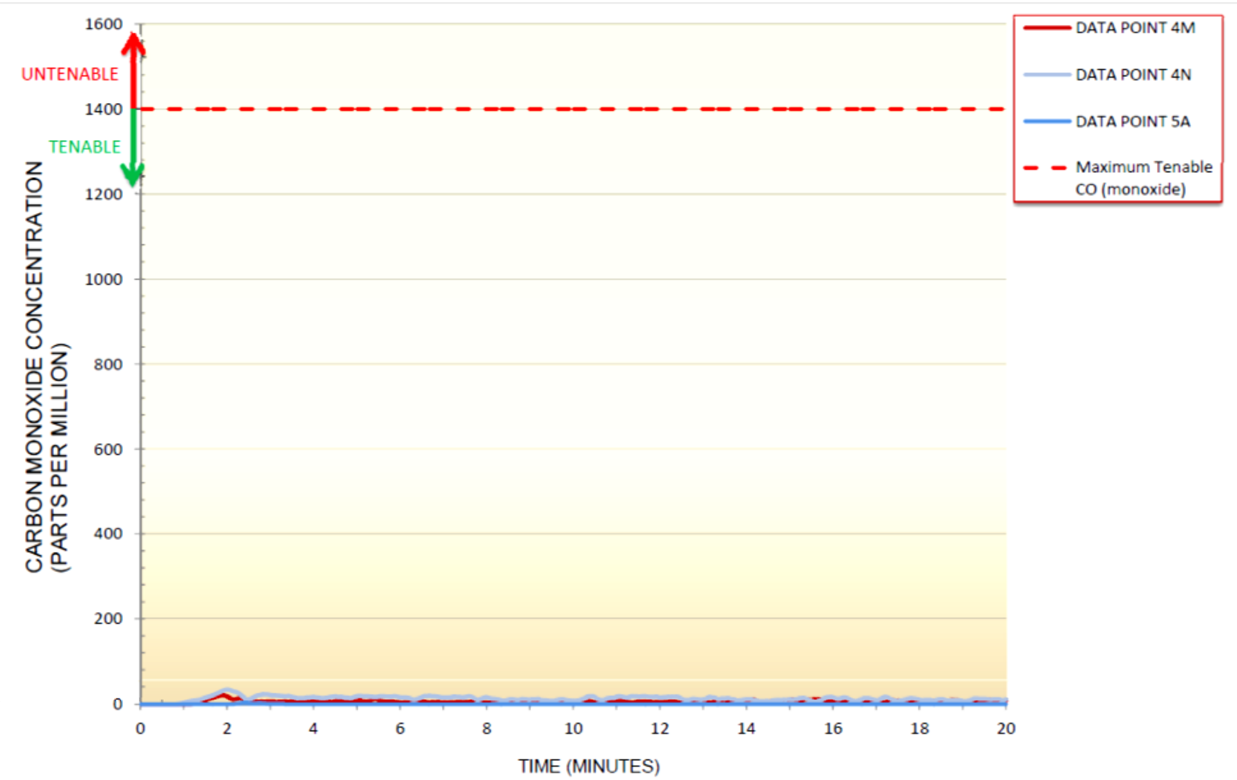
Temperature levels are maintained within tenable limits during the simulation.

Figure 3.37
Design Fire 5
Visibility Measurements at Tenability Data Collection Points
(Six Feet Elevation)



Visibility levels are maintained within tenable limits during the simulation.

Figure 3.38
Design Fire 5
Carbon Monoxide Concentration Measurements at Tenability Data Collection Points
(Six Feet Elevation)



Carbon monoxide levels are maintained within tenable limits during the simulation.

4.0 CONCLUSION

The purpose of the mechanical smoke control system in the Cumberland County Civic Center is to control the accumulation of smoke in the Arena in order to maintain tenable conditions six feet above the highest level of egress in order to allow Arena occupants sufficient time to exit through the Arena. The proposed smoke control system achieves this objective.

APPENDIX A

FIRE MODELING DISCUSSION

FIRE MODELING DISCUSSION

Fire modeling is used to depict possible fire scenarios, to predict fire growth and the amount of combustion products formed, and to estimate the amount of time that a space may remain tenable. Results of all depicted fire scenarios are documented.

The following discussion documents the methodology of the fire modeling calculations for this project and includes the following topics:

- Fire growth models and their limitations - in particular, Fire Dynamics Simulator (FDS), the fire model used for this analysis
- Standard T-squared fire growth, including fire sizes and fuel sources
- Tenability

Fire Growth Models

Fire growth models are defined as mathematical procedures developed to estimate the change in the environment of a space or building caused by the existence of a fire in that space that varies in intensity and/or area of involvement with time. There are two types of fire growth models: zone models and field models.

Zone Models

A single-compartment zone type of fire model divides the room into two control volumes - a hot upper smoke layer and a cooler fresh air lower layer - and solves conservative equations for these regions. Key conditions (temperature, gas concentrations, etc.) are determined in each layer as a function of time. Zone models are a proven method of providing practical first-order estimates of fire processes in enclosures.

Field Models

In a field model, the space being evaluated is subdivided by a grid into many nodes at which gas properties, including temperature and velocity, are calculated, allowing the space to be examined in greater detail. As a result, the output of a field model shows the levels of gas properties changing gradually in the atmosphere as opposed to the zone model which has a sharp demarcation between the smoke layer and fresh air layer. FDS is a field model, which utilizes a computational fluid dynamics (CFD) method, to model fire driven fluid flow. This type of model requires the use of a large-capacity computer, requires extensive time and expertise to set up and run, and is much more costly than using a zone model. This type of model is best suited for use when evaluating irregular, complex spaces requiring a very high level of detail.

Fire Dynamics Simulator

The FDS computer program and its associated routines were developed by the Building and Fire Research Laboratory (BFRL) Division at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland (formerly the Center for Fire Research at the National Bureau of Standards), with significant support from the General Services Administration. The FDS program is a field model which addresses fire development in buildings, the resulting conditions, and the response of fire protection systems. The program operates on a variety of computing platforms and the version used for this study is Version 5 released in September 2004, which is available from NIST.

FDS requires the following input: the geometry and material of the enclosure, a description of the initiating fire and the parameters for the smoke exhaust fans and make-up air vents. Parameters for the smoke exhaust fans and vents include position, dimension of openings, and volume flow rates. The information which may be generated from this computer model is the flow of smoke from openings; the response of heat activated detection devices, such as sprinklers and smoke detectors; the gradients of temperature, oxygen, carbon monoxide, and carbon dioxide concentrations in the atmosphere; and the effects of available oxygen on combustion.

The FDS program represents state-of-the-art approaches currently available for evaluating the life safety characteristics of buildings. The documentation for these programs indicates that the results are accurate for small rooms and buildings, as well as for larger spaces.

Standard T-Squared Fire Growth

Both simulators use a T-squared fire growth model, which is the fire growth model most commonly recognized in the fire protection industry. A T-squared fire is one whose heat output quadruples as its duration doubles. This model represents the growth rate of fires involving a wide range of commodities and arrangements. While the growth rate of fires involving different types of combustibles is similar, the actual heat output of fires involving those commodities can vary significantly. For instance, separate fires involving a bag of newspapers and a truck full of Styrofoam packing peanuts will both grow in T-squared fashion but the heat output of the plastic fire will be much greater than the newspaper fire in any given amount of time.

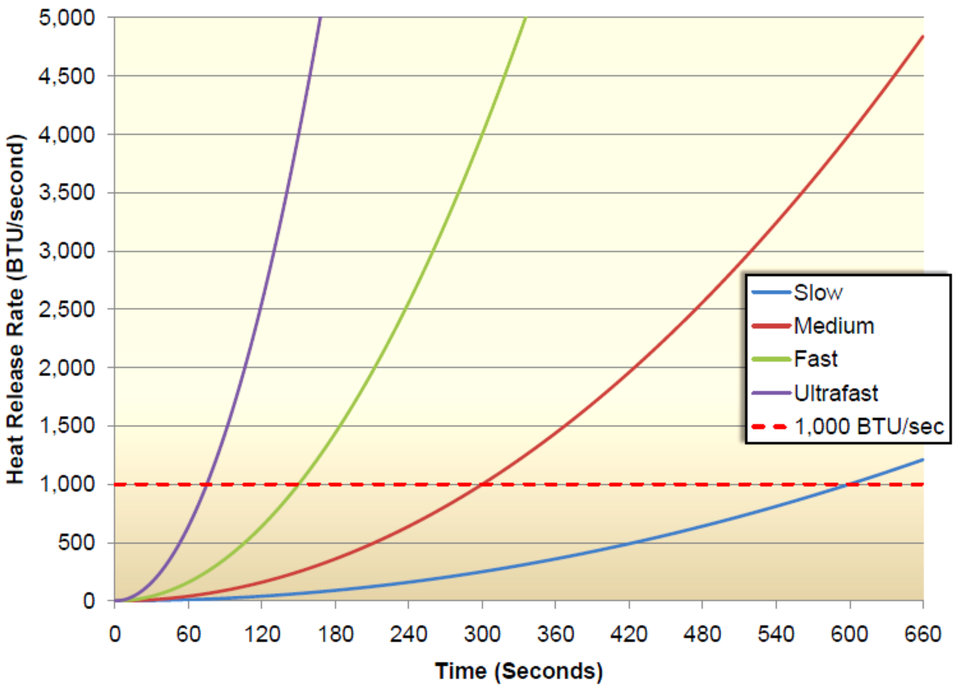
The T-squared growth model is an accepted fire protection industry standard. It assumes a fire continues to grow to a size and burn indefinitely. In reality, fires experience a period of growth, stabilize at some burning rate (which is affected by the amount of available air for combustion, etc.), then experience a period of decline until all available energy has been released. Fire models for enclosed spaces; reflect the effect of sprinklers on the growth of the fire. After sprinklers activate, the fire is assumed to no longer increase in size, as is permitted by code.

Fire Types

Fires are generally classified based upon their initial growth, specifically the time required for them to reach a heat release rate of 1,000 BTU/second [1,055 kW].

Type of Fire	Time to Reach 1,000 BTU/second [1,055 kW]
Slow	600 seconds
Moderate	300 seconds
Fast	150 seconds
Ultra Fast	75 seconds

Figure A.1
Standard Fire Model Growth Rate Curves



A "slow" fire represents a fire involving materials with a low level of combustibility. A "moderate" fire represents ordinary combustible materials, such as wood stacked and arranged. A "fast" fire represents a mix of ordinary combustibles and plastics in an arrangement which promotes fast burning. "Ultra fast" describes the fire growth rate of many plastics and some combustible liquids.

A "fast" fire represents a condition that might be expected in the spaces analyzed. The standard "fast" fire growth closely resembles a fire allowed to grow uncontrolled in a five foot high stack of wood pallets with 6-12% moisture content with the potential to release an unlimited amount of energy as if pallets were continually added. Other examples of fast fires include paper cartons in rack storage on pallets, 15-30 feet high; filled polyethylene letter trays, stacked five feet high; polystyrene tubs and toys stacked to approximately 15 feet high. The latter example can represent kiosks that are expected to be found in the spaces analyzed.

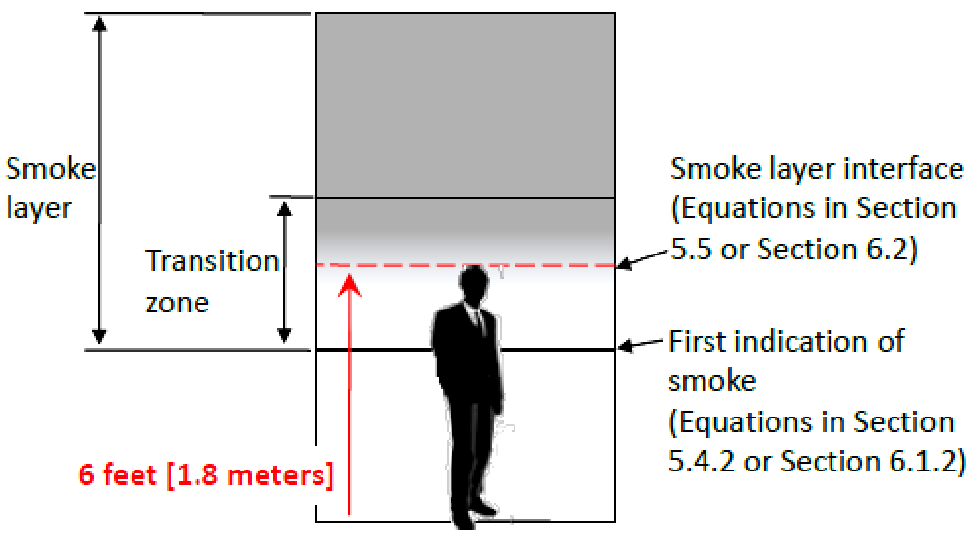
Tenability

Fire modeling of a space (using computational fluid dynamics [CFD] field fire models) may be used to analyze a proposed smoke management system in accordance with the [model building code] which references the 2005 Edition NFPA 92B *Smoke Management Systems in Malls, Atria, and Large*.

Section 5.1.3 of the 2005 Edition NFPA 92B permits the use of CFD fire models for smoke management systems analysis. Using a CFD fire model to determine if the occupants will be able to exit the space in an acceptably safe (tenable) atmosphere where smoke may be present is permitted in Section 3.3.21 of the 2005 Edition NFPA 92B.

By contrast, zone models such as the Fire Simulator or the algebraic equations found in Section 6.2 of the 2005 Edition NFPA 92B determine the smoke layer interface at a certain height above the highest level of egress access or some other design reference location. It should be noted that even for these calculations, some smoke may be present as these calculation methods define the smoke layer interface in the transition zone of the smoke layer (the point where the cool fresh air layer below the smoke transitions to the smoke layer) as illustrated in Figure A.2 below (taken from Figure A.3.3.8 of the 2005 Edition NFPA 92B).

Figure A.2
First Indication of Smoke from Figure A.3.3.8 of the 2005 Edition NFPA 92B



If the desired smoke layer interface (located within the transition zone) is not directly determined as is common in CFD field fire modeling, then maintaining tenable conditions up to a height of six feet above the highest egress surface level is used. The effect of asphyxiants is due to the concentration of the dose, in addition to the amount of time exposed to that dose. Tenability criteria, which are based upon temperature, visibility (optical density of the smoke), and gas concentrations, are examined as the benchmark of acceptability.

It should be noted that the FDS program does not document the concentration of all combustion products. It has been shown that well ventilated fires (such as the ones modeled in this analysis), tend to destroy organic irritants and that the toxicity of the smoke is most likely to be a result of combustion products, such as carbon monoxide. Carbon monoxide is approximately twenty times more toxic than carbon dioxide. Well ventilated fires, as well as fires in the early stage of development, yield efficient combustion and a low production of carbon monoxide. The exception to this is fire retardant materials. The burning of fire retardant materials, even in well ventilated fires, will produce a low carbon dioxide to carbon monoxide ratio. This means that the toxicity level of carbon monoxide, in relation to the other products of combustion, will be reached sooner than with non-fire retardant materials. Generally, if the carbon monoxide levels are found to be at acceptable tenability levels, then the carbon dioxide and oxygen levels are also found to be within tenable limits as well. These values were recorded but not included in our report graphs.

The limits given below are used as tenability criteria for egress analysis:

THREAT	TENABILITY LIMIT	SOURCES
Temperature	• Maximum 140°F (60°C) exposure less than 30 minutes • Maximum 212°F (100°C) exposure less than 12 minutes	(1)
Carbon Monoxide (CO)	Maximum 1,400 ppm (0.14%) exposure less than 30 minutes	(2)
Visibility (Optical Density) [OD]	0.5 OD/m (Allows visibility as low as 2m or 6.6 feet); 30 feet minimum visibility for turn back	(3,4,5)

REFERENCES

1. Toxicity Assessment of Combustion Products, SFPE Handbook of Fire Protection Engineering, Third Edition, 2002; Table 2-6.19; p2-129.

2. Toxicity Assessment of Combustion Products, SFPE Handbook of Fire Protection Engineering, Third Edition, 2002; Table 2-6B (a); p.2-165.

3. National Institute of Standards and Technology, Handbook 146, Volume II, Technical Reference Guide for the HAZARD I Fire Hazard Assessment Method, Building and Fire Research Laboratory, June 1991.

4. Babrauskas, V., Technical Note 1103. National Bureau of Standards, 1979.

5. Hazard Calculation, SFPE Handbook of Fire Protection Engineering, Third Edition, 2002; Table 3-12.20; p3-334.

APPENDIX B

TIMED EGRESS ANALYSIS

B.1 TIMED EGRESS ANALYSIS – DESIGN FIRE 1 [SEATING BOWL]

A timed egress analysis is presented to demonstrate that the occupants of the Seating Bowl of the Cumberland County Civic Center can exit from the Seating Bowl before the visibility recorded at data points 1E and 2E (six feet above the highest seats in the Seating Bowl) drops below 30 feet as referenced by Appendix A of this report (the tenability limit for visibility based on data from studies referenced in the Society of Fire Protection Engineers Handbook). Below are the calculations for the total required egress time:

1. Methodology

The exit rate calculations used in this analysis are similar to the flow rates found in Dr. John Fruin's work, Pedestrian Planning and Design as a Level of Service "E" referenced in Chapter 14, Section 3 of the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 3rd Edition. The flow rates and travel speeds used in this study are conservative and are consistent with emergency exiting considerations. During non-emergency conditions, many persons exit at their leisure and exit times longer than those reported in this study are expected. Studies indicate the human behavior known as panic is rare and does not occur if adequate exits are provided.

The flow rate used for persons traveling through doors or on level accessways is on the lower end of the range provided by Fruin.

The following flow rates and travel speeds have been used:

Table B.1.1
Travel Speeds and Flow Rates

ELEMENT	TRAVEL SPEED IN FEET/MINUTE (ft/m)	FLOW RATE IN PEOPLE/FEET/MINUTE (pfm)
Stairs & stepped aisles (7 inch risers)	60.0 (slow); 100.0 (fast)*	17.0
Stairs & stepped aisles (8 inch risers)	35.0 (slow); 80.0 (fast)*	15.3
Doors	-----	21.0
Seating Rows	35.0 (slow); 80.0 (fast)*	-----
Level exit components	150 (slow); 200 (fast) *	21.0

* *The faster speed is used to consider the time for the first person to reach an exit (i.e., the lead person in a crowd). The slower speed is used to address the movement expected by the elderly, persons with disabilities and the last person in a crowd.*

2. Definitions

The following terms are defined to provide clarity:

Queue (Queuing) - Pedestrian waiting condition where forward movement essentially stops and people become stationary for a period of time.

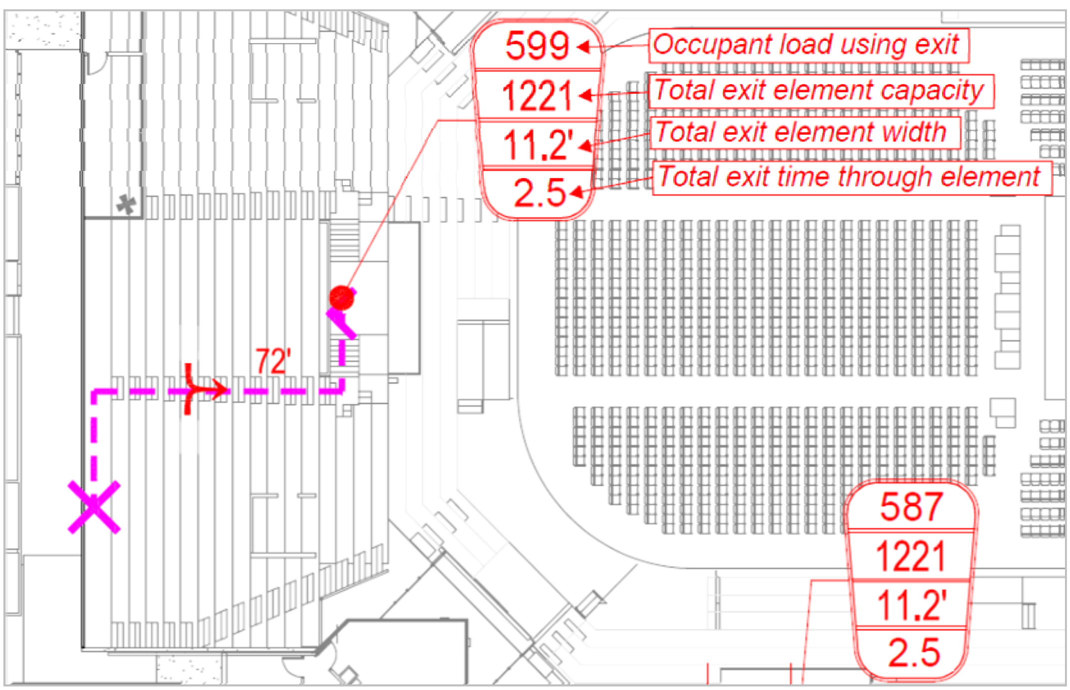
Flow Time - This is the amount of time for a population to pass a particular point.

Egress Time - This is the total time for a population to traverse across a space and includes both the flow time through a point and the travel time to an exit element.

3. Population

The exit analysis uses the populations calculated from the Seating Bowl seating section manifests. The largest population of the Seating Bowl section with the longest travel distance is 599 people (see Figure B.1.1 below). The Seating Bowl opens into the Main Concourse through vomitories located midway up the Seating Bowl from the Event Level. It was considered that once an occupant could reach and pass through a vomitory then the timed egress analysis is complete as the Main Concourse was assumed to be an egress path clear of smoke.

Figure B.1.1
Travel Distances in the Seating Bowl



The vomitory provides 11.2 feet of clear egress width. The vomitory can accommodate 1,221 people. This was calculated using the smoke protected exit factors Table 1028.6.2 of the 2009 MUBEC and Table 12.4.2.3 of the 2009 Edition NFPA 101 for an occupancy with 8,700 occupants (interpolated to 0.11 inches per occupant).

$$W_{Vomitory} = \left(0.11\ \frac{inches}{occupant} \times \frac{1\ foot}{12\ inches} \times \frac{Vomitory\ width}{11.2\ feet}\right)^{-1} = 1{,}221\ occupants$$

4. System Activation and Alarm Notification

The occupants of the Seating Bowl can see the Event Level floor so notification of a fire event was assumed to be by observation from the Seating Bowl occupants and not by alarm.

5. Egress Initiation

For a fire in the Seating Bowl, the time for occupants to recognize there was a fire and start to move is estimated to be 0.5 minutes. This number includes time required for both alarm pre-action and alarm recognition. This time accounts for people to realize there is an emergency and begin their egress into the Seating Bowl.

6. Timed Egress Calculations

The following section calculates the time required for the last person to exit the Seating Bowl after alarm recognition.

The time required for the last person to exit through the vomitory in the Seating Bowl is calculated by dividing the longest travel distance to the vomitory by the slow travel speed(s), in Table B.1.1 above, and comparing these times to the times required for queues to flow through the various egress elements encountered. The maximum travel distance was calculated from the center seat of the highest row of the Seating Bowl to the vomitory.

Time to travel the maximum travel distance of 72 feet (a summation of different egress conditions including seating rows and stairs with 7 inch risers) was calculated using the slow travel speed (60 feet/minute) from Table B.1.1 above. The following equations illustrate the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.1.1 above):

Travel Time at 60 Feet per Minute:

$$72\ feet \times \frac{1\ minute}{60\ feet} = 1.2\ minutes$$

The flow time through the vomitory was calculated using the flow rate through doors (21 people/feet·minute) from Table B.1.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.1.1 above):

Time to flow through the vomitory:

$$\frac{21\ people}{feet \cdot minute} \times (11.2\ foot\ wide\ vomitory\ width) = \frac{235.2\ people}{minute}$$

$$587\ people\ (population) \times \frac{1\ minute}{235.2\ people} = 2.5\ \ minutes$$

Note: The Seating Bowl population that serves this vomitory was determined to be the largest population exiting through a vomitory and is therefore the worst case scenario.

If the last slowest person arrives at the vomitory in a greater time than the vomitory flow time, no queue will exist at the vomitory; however, if the last slowest person arrives at the vomitory in less time than the vomitory flow time, they must wait until the queue subsides before they can exit the Seating Bowl.

Since the exit flow time (2.5 minutes) is greater than the travel time (1.2 minutes), the exit flow time of 2.5 minutes will be used for the total egress time calculations. The total egress time is summed up in Table B.1.2 below:

Table B.1.2
Seating Bowl Total Egress Time

PHASE	TIME
Fire Alarm activation (beam smoke detector)	N/A [1]
Time to initiate egress	0.5 minutes
Vomitory flow from Seating Bowl (greater than travel time)	2.5 minutes
Seating Bowl Total Egress Time:	**3.0 minutes**
Total Egress Time with 2009 MUBEC Safety Factor (1.5):	**4.5 minutes**

[1] See Item 4 above. The occupants of the Seating Bowl can see the Event Level floor so notification of a fire event was assumed to be by observation from the Seating Bowl occupants and not by alarm.

The visibility for all occupants to exit the Seating Bowl is sufficient before the visibility recorded at data points 1E and 2E (six feet above the highest seats in the Seating Bowl) drops below 30 feet as referenced by Appendix A of this report (the tenability limit for visibility based on data from studies referenced in the Society of Fire Protection Engineers Handbook).

Since the total egress time multiplied by the 1.5 safety factor (4.5 minutes) is less than the time it takes for the visibility at data points 1E and 2E (six feet above the highest seats in the Seating Bowl) to drop below 30 feet (9.1 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six (6) feet above the highest seats in the Seating Bowl in accordance with Section 909.8 of the 2009 MUBEC.

B.2 TIMED EGRESS ANALYSIS – DESIGN FIRE 4 [MAIN CONCOURSE LEVEL]

A timed egress analysis is presented to demonstrate that the occupants of the Main Concourse Level of the Cumberland County Civic Center can exit from the Main Concourse before the visibility recorded at data points 4A, 4C, 4D, and 4E (six feet above the south Main Concourse) drops below 30 feet as referenced by Appendix A of this report (the tenability limit for visibility based on data from studies referenced in the Society of Fire Protection Engineers Handbook). This specific scenario is based upon Design Fire 4 Scenario that models a fire on the Mechanical Level below the southeast corner of the Main Concourse. Below are the calculations for the total required egress time:

1. Methodology

The exit rate calculations used in this analysis are similar to the flow rates found in Dr. John Fruin's work, Pedestrian Planning and Design as a Level of Service "E" referenced in Chapter 14, Section 3 of the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 3rd Edition. The flow rates and travel speeds used in this study are conservative and are consistent with emergency exiting considerations. During non-emergency conditions, many persons exit at their leisure and exit times longer than those reported in this study are expected. Studies indicate the human behavior known as panic is rare and does not occur if adequate exits are provided.

The flow rate used for persons traveling through doors or on level accessways is on the lower end of the range provided by Fruin.

The following flow rates and travel speeds have been used:

Table B.2.1
Travel Speeds and Flow Rates

ELEMENT	TRAVEL SPEED IN FEET/MINUTE (ft/m)	FLOW RATE IN PEOPLE/FEET/MINUTE (pfm)
Stairs & stepped aisles (7 inch risers)	60.0 (slow); 100.0 (fast)*	17.0
Stairs & stepped aisles (8 inch risers)	35.0 (slow); 80.0 (fast)*	15.3
Doors	-----	21.0
Seating Rows	35.0 (slow); 80.0 (fast)*	-----
Level exit components	150 (slow); 200 (fast) *	21.0

* The faster speed is used to consider the time for the first person to reach an exit (i.e., the lead person in a crowd). The slower speed is used to address the movement expected by the elderly, persons with disabilities and the last person in a crowd.

2. Definitions

The following terms are defined to provide clarity:

Queue (Queuing) - Pedestrian waiting condition where forward movement essentially stops and people become stationary for a period of time.

Flow Time - This is the amount of time for a population to pass a particular point.

Egress Time - This is the total time for a population to traverse across a space and includes both the flow time through a point and the travel time to an exit element.

3. Population

The exit analysis uses the populations calculated according to Chapter 10 of the 2009 MUBEC for the total occupants of the southeast corner of the Main Concourse. The total population of the southeast corner of the Main Concourse is 278 people (see Figure B.2.1 below). This population was determined by dividing the floor area of the southeast corner of the Main Concourse by the concentrated floor area allowance per occupant from Table 1004.1.1 of the 2009 MUBEC. The floor area of the southeast corner of the Main Concourse was calculated at 1,940 square feet. Since the southeast corner of the Main Concourse is to function as an assembly space (concession area) with tables and chairs, the floor area allowance per occupant chosen was 7 square feet per person (net) for concentrated use. This floor area per occupant value is consistent with those provided in Table 7.3.1.2 of the 2009 NFPA 101. Dividing the floor area by the square feet per person yields a maximum occupant load of 278 people.

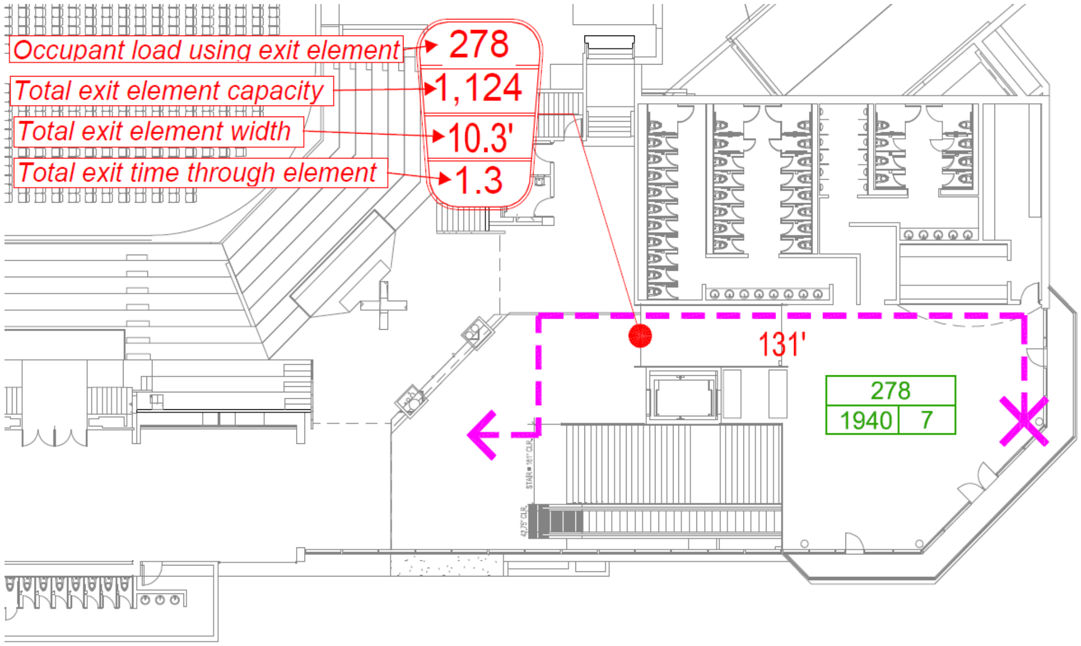
$$O_{Main\ Concourse} = 1{,}940\ sqft \times \frac{1\ occupant}{7\ sqft} = 278\ occupants$$

The southeast corner of the Main Concourse opens directly into the south end of the Main Concourse by a ramp that is 10.3 feet wide.

The ramp can accommodate 1,124 people. This was calculated using the smoke protected exit factors Table 1028.6.2 of the 2009 MUBEC and Table 12.4.2.3 of the 2009 NFPA 101 for an occupancy with 8,700 occupants (interpolated to 0.11 inches per occupant).

$$W_{Ramp} = \left(0.11\ \frac{inches}{occupant} \times \frac{1\ foot}{12\ inches} \times \frac{Ramp\ width}{10.3\ feet}\right)^{-1} = 1{,}124\ occupants$$

Figure B.2.1
Travel Distances in the Southeast Corner of the Main Concourse



Populations for the exiting from the Seating Bowl were calculated from the Seating Bowl seating section manifests. See Figure B.2.2 through B.2.5 below for the travel distances and flow calculations used in this analysis.

Figure B.2.2
Travel Distances in the South Main Concourse from the Vomitories

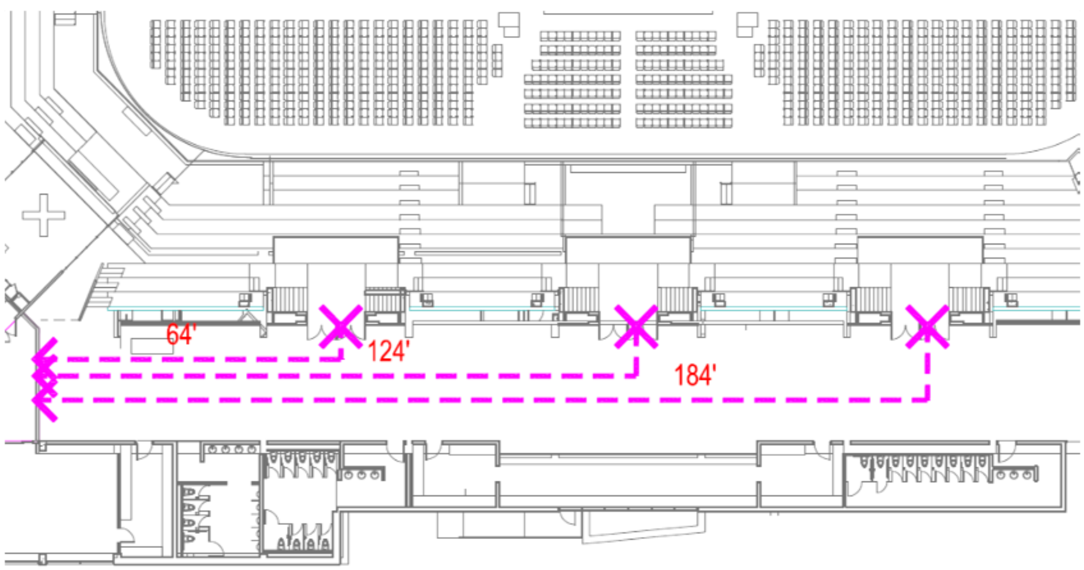


Figure B.2.3
Travel Distances and Flow Times in the Seating Bowl for the East Vomitory

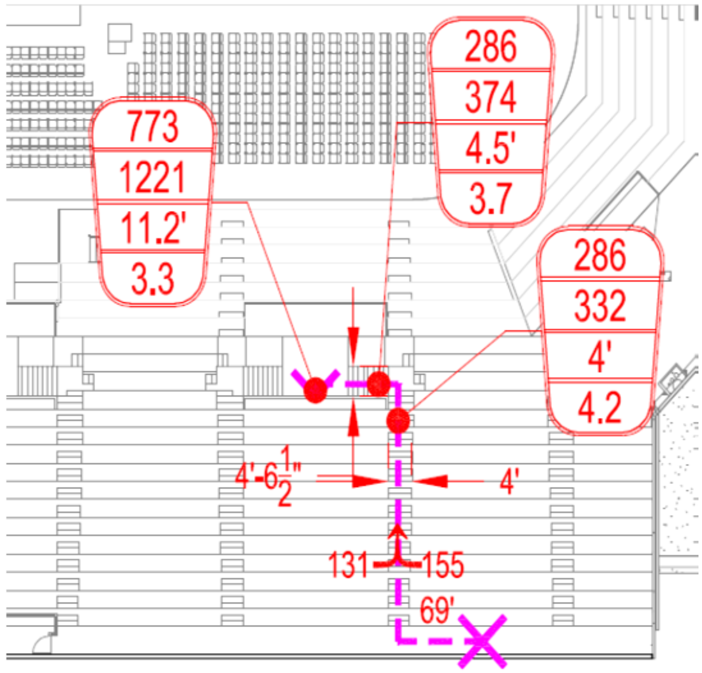


Figure B.2.4
Travel Distances and Flow Times in the Seating Bowl for the Central Vomitory

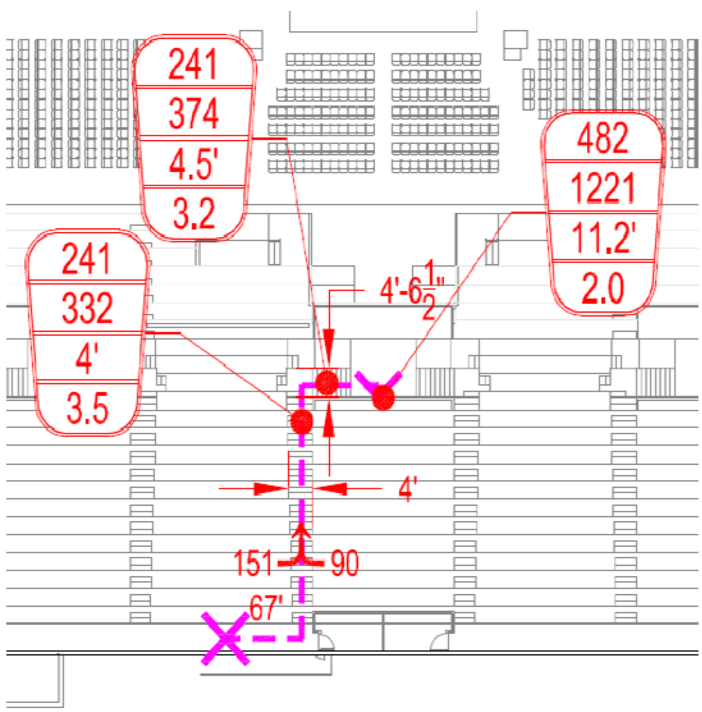
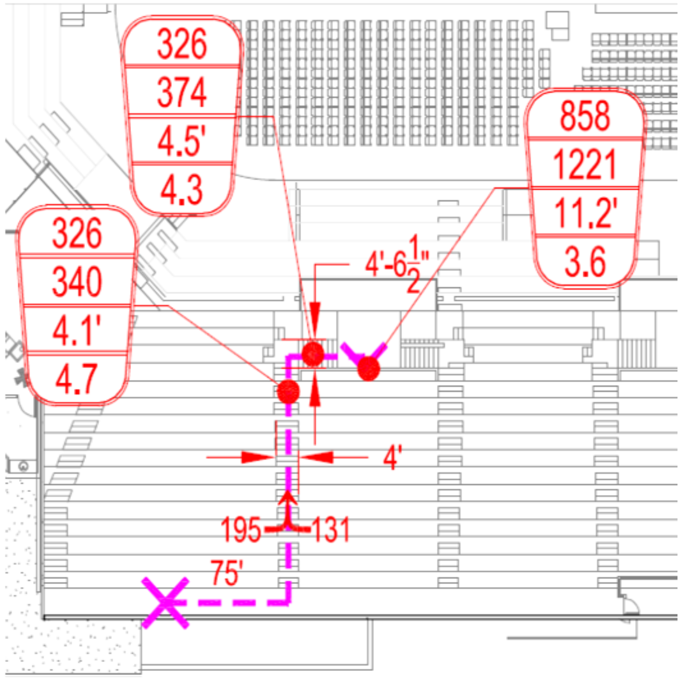


Figure B.2.5
Travel Distances and Flow Times in the Seating Bowl for the West Vomitory



4. System Activation and Alarm Notification

The time required for the building systems to detect a fire on the Mechanical Level was determined based upon the simulation results from the FDS software. The worst case scenario modeled area smoke detector activation at 38.4 seconds. By adding 10 seconds for transmission time of the detector activation to the alarm panel a total time of 48.4 seconds or 0.8 minutes was estimated for system activation and alarm notification.

5. Egress Initiation

For a fire at the Mechanical Level Lobby, the time for occupants of the Seating Bowl and the southeast corner of the Main Concourse to recognize there was a fire and start to move is estimated to be 0.5 minutes. This number includes time required for both alarm pre-action and alarm recognition.

6. Timed Egress Calculations

The following section calculates the time required for the last person to exit the southeast corner of the Main Concourse and for the last person to exit from the Seating Bowl through the south vomitories after alarm recognition.

6.1 The time required for the last person to exit from southeast corner of the Main Concourse is calculated by dividing the longest travel distance to the exit discharge door by the slow travel speed(s), in Table B.2.1 above, and comparing these times to the times required for queues to flow through the various egress elements encountered. The maximum travel distance was calculated from the farthest end of the southeast corner of the Main Concourse to the stairs that egress to the Mechanical Level.

Time to travel the maximum travel distance of 125 feet was calculated using the slowest travel speed (150 feet/minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.1 above):

Travel Time at 150 Feet per Minute:

$$131\ feet\ \times \frac{1\ minute}{150\ feet} = 0.9\ minutes$$

The flow time through the ramp was calculated using the flow rate through a level exit component (21 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.1 above):

Time to flow through the ramp:

$$\frac{21\ people}{feet \cdot minute} \times (10.3\ foot\ wide\ door\ width) = \frac{216.3\ people}{minute}$$

$$278\ people\ (population) \times \frac{1\ minute}{216.3\ people} = 1.3\ \ minutes$$

If the last slowest person arrives at the ramp in a greater time than the ramp flow time, no queue will exist at the ramp; however, if the last slowest person arrives at the ramp in less time than the ramp flow time, they must wait until the queue subsides before they can exit the southeast corner of the Main Concourse.

Since the largest exit flow time (1.3 minutes) is greater than the greatest travel time (0.9 minutes), the exit flow time of 1.3 minutes will be used for the total egress time calculations with respect to Data Point 4A (the data point of concern on the southeast). The total egress time is summed up in Table B.2.2 below:

Table B.2.2
Southeast Corner of Main Concourse Total Egress Time

PHASE	TIME
Fire Alarm activation (spot smoke detector)	0.8 minutes
Time to initiate egress	0.5 minutes
Ramp flow from southeast corner of the Main Concourse (greater than travel time)	1.3 minutes
Southeast Corner of the Main Concourse Total Egress Time:	**2.6 minutes**
Total Egress Time with 2009 MUBEC Safety Factor (1.5):	**3.9 minutes**

The visibility for all occupants to exit the southeast corner of the Main Concourse is sufficient before the visibility on the Main Concourse in the vicinity of Data Point 4A drops below 30 feet as referenced by Appendix A of this report (the tenability limit for visibility based on data from studies referenced in the Society of Fire Protection Engineers Handbook).

Since the total egress time multiplied by the 1.5 safety factor (3.9 minutes) is less than the time it takes for the visibility at the southeast corner of the Main Concourse in the vicinity of Data Point 4A to drop below 30 feet (4.6 minutes), sufficient time is allowed for all occupants to exit with tenable conditions six (6) feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC.

6.2 The time required for the last person to exit from Seating Bowl through the vomitories to the Main Concourse was calculated by dividing the longest travel distance to the vomitories by the slow travel speed(s), in Table B.2.1 above, and comparing these times to the times required for queues to flow through the various egress elements encountered. The maximum travel distance was calculated from the farthest seat from each vomitory used for egress from the Seating Bowl.

6.2.1 East Vomitory

6.2.1.1 Travel Distance

Two separate travel distances were analyzed to determine the maximum travel time anticipated for egress from the Seating Bowl and out of the south Main Concourse.

1. Time to travel the maximum travel distance in the Seating Bowl of 69 feet (a summation of different egress conditions including seating rows and stairs with 7 inch risers) was calculated using the slow travel speed (60 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.3 above):

   Travel Time at 60 Feet per Minute:

$$69\ feet \times \frac{1\ minute}{60\ feet} = 1.2\ minutes$$

2. Time to travel the maximum travel distance on the Main Concourse of 184 feet was calculated using the slow travel speed (150 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.2 above):

   Travel Time at 150 Feet per Minute:

$$184\ feet \times \frac{1\ minute}{150\ feet} = 1.2\ minutes$$

   The resulting greatest travel time was 1.2 minutes (equal between the two travel distances measured).

6.2.1.2 Flow Time

Three separate flow times were analyzed to determine the maximum flow time anticipated for egress from the Seating Bowl and out of the south Main Concourse. Seating Bowl populations were based on fixed seat counts for the Upper Bowl.

1. The flow time down the narrow stair aisle from the highest seat was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.3 above):

Time to flow through the narrow stair aisle (4’ 0” wide):

$$\frac{17\ people}{feet \cdot minute} \times (4\ foot\ width) = \frac{68\ people}{minute}$$

$$286\ people\ \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{68\ people} = 4.2\ \ minutes$$

2. The flow time down the wide stair aisle that leads to the vomitory was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.3 above):

   Time to flow through the wide stair aisle (4’ 6” wide):

$$\frac{17\ people}{feet \cdot minute} \times (4.5\ foot\ width) = \frac{76.5\ people}{minute}$$

$$286\ people\ \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{76.5\ people} = 3.7\ \ minutes$$

3. The flow time through the vomitory was calculated using the flow rate through a level exit component (21 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.3 above):

   Time to flow through the vomitory (11’ 2” wide):

$$\frac{21\ people}{feet \cdot minute} \times (11.2\ foot\ width) = \frac{235.2\ people}{minute}$$

$$773\ people\ \left(\frac{population}{Upper\ /\ Lower\ Bowl}\right) \times \frac{1\ minute}{235.2\ people} = 3.3\ \ minutes$$

   The resulting greatest flow time was 4.2 minutes (from the Upper Seating Bowl through the narrow stair aisle).

6.2.2 Central Vomitory

6.2.2.1 Travel Distance

Two separate travel distances were analyzed to determine the maximum travel time anticipated for egress from the Seating Bowl and out of the south Main Concourse.

1. Time to travel the maximum travel distance in the Seating Bowl of 67 feet (a summation of different egress conditions including seating rows and stairs with 7 inch risers) was calculated using the slow travel speed (60 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.4 above):

   Travel Time at 60 Feet per Minute:

$$67\ feet\ \times \frac{1\ minute}{60\ feet} = 1.1\ minutes$$

2. Time to travel the maximum travel distance on the Main Concourse of 124 feet was calculated using the slow travel speed (150 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.2 above):

   Travel Time at 150 Feet per Minute:

$$124\ feet\ \times \frac{1\ minute}{150\ feet} = 0.8\ minutes$$

The resulting greatest travel time was 1.1 minutes (from the Upper Seating Bowl).

6.2.2.2 Flow Time

Three separate flow times were analyzed to determine the maximum flow time anticipated for egress from the Seating Bowl and out of the south Main Concourse. Seating Bowl populations were based on fixed seat counts for the Upper Bowl.

1. The flow time down the narrow stair aisle from the highest seat was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.4 above):

   Time to flow through the narrow stair aisle (4' 0" wide):

$$\frac{17\ people}{feet \cdot minute} \times (4\ foot\ width) = \frac{68\ people}{minute}$$

$$241\ people\ \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{68\ people} = 3.5\ \ minutes$$

2. The flow time down the wide stair aisle that leads to the vomitory was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.4 above):

   Time to flow through the wide stair aisle (4' 6" wide):

$$\frac{17\ people}{feet \cdot minute} \times (4.5\ foot\ width) = \frac{76.5\ people}{minute}$$

$$241\ people\ \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{76.5\ people} = 3.2\ \ minutes$$

3. The flow time through the vomitory was calculated using the flow rate through a level exit component (21 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.4 above):

   Time to flow through the vomitory (11' 2" wide):

$$\frac{21\ people}{feet \cdot minute} \times (11.2\ foot\ width) = \frac{235.2\ people}{minute}$$

$$482\ people\ \left(\frac{population}{Upper\ /\ Lower\ Bowl}\right) \times \frac{1\ minute}{235.2\ people} = 2.0\ \ minutes$$

The resulting greatest flow time was 3.5 minutes (from the Upper Seating Bowl through the narrow stair aisle).

6.2.3 West Vomitory

6.2.3.1 Travel Distance

Two separate travel distances were analyzed to determine the maximum travel time anticipated for egress from the Seating Bowl and out of the south Main Concourse.

1. Time to travel the maximum travel distance in the Seating Bowl of 75 feet (a summation of different egress conditions including seating rows and stairs with 7 inch risers) was calculated using the slow travel speed (60 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.5 above):

   Travel Time at 60 Feet per Minute:

$$75\ feet\ \times \frac{1\ minute}{60\ feet} = 1.3\ minutes$$

2. Time to travel the maximum travel distance on the Main Concourse of 64 feet was calculated using the slow travel speed (150 feet/minute) from Table B.2.1 above. The following equation illustrates the methodology for determining the total required egress time based on travel distance (based on the calculated travel distance shown in Figure B.2.2 above):

   Travel Time at 150 Feet per Minute:

$$64\ feet\ \times \frac{1\ minute}{150\ feet} = 0.4\ minutes$$

The resulting greatest travel time was 1.3 minutes (from the Upper Seating Bowl).

6.2.3.2 Flow Time

Three separate flow times were analyzed to determine the maximum flow time anticipated for egress from the Seating Bowl and out of the south Main Concourse. Seating Bowl populations were based on fixed seat counts for the Upper Bowl.

1. The flow time down the narrow stair aisle from the highest seat was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.5 above):

   Time to flow through the narrow stair aisle (4' 1" wide):

$$\frac{17\ people}{feet \cdot minute} \times (4.1\ foot\ width) = \frac{69.7\ people}{minute}$$

$$326\ people \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{69.7\ people} = 4.7\ \ minutes$$

2. The flow time down the wide stair aisle that leads to the vomitory was calculated using the flow rate through an exit component with assumed 7-inch risers (17 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.5 above):

   Time to flow through the wide stair aisle (4' 6" wide):

$$\frac{17\ people}{feet \cdot minute} \times (4.5\ foot\ width) = \frac{76.5\ people}{minute}$$

$$326\ people \left(\frac{population}{Upper\ Bowl}\right) \times \frac{1\ minute}{76.5\ people} = 4.3\ \ minutes$$

3. The flow time through the vomitory was calculated using the flow rate through a level exit component (21 people/feet·minute) from Table B.2.1 above. The following equations illustrate the methodology for determining the total required flow time (based on the calculated flow width and population shown in Figure B.2.5 above):

   Time to flow through the vomitory (11' 2" wide):

$$\frac{21\ people}{feet \cdot minute} \times (11.2\ foot\ width) = \frac{235.2\ people}{minute}$$

$$858\ people \left(\frac{population}{Upper\ /\ Lower\ Bowl}\right) \times \frac{1\ minute}{235.2\ people} = 3.6\ \ minutes$$

   The resulting greatest flow time was 4.7 minutes (from the Upper Seating Bowl through the narrow stair aisle).Since the largest exit flow time for the East, Central and West Seating Bowl/vomitory scenarios (4.2 minutes, 3.5 minutes, and 4.7 minutes, respectively) is greater than the greatest travel time for the East, Central and West Seating Bowl/vomitory scenarios (1.2 minutes, 1.1 minutes, and 1.3 minutes, respectively), the exit flow times for each scenario will be used for the total egress time calculations with respect to each of the data points of concern. The total egress time is summed up in Table B.2.3 below:

Table B.2.3
South Main Concourse Total Egress Time

PHASE	TIME		
Fire Alarm activation (spot smoke detector)	0.8 minutes		
Time to initiate egress	0.5 minutes		
Narrow stair aisle flow from Upper Seating Bowl (greater than travel time)	4.2 minutes	3.5 minutes	4.7 minutes
South Main Concourse Total Egress Time:	**5.5 minutes**	**4.8 minutes**	**6.0 minutes**
Total Egress Time with 2009 MUBEC Safety Factor (1.5):	**8.3 minutes**	**7.2 minutes**	**9.0 minutes**

The visibility for all occupants to exit the south Main Concourse is sufficient before the visibility on the Main Concourse in the vicinity of Data Points 4C, 4D, and 4E drops below 30 feet as referenced by Appendix A of this report (the tenability limit for visibility based on data from studies referenced in the Society of Fire Protection Engineers Handbook).

Since the total egress time multiplied by the 1.5 safety factor for East, Central, and West vomitories (8.3 minutes, 7.2 minutes, and 9.0 minutes, respectively) is less than the time it takes for the visibility on the south Main Concourse in the vicinity of Data Points 4C, 4D, and 4E to drop below 30 feet (9.7 minutes, 14.5 minutes, and 18.1 minutes, respectively), sufficient time is allowed for all occupants to exit with tenable conditions six (6) feet above the Main Concourse in accordance with Section 909.8 of the 2009 MUBEC.