Fire Protection Analysis of the ‘Center for the Arts’ Building

Steven W. Carman

California Polytechnic University, San Luis Obispo

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Abstract

In partial fulfillment of the requirements for the Degree of Masters of Science in Fire Protection Engineering, a prescriptive and performance-based analysis was performed on a building housing the Center for the Arts. The building was constructed in 1947 in California as an automobile dealership and repair shop under the provisions of the then-controlling Uniform Building Code. It subsequently underwent several occupancy changes and has since served as a beauty school, gymnastics center, and currently as a performing and visual arts center.

Prescriptive analyses were conducted based primarily upon the provisions of the 2010 California Building and Fire Codes, and the 2009 edition of NFPA 101, Life Safety Code. Where required, other NFPA codes such as the 2010 editions of NFPA 13, Automatic Sprinkler Systems Handbook and NFPA 72, National Fire Alarm and Signaling Code were also referenced.

The overall fire protection system was divided into subsystems and then examined. Subsystems included those involving safe egress, fire detection and notification, water-based suppression and structural fire protection. Results are provided with respect to each.

The performance based analyses focused primarily upon the ability of occupants to safely escape the building after the onset of various fire events. The computer fire model, “Fire Dynamics Simulator”, was used to estimate the available safe egress times of occupants under various fire scenarios. The required times needed for safe egress

were determined based upon calculation methods set forth in the Society of Fire Protection Engineering Handbook. Available and required safe egress times were compared for each of the different fire scenarios.

Where deficiencies in fire protection systems were noted in the existing building layout and arrangements, recommendations for improvements are provided herein. It should be noted that these recommendations are considered a best effort and are presumed technically valid. Even so, any changes or upgrades made based upon these recommendations must still be reviewed and approved by a licensed professional fire protection engineer and the local authority having jurisdiction.

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Project Scope

Background

Fire protection analyses of buildings are performed to evaluate the level of protection from fire afforded to both life and property. Such protection may come from both passive and active systems associated with a particular facility as well as through proper procedures. Complete fire safety is extremely difficult if not impossible to design into a building and its operations since fire risk cannot be completely eliminated. It is the responsibility of building stakeholders such as owners and occupants as well as designers, builders and officials having jurisdiction to ensure fire safety objectives for a particular facility are established and pursued to provide a minimum acceptable level of safety of life and property from fire as well as to prepare for continuity of operations in the event of a fire.

Prescriptive Based Analysis

Prescriptive or specification-oriented codes and regulations such as building and fire codes exist to provide guidance for design and operational factors that have been shown to offer an acceptable level of safety. Such codes have been developed over time and changes to their contents regularly occur in response to changes in building materials, procedures and designs as well as to fire incidents shown to require modifications.

Further, changes in building designs, occupancies and uses over time often lead to modifications to building and fire protection systems required by applicable codes.

This prescriptive-based analysis is intended to examine the current state of fire protection to persons and property associated with the Center for the Arts. Changes in the building, its occupancy and its operation since being built almost 60 years ago have been outpaced by changes to the codes that existed at the time of construction. Evaluation of the current state of fire protection will afford the owners and operators a look at the current risks to life and property as well as the protections afforded to occupants, clients and visitors. It will also compare facets of the existing levels of protection with those required of new buildings.

The state of fire protection at the Center for the Arts was evaluated against several prescriptive codes. Those include: the 2010 editions of the California Building Code (CBC) and the California Fire Code (CFC); the 2009 edition of NFPA 101, the Life Safety Code (LSC); the 2010 edition of NFPA 13, Standard for the Installation of Sprinkler Systems; and the 2010 edition of NFPA 72, the National Fire Alarm and Signaling Code. In the analyses discussed below, other codes or standards will also be referenced and identified as to their specific applications.

Readers are cautioned not to consider the extent of this evaluation as all-inclusive in its findings and recommendations but more of an overall summary of present conditions. Limitations in resources and time available preclude a complete evaluation of all aspects of the total fire safety picture.

Performance Based Analysis

In examining the Center for the Arts in terms of a performance-based analysis, several design fires were devised and considered that represent realistic and possible fire scenarios that might be anticipated to occur in the building. The extent of these fires and their threat to life and property have been evaluated in terms of the existing building and fire protection systems design. While a performance based analysis for a new building design is more comprehensive, the design fires used to examine the Center for the Arts address existing conditions and their effect on occupants' tenability under various fire scenarios. Computer fire modeling was used to estimate conditions that would affect that tenability.

Prescriptive Analysis

Building Description

The Center for the Arts is a privately owned and operated performing arts center. It occupies a building completed in 1947 and built of Type III construction, commonly referred to as “Ordinary Construction”. The structure’s original function was quite different than its current use. From 1947 until 1984 it served as an automobile dealership and repair facility. It consisted of an indoor showroom at the south, offices above, and a mechanical repair facility to the north. Auto painting and body-shop repair spaces were added years later to the north.

The Center for the Arts is presently classified under the Life Safety Code (LSC) as a mixed occupancy building with specific occupancies for assembly, business and storage. It contains two theaters, one with 170 fixed and several portable seats and the other, a smaller day-theater known as the “Off Center Stage” with about 60 portable seats.

The building is oriented in a north-south direction and measures approximately 262 feet long and 72 feet wide at its limits. It is built on a sloping hillside that rises to the west. A perimeter foundation with fill supports the concrete slab floor. The front of the building opens onto a public street at the south. The northern, narrower portion of the

building opens to a private parking lot at the north and west of the property that in turn borders and empties onto a public street to the north.

Figure 1: Front (south) side of the Center for the Arts

The building consists of two floors in the front (south), a tall, single-story space in the middle section, and a shorter, single story wing further to the rear (north). The total estimated floor space is approximately 19,000 square feet with approximately 13,900 of that being on the ground floor. There are no known existing plans for the building. Measurements referred to herein are based on estimations made from direct observation.

The first floor at the front of the building houses an art gallery, theater lobby and gathering place, storage spaces, dressing rooms, restrooms and offices. The second floor

at the front of the building houses an independently operated dance studio, associated offices, dressing room and a sound studio.

Figure 2: Aerial view of the Center for the Arts (Google, 2013). North is to the left.

Figure 3: Sketch of building layout from southwest with roof shown in place

Figure 4: Sketch of building layout viewed from northwest with roof shown in place

The original two-story portion of the building at the front (southern) measures approximately 72 feet wide by 65 feet deep. Each of the two floors there is about 12 feet high and fitted with 8-foot high drop ceilings mounted in a metal “t-bar” grid framework. Exterior walls are concrete-filled, masonry block with some large display windows in the front. Interior walls are primarily gypsum board over a wooden framework.

North of the front, two-story portion of the building and separated by a 27-foot high wood-framed wall is single-story section housing the main theater that measures approximately 72 feet by 75 feet. It is open to the 27-foot high peak of the arched truss roof. Sidewalls at the base of the roof are about 16 foot high. An open, elevated platform

of slightly more than 1,000 square feet in the west portion of the theater serves as a stage. Though used as a stage, the platform it is not so classified by Section 410 of the California Building Code since it has “...no overhead hanging curtains, drops, scenery or stage effects other than lighting and sound.” A stage on the other hand is defined as having “...overhead hanging curtains, drops, scenery or stage effects other than lighting and sound.” The main floor of the theater is of a slightly elevated wood design likely installed for cushioning when the building housed a gymnasium in that space.

Figure 5: Main theater platform viewed from the fixed seating area. Note the lack of overhead curtains leading to the designation as a platform.

Much of the eastern half of the main theater is filled by 170 fixed, loge-type seats mounted to an enclosed, stepped, wooden framework. The highest level of seating is

about 6 feet above the main floor. Just north of the seating area is a part-time lounge complete with a small bar to serve light food and drink.

Figure 6: Fixed seating in the main theater and portable seats in front. Arched roof trusses are visible as well as elevated theatrical lighting fixtures.

Figure 7: Lounge area north of fixed seating in main theater

Two, 12-foot high storage areas/rooms arranged one on top of the other are located immediately north of the platform/stage and occupy the northwest corner of the main theater space. Access to the upper storage is from the north end of the platform while the lower storage is entered through a garage-door sized opening immediately west of the lounge area. At the northeast corner of the main theater space are two more storage rooms that extend approximately fifteen feet north of the north wall of the theater and mark the original northern extent of the building.

The newer, single-story wing north of the main theater is attached to the eastern half of the original structure. This wing measures about 30 feet east-west as compared to the original building's 72-foot width. It contains four primary spaces that serve as a

smaller theater, lobby, dressing and accessory rooms and storage. A bow-truss roof tops this part of the building. The peak of the roof rises to about 16 feet. Sidewalls are about 11 feet high. There are no direct connections for interior passage between the original building and the newer wing to the north. Access to the northern wing is only through doors in the west exterior wall.

Figure 8: North wing of the Center for the Arts viewed to the southeast

Figure 9: Exploded sketch of building viewed from southwest

Figure 10: Exploded sketch of building viewed from northwest

Figure 11: Rear theater audience seating viewed from the platform/stage

Egress

Despite all the attempts made to prevent fires in buildings, it is unrealistic to believe complete fire safety can be fully achieved in public buildings since the risk of fire can never be eliminated. As a result, a major part of fire prevention efforts is the application of minimum criteria for egress provisions to allow and foster the timely escape of occupants from buildings in the event of a fire. Because of the obvious importance of this aspect of fire prevention, egress analysis of the Center for the Arts is the first topic to be discussed.

Egress analysis includes examination of a wide array of factors including the type and numbers of people occupying a building, the uses in which a building might be expected to be employed, the number, layout and access to exits from a building and factors that might inhibit the prompt and safe evacuation of occupants through those exits. Each of these topics is addressed below as they apply to the Center for the Arts. Lastly, a specific analysis of the Center for the Arts layout is offered in terms of determining the required safe egress time (RSET). That required time needed to safely exit will subsequently be compared with the available safe egress time (ASET) determined in the performance based analysis by evaluating potential fire scenarios.

Occupancy

Section 302 of the 2010 edition of the California Building Code (CBC) classifies building occupancy based upon the use of a structure. In instances where there are multiple uses, building are classified by Section 508 of the CBC as having multiple occupancies.

The occupancy classifications of the Center for the Arts have changed over time. Presently, the building meets the definition of a multi-occupancy structure. The various classifications assigned as part of this analysis include: Assembly (Group A-1) for the theaters, lobbies/waiting areas, art gallery and dance studios; Business (Group B) for rooms and areas used for business administration of the facilities; and Storage (Group S-1) for those spaces used to store the various equipment, props and theatrical equipment needed to support various productions and dance studio operations.

The 2009 edition of the Life Safety Code also specifies occupancy classifications in addition to those set forth in the CBC. Section 6.1.2.1 defines Assembly occupancy as covering a building or space in which 50 or more persons gather for amusement including in theaters. Section 6.1.11.1 defines Business occupancies as used for the transaction of business other than mercantile. Section 6.1.13.1 defines Storage occupancy as an occupancy used primarily for the storage or sheltering of goods, merchandise, products, or vehicles. Each of these generally agrees with the CBC in the broad classifications that have been assigned to spaces in the Center for the Arts although sub-classifications such as A-1 or S-1 are not included.

The Authorities Having Jurisdiction (AHJ) over the Center for the Arts are the local city fire and building departments. Should questions arise as to classifications of various spaces in the building, Section 6.1.1 of the Life Safety Code assigns the AHJ as responsible for determining whether the occupancy has been correctly classified.

The distributions of the various occupancy classifications throughout the building are shown in Figures 12 through 14. In each of the figures, North is to the left. Figure 12 depicts a plan view of the first floor at the front of the building. Figure 13 shows the northern wing. Figure 14 is for the second floor of the building. The color legend shown in Table 1 shows the occupancy classifications in terms of colors displayed in the occupancy diagrams.

Compartment Occupancy Key	
	Assembly
	Business
	Storage
	Exit Stairs

Table 1: Compartment Occupancy Key

Figure 12: Occupancy Classification of the Front First Floor Spaces. North is depicted towards the left.

Occupancy Areas (ft ²) by Classification			
	Occupancy Classification		
Area of Building	Business	Assembly	Storage
Front Office / Lobby / Art Gallery	1,950	2,410	0
Main Theater / Platform/Stage	0	4,450	1,550
North (Rear) Wing	560	1,950	1,140
Second Floor	990	2,975	270

Table 2: Approximate Building Areas by Occupancy Classification

Figure 13: Occupancy Classification of the Rear First Floor Spaces. North is depicted towards the left.

Figure 14: Occupancy Classification of the Second Floor Spaces. North is depicted towards the left.

The layout of exits in the Center for the Arts building was established long before the current occupancy usage began. When the occupancy of the building shifted in about 2002 to that currently in use, the AHJ did not require significant changes as to the number or arrangement of exits. As a result, in some instances, the remoteness and location of exits today do not meet the prescriptive code requirements of either the CBC, CFC or the LSC. Whether a formal waiver was granted by the AHJ is uncertain. Present day AHJ staff members are aware of the layout of the exits.

Occupancy Load

The building's overall occupancy load was calculated using Table 7.3.1.2 of the Life Safety Code based upon occupancy classifications assigned individual spaces. Though the building is listed as "multiple-occupancy", its primary use throughout is Assembly (A-1). The sizes and occupancy classifications of the various spaces are detailed in Table 2 and specified in greater detail in Appendix A.

The building's maximum occupancy was determined to be 1,061 persons. That consists of 849 persons on the ground floor and 211 on the second floor. For calculation purposes, the ground floor occupancy was subdivided into three areas including, 1) the art gallery, 2) the main theater, front lobby and business areas, and 3) the rear theater, rear lobby and rear storage rooms. Primary occupancy loading was determined in accordance with the factors set forth in Table 7.3.1.2 of the LSC. Minor exceptions were

made specifically as related to restroom capacity (which is not detailed in the LSC) and areas to the front and sides of the main theater fixed seating.

Some modifications to the maximum occupancy load might be called for based upon the normal Center for the Arts' practices. Those modifications relate to the fact that when the main theater is in use for productions, the areas to the front and side of the fixed theater seating are, as a matter of practice either void of people or not filled to capacity. Even so, for purposes of this analysis, each of those areas were considered at maximum capacity as per the LSC to provide a more conservative estimate of required safe egress time (RSET).

Adequacy of Exits

The overall adequacy of the number of exits and means of egress was evaluated using the general provisions of Sections 7.3 through 7.10 of the LSC as well as Chapter 10 of both the CBC and the CFC. Since the requirements of each of these codes are similar with regards to egress, only the requirements of the LSC will be discussed herein.

Required Number of Exits

The building, due to its varying occupancy types was evaluated in terms of egress capacity both for specific sections as well as overall. The maximum occupancy load was calculated as 1,061. Section 7.4.1.2 of the Life Safety Code (2009 edition) requires a building with an occupancy load of more than 1,000 to have 4 exits. This building,

because of its somewhat complex layout has 7 exit discharge doors. With regards to number of exits alone, the building design adequately complies with this mandate of the LSC. The layout of exits and travel paths to those exits are presented in Figures 86 through 92 in Appendix B.

Exit Access Apart from Passing Through Intervening Rooms

Section 7.5.1.2 of the LSC states, “Corridors shall provide exit access without passing through intervening rooms other than corridors, lobbies, and other spaces permitted to be open to the corridor unless otherwise provided in 7.5.1.2.1 and 7.5.1.2.2.” The first of these two exceptions allow for existing buildings to continue using passage through a room to access an exit if approved by the AHJ, if the travel path is marked, doors along the path are in compliance with other exit requirements and there is no other prohibition.

In the Center for the Arts, some of the exit paths pass through other rooms. Even so, it appears that such a layout is generally in compliance with the provisions set forth in Section 7.5.1.2.1 of the LSC. The building layout also complies with Section 7.5.1.6, which allows for continued use of existing passages to pass through other rooms if approved by the AHJ.

Access to the first floor exit from the front lobby and half of the main theater is adequate if people use both the main entry door and the art gallery exit door. The occupant load of 378 (for half of the main theater and all of the front lobby) is excessive

for the 360-person capacity served by just the 72-inch wide main lobby door. This extra load is adequately handled however if some of the people divert into and through the art gallery and used the exit discharge door there. The location of the art gallery door does not strictly meet the LSC provisions with regard to remoteness of exits since the art gallery exit and main exit are not adequately separated as required by Section 7.5.1.3.2 of the LSC. That provision requires they be located at a distance from one another of not less than one-half the diagonal dimension of the area to be served. To meet this requirement, the two doors would have to be about 60 feet apart. They are in fact about 12 feet from each other.

The second floor has two exits doors. The first is the normal entrance and exit located at street level at the southeast corner of the building that is used by most people. A second exit, an emergency exit located at the north wall of the second floor does not lead directly out of the building but instead passes into and through the main theater. Stairs for this exit lead down to the south edge of the platform/stage. There, evacuees can choose to go directly to the theater's north exit door that discharges into the rear parking area or use one of two paths to go the main exit door to the south. The second floor rear exit stairs terminate adjacent to a door to the front dressing room. That dressing room in turn opens into the front lobby. Evacuees could also leave the platform/stage and use the south exit from the theater into the front lobby and out the front of the building that way.

Remoteness of Exits

The remoteness requirements for exits set forth in Sections 7.5.1.3.1 and 7.5.1.3.2 of the LSC are satisfied in only part of the Center for the Arts building. The main theater has exits in the north and south walls. Those doors are sufficiently distant from each other. The north exit discharges to a parking lot at the north exterior of the building. The south exit leads into the front lobby. That lobby has a single main exit discharge in the south wall that empties onto a public street. Section 7.5.1.6 of the LSC states, “Exit access from rooms or spaces shall be permitted to be through adjoining or intervening rooms or areas, provided that such rooms or areas are accessory to the area served. *Foyers, lobbies, and reception rooms* constructed as required for corridors shall not be construed as intervening rooms.” Accordingly, the south door of the theater is permitted to empty into the front lobby.

As mentioned earlier, the exit doors in the front lobby do not meet the remoteness requirement. There are two ways out of this room besides the main entry. One requires going into and through the adjoining art gallery to an exit that discharges onto a public street. The interior door to the art gallery is only about five feet away from the main exit. The second path out of the main lobby other than through the main exit would be going north through the door into the main theater. If the people evacuating the building originated in the theater, then clearly the theater door would be an entrance into the front lobby and not an exit out of it.

Figure 15: The main exit from the front lobby (shown centered) is only steps away from the entry to the art gallery (shown behind the easel) that leads to another exit.

The door between the front lobby and the theater would qualify as a final exit from either room if the separating wall between them met the requirements for a horizontal exit. Currently it does not.

Section 3.3.75.1 of the LSC defines a horizontal exit as, “A way of passage from one building to an area of refuge in another building on approximately the same level, or a way of passage through or around a *fire barrier* to an area of refuge on approximately the same level in the same building that affords safety from fire and smoke originating from the area of incidence and areas communicating therewith.” The wall separating the main theater from the front lobby (and from the second floor) does not meet the fire resistance requirements of a fire barrier. First, the 72-inch wide door between the theater

and the front lobby is not a fire-rated door. Also, there are several non-sealed penetrations at various levels including several HVAC ducting runs.

Figure 16: The door between the front lobby and the main theater. The non fire-rated door plus wall penetrations prevent use of this passage as a horizontal exit.

Exit remoteness requirements are likely not met in the rear theater either. While the distance between two openings that could be used as exits is sufficient, most theater occupants will likely only be aware of one of them. The main 72-inch wide exit in the west wall opens from the theater into a parking lot and is clearly visible. A 36-inch doorway located 30 feet north behind the stage is not readily apparent from audience seating. That doorway leads from behind the platform/stage and into and through the sprinkler control room, which in turn opens to the exterior. Because stage sets are

usually positioned between that doorway and the audience blocking its view, most people would be unaware it exists. Section 7.5.1.1 of the LSC requires that, “Exits shall be located and exit access shall be arranged so that exits are readily accessible at all times.” While these two exits are separated by more than half of the 55 foot diagonal measurement of the rear theater, until both doors are clearly visible at all times, the exit arrangement in the room is deficient.

Figure 17: A 36-inch doorway leading to an exit in the sprinkler control room is located behind the platform/stage and is neither clearly marked nor readily accessible.

Figure 18: 16 feet beyond the main exit (at the right) is an exit hallway to the rear lobby. Each requires travel past the edge of the seating through a 52-inch wide walkway.

A third exit also leads out of the rear theater. A 36-inch hallway behind the seating and south of the theater's main exit connects to the rear lobby. The entrance to the hallway is about 16 feet away from the theater's primary exit. If the main exit is blocked by fire or an obstruction, reaching the hallway would be very difficult. The second exit behind the stage that leads into and through the sprinkler control room would be the only alternative egress path.

On the second floor, remoteness requirements are met both in individual rooms as well as for the two exits from the floor. The main exit leads down stairs and discharges on a public street. A second, emergency exit passes through a fire door in the north wall and to an open staircase that leads down to the south edge of the main platform/stage.

Further exit from there is either through a door into the front dressing room and then onto the front lobby or into the main theater and through one of its two theater exits. Although these interior stairs to the main theater allow an alternate path out of the second floor, because of their location high in the main theater, they would be almost immediately subject to smoke conditions and unusable if a fire was burning in the theater.

If the wall between the main theater and the second floor was a qualifying firewall as defined in Section 3.3.75.1 of the LSC for a horizontal exit, the rear stairs might be an adequate exit. Currently however, that is not the situation. In order for the stairs to comply with the prescriptive requirements of the LSC, they would have to either enter a smoke proof enclosure inside the theater or a separating wall would have to be constructed to qualify that door as a horizontal exit. The rear exit door from the second floor currently is a fire rated door.

Dead Ends

Provisions related to dead-end travel are set forth in Table A.7.6 of the LSC. For both new and existing assembly occupancies, regardless of whether or not they are sprinklered, the limit for dead end travel is 20 feet. The only dead ends in the front lobby could be entered either by moving into the hall leading towards the bathrooms or entering the business office from the main entrance lobby foyer. The bathroom path extends less than 20 feet from the main lobby and does not violate the dead end provision. Someone walking into and through the office however could travel more than 20 feet before

reaching a dead end, forcing them to turn around. This path is technically in violation of the 20-foot long dead end limit. Since the main exit is a glass double door in a glass wall however, it seems unlikely anyone leaving the building would instead bypass the exit door by making a sharp left turn and entering the office rather than just continuing straight ahead through the main exit door only 4 feet away.

Figure 19: Dead end hallway from front lobby leading to restrooms.

In the main theater, a dead end path lies alongside the south side of the fixed seating, but as with the office scenario, the possibility of people traveling that path seems remote. To enter that dead end, one would have to walk past the adjacent exit door. It seems unlikely anyone would pass immediately next to the exit door without noticing it. Since the theater ceiling height is 27 feet high at the peak and since it is sprinklered,

smoke levels would likely remain above the door for a long enough period after the onset of a fire so the first people moving to the exit would not bypass the door without seeing it. If they did however, the distance they might travel before having to turn around would be approximately 20 feet. During each of the assessment visits to the Center for the Arts, the rear portion of that pathway was blocked by chair storage usually making the dead end distance less than 20 feet.

Another possible dead end path in the theater would involve travel towards the bar at the north of the fixed seating area. Like the previous mentioned path at the south end of the fixed seating, turning towards the bar seems an unlikely choice. Normal exit flow to the north would have to be interrupted by a sharp turn to the east. Should that happen, the distance to the east wall dead end would be approximately 36 feet.

On the second floor, the only potential dead end would be leaving Dance Studio 3 towards the exit stairs to the exterior and entering a short walkway leading to the storage room. The walkway is adjacent to the exit stairs. Both paths initially lead to the east. The dead end distance involved is less than 10 feet.

Travel Distance Limit

Travel distance limits are prescribed in Table A.7.6 of the LSC. The travel distance limit of 250 feet for sprinklered buildings is easily met throughout the Center for the Arts. The entire structure is approximately 262 feet long and there is no means by which one could travel completely inside the building over that entire distance.

On the second floor, exceeding the travel distance limits is not an issue. Egress through the main exit to the exterior of the building involves a maximum distance of about 100 feet. If one exited through the rear of the second floor into the main theater below, then once on the ground floor, the travel distance to either the rear or front exits would be approximately 100 feet. Even considering the longest possible second floor path in addition to the remaining distance on the ground floor, the overall travel path remains well below the allowable 250 feet.

Discharge from Exits

All paths to exits on the first floor lead directly to exit discharges from the building. From the second floor, the emergency exit first leads into the main theater where paths to first floor exit discharges are located. Neither of the second floor exits require a change in direction to head in an upward direction once downward travel commences.

The three exits at the front of the building, in the art gallery, the main lobby and the second floor stairs each discharge directly to a public sidewalk. That sidewalk allows movement away from the building in either direction. At the rear, exits open at a large parking lot owned by the Center for the Arts, which in turn connects to a public street and sidewalk and allows for movement away from the building.

Illumination of Means of Egress

During musical and stage productions, both theaters are typically darkened with only dim theater lighting showing. All of the exits out of the main theater are lit with standard, interior backlit green illumination signs marked "EXIT". The main exit from the rear theater is also clearly marked in the same manner. Other exits including those in the main and rear lobbies, the art gallery, and those from the second floor are similarly marked. Each "EXIT" sign has battery backup systems that are tested regularly. Packaged with the signs are dual floodlights that also have emergency battery power. These signs are mounted directly above each exit, no more than a foot above the top of the 80-inch high doors in accordance with Section 7.10.1.9 of the LSC. The doorway behind the rear stage leading into the sprinkler control room is the only exit not marked with an "EXIT" sign.

The main theater fixed seating has rows of flexible tube lights with LED lighting that mark the exit pathways out of the seating area and onto the main floor which then leads to exits marked with lighted signs. Similarly, the railing along the stairs from the second floor into the theater is also marked with LED lighting.

Interior Finishes

The requirements for interior finish of buildings are found in section 10.2 of the LSC. In addition to describing the various testing methods allowed for testing finishes, multiple finish classifications are also listed.

Interior finish requirements set forth in A.10.2.2 of the LSC call for all exits in an assembly occupancy to meet interior finish Class A materials. Exit access corridors and most other spaces must meet Class A or B. The Center for the Arts is sprinklered throughout. Accordingly in any area where Class B finish materials are called for, Class C materials suffice. Likewise, because of the sprinklers, where Class A materials are called out, Class B materials will suffice in their place. Section 13.3.3.3 of the LSC requires that in existing buildings with general assembly areas having occupant loads of more than 300, interior wall and ceiling finish materials shall also be rated Class A or Class B. These classifications are obtained through testing using either the ASTM E84 “Steiner Tunnel” test or ANSI/UL 723 test.

The interior ceiling finish throughout the main and rear theaters in the Center for the Arts and much of the second floor dance studios poses a serious concern in this regard. Ceilings in these areas are lined with exposed insulation affixed to the underside of the roof. The facing of the insulation on the exposed side is a paper-like material. In each of the theaters, this facing has been painted black to reduce light reflection.

Figure 20: Exposed, painted, paper-like insulation facing on the underside of the entire main theater ceiling

Figure 21: Close up view of exposed, paper-like insulation facing under the main theater ceiling. Here it is shown cut where penetrated by sprinkler piping.

Figure 22: Similar exposed, insulation facing on the underside of rear theater ceiling

Figure 23: Exposed, insulation facing on the underside of the ceiling on the second floor. It is unknown if white is the material's original color or if it also has been painted.

Center for the Arts personnel were unaware whether the exposed ceiling finish throughout the building had been tested for flame spread and smoke generation in accordance with the ASTM E-84 or ANSI/UL 723 tests or if it was ever assigned an interior finish classification. A simple, open flame test of the insulation facing was conducted by Center for the Arts personnel. A small section of the painted, paper-like facing was exposed to an open flame of a cigarette lighter. The material readily ignited. While such a test is insufficient to assign a flame spread rating, it clearly shows the need to have the material properly tested at the soonest opportunity. If it does not achieve at least a Class B rating as required by 13.3.3.3, prompt, remedial measures should be taken to either treat, remove or cover the exposed insulation facing.

Another potential fire safety issue with interior finish is the flammability of the vertical hanging curtains/sound dampening cloth panels located at each side and the rear of the main platform/stage. Section 10.3.1 of the LSC states, “Where required by the applicable provisions of this Code, draperies, curtains, and other similar loosely hanging furnishings and decorations shall meet the flame propagation performance criteria contained in NFPA 701, Standard Methods of Fire Tests for Flame Propagation of Textiles and Films.” Section 13.7.4.1 of the LSC governing *existing* assembly occupancies states, “Fabrics and films used for decorative purposes, all draperies and curtains, and similar furnishings shall be in accordance with the provisions of 10.3.1.” Section 806.1 of the CBC states that in assembly occupancies, “...curtains, draperies, hangings and other decorative materials suspended from walls or ceilings shall meet the flame propagation performance criteria of NFPA 701 ... or be noncombustible.” These sections clearly require that the curtains in the Center for the Arts’ theater must be or have been tested and meet related flame propagation standards.

The NFPA 701 tests involve applying a burner flame to a vertically positioned sample of a material (such as the curtains) for a specified time. Upon removal of the flame, the sample must self-extinguish and must not have charred beyond a specified distance in order to pass the test.

Figure 24: Main theater curtains immediately adjacent to the second floor exit stairs

Though there are anecdotal reports that the Center for the Arts' curtains may have been treated with fire retardant materials, no known documentation was found showing evidence they had undergone NFPA 701 flame propagation testing. Curtains that do not pass such a test could, if ignited, pose a danger not only to the actors/stagehands on or near the platform/stage but also to the audience throughout the main theater. Non-fire-resistant curtains would also present an extreme threat to occupants of the second floor who might be forced to use the rear, emergency exit stairs. Those stairs discharge to the south edge of the stage immediately adjacent to the curtain panels.

The Center for the Arts' exterior walls are painted, concrete block. Flooring generally consists of hardwood panels mounted over a concrete underlayment. Interior walls are typically gypsum board attached to wooden studs. The front lobby and business

spaces have a “T-bar”, metal, ceiling grid support system into which standard mineral tiles are laid. Above the 9-foot high drop ceilings are approximately 3 foot ceiling void spaces through which standard HVAC systems and other support systems such as electrical power is routed.

Types of Occupants

Since the Center for the Arts now serves primarily as a public venue for various types of live entertainment, it is likely that many occupants will be visitors not intimately familiar with the layout of the building or its egress systems. Alcohol is not regularly served in the building but occasionally some alcohol is available at one of two portable bars. Such alcohol service is not the primary focus of the businesses but is merely an ancillary activity. Rarely is inebriation by guests a concern.

The occupants of the upper floor are also generally transient in nature with the typical visitors there attending the dance studio and instruction facility. It is possible that many of those people are repeat visitors who are more likely to be familiar with the regular exit that is also the principal entrance, than would be visitors to the ground floor theaters.

The second floor facilities are typically operated during standard business hours and the majority of the visitors are juveniles or young adults. Some mature adults also visit the facility either as tenants, instructors or for other business interests. The ground floor theaters are used both for with matinee presentations as well as more typical

evening performances. The main theater also serves as a training facility for actors and entertainers during non-event hours.

If a fire were to occur on the second floor, that area in the building will likely be staffed with regular employees who are familiar with the egress systems and exit passages. It is not known whether these employees participate in regular fire or other emergency drills or if they regularly instruct their students or customers about the same information.

Pre-movement activities for the second floor are expected to be similar to those experienced with most business occupancies. If regular fire drills are not conducted it is likely that the persons inside could spend the first few minutes attempting to verify the validity of an fire if they do not receive outside confirming signals such as the odor of smoke to indicate a fire.

Dance students on the second floor might be dressed in atypical public attire such as leotards or other dance garb. With many of these participants being young females, it could be expected that prior to exiting the building, they might try to gather clothing and personal belongings from the second floor dressing room. Also, there may be music playing to accompany their dance or exercise routines. Such music might interfere with prompt recognition of alarm notification signals.

Accordingly, for the second floor, the pre-movement time before occupants actually departing through the two exit doors is estimated at up to three to five minutes. The second floor is only about 75 foot square so once occupants decide to move, travel

times to an exit will be relatively short. Once egress begins, there is only one floor to descend through with a vertical height of approximately 12 feet.

In the main theater, lighting is typically dimmed during performances. One danger in any performing arts venue is that the event of a fire, the audience might not immediately recognize an alarm or fire as a real event and not merely part of the show. Dimmed lighting and potentially loud music from performances are expected to add to the recognition time of a fire event. This was one of the problems encountered at the Station Nightclub fire in 2003 in Rhode Island where people did not recognize that the initial fire posed a real threat and was not just part of the show. As a result, extended pre-movement times and flammable interior finish contributed to the deaths of 100 people and injuries to about 230 more.

It is anticipated that people inside the main theater will start moving towards an exit within two minutes of hearing or seeing the results of an alarm activation or fire. Pre-movement times for main theater guests may be shorter than for second floor dance studio visitors since theater guests will not typically have many belongings to be concerned about. Further, the onset of several people starting to leave the theater should serve as a signal to others that they should also evacuate.

The front lobby south of the main theater can serve as gathering/meeting place for local events. Visitors there may not readily appreciate a fire event in the main theater. Double doors separate the front lobby and theater. Door windows are covered with privacy fabric to keep light out of the theater.

It is anticipated that should a fire occur in the main theater or in an adjoining space, the occupants in the front lobby may have extended pre-movement times since it may take considerably longer for them to recognize that a fire is burning. That along with a set of glass doors in clear view less than 50 feet away may make these persons feel more secure in their ability to exit. Two to three minutes of pre-movement time is anticipated for these people. The front occupants' first indication of a fire elsewhere in the building might be seeing people from inside the main theater evacuating through the doors that open to the front lobby on their way to the main exit.

The total floor space in the smaller, rear theater is slightly less than 1,000 square feet. Between the actors, the stagehands and the approximately 60 guests expected during a performance, it is not anticipated that a fire in that space would go unnoticed for long. Distances to adjacent exits are no greater than 40 feet so once people start moving towards an exit the movement should be quickly noticed. Pre-movement time in the rear theater would likely be on the order of one minute or less.

RSET Estimations

Required Safe Egress Time or RSET, the estimated time needed to evacuate a building is dependent upon several variables. These variables include the time to detect and notify occupants of a fire, the time taken by occupants to recognize the need to evacuate and then start moving, and then the travel time of the actual evacuation. According to Nelson and Mowrer's chapter on "Emergency Movement" in the 3rd edition

of the Society of Fire Protection Engineering Handbook, “RSET can be subdivided into a number of discrete time intervals, the sum of which constitute the total RSET...” An equation proposed to demonstrate this principle is:

$$RSET = t_d + t_a + t_o + t_i + t_e$$

where: t_d = time from ignition to detection

t_a = time from detection to notification of occupants

t_o = time from notification until occupants decide to take action

t_i = time from decision to take action until evacuation commences

t_e = time from the start to the completion of evacuation

These time relationships and their relationship to one another are depicted in the following diagram.

Figure 25: Graphical relationship between ASET and RSET

Often in such analyses, detection and notification time (shown above as t_d) is based upon detection by smoke and/or heat detectors which in turn activate notification devices such as horns or strobes. Because of the lack of these devices in the Center for the Arts, such a time equivalency does not exist throughout most of the building. As a result, determination of detection and notification time in determining RSET is based upon an evaluator's best judgment.

At present, there are no smoke detectors installed in the main theater area nor are there any notification devices. Previously, the AHJ decided that the presence of sprinklers were adequate for notification. If a fire started and hot gases rose to the arched roof and activated sprinklers, then visitors may be "notified" in the manner of a notification

device. The problem with such a scenario is that with a flammable ceiling finish throughout the theater, by the time a sprinkler activated, fire growth could be extremely fast and untenable conditions could be quickly reached.

If a fire was to occur on the platform/stage out of sight of main theater visitors but not trigger sprinklers to activate, the first indication of a fire by guests might be an interruption of a production and unexpected, yet hurried evacuation of the stage area. The confusion by visitors that would be expected to accompany such an interruption could cause a significant delay in deciphering whether the actions are part of the show. That confusion may extend the detection time far beyond what would be expected if detection and notification devices were in place and functioning.

It is anticipated that pre-movement times for occupants in most spaces of the Center for the Arts, particularly during productions, will be noticeably longer than perhaps they would be for the same people in most business or mercantile facilities. These delays will in large part depend upon how long it takes for the first occupants to detect something that is extremely unusual by their seeing flames, smelling smoke, being directed by others who have already detected the fire or by seeing an unexpected and hurried movement of people towards exits.

Uncertainty in the analysis of movement time is based in part on occupant characteristics and their conditions at the time of evacuation. The ages of visitors to the Center for the Arts ranges from the very young to the elderly, some perhaps in wheelchairs or with limited mobility. A majority of the people in the facility during

productions could be first time visitors. Even those who might be more familiar with the facility due to having attended numerous productions may still be completely unfamiliar with any egress path besides their typical route in and out of the building.

According to Center for the Arts staff, while alcohol is occasionally served, it rarely results in inebriation. Even so, considering the likely lack of familiarization by visitors with the building, the variations in their physical condition, and the prospect of their being in darkened and loud conditions during productions and thus not having their normal levels of sight and hearing, the movement times estimated herein should be considered as minimums for fires occurring during productions. At other times such as during visits to the facility outside productions, occupancy levels would be expected to be far lower than at the maximum and fewer people would be available to signal the need to evacuate.

In light of these factors, it is imperative that the Center for the Arts staff and performers are trained in and willing participants for notifying visitors of possible fires and assisting them in evacuations. The leadership role of staff members can, if enthusiastically embraced, reduce pre-movement time and as a result, overall evacuation time.

Estimated Movement Times

Calculations of estimated movement times are detailed in Appendix A. The general factors regarding each space that are used in those calculations are discussed below.

Art Gallery

The art gallery is located at the front of the building and fronts a public street. It measures slightly less than 1,000 square feet in area and is used for various meetings and art displays independent of productions in either of the theaters. The maximum occupancy of the gallery was determined to be 132 persons based on a concentrated usage calculation in which space allotted per person is less than half of “less concentrated” use (see Appendix A). Under “less concentrated” use conditions such as when tables are used in the room and seating is provided, the occupancy load would be 62 persons. The gallery has one, 72-inch exit door that discharges onto the street. It also has another 72-inch door that leads to the front lobby about 5 feet from the building’s main exit. Assuming everyone is equally spaced through the art gallery and heads to the exit at about the same time, it is estimated that evacuating the maximum 132 people from the art gallery will take about 66 seconds.

Front Lobby and Adjacent Rooms (less main theater population)

The front lobby and adjacent rooms encompass the first floor of the structure south of the main theater apart from the art gallery. The area includes offices, the main lobby, restrooms, and a dressing room for performers. It will be referred to collectively as the front lobby. Its maximum occupancy load is 199 people (see Appendix A). The front lobby discharges to the exterior of the building through a 72-inch wide glass door. Another 72-inch wide door within feet of the main exit door leads into the art gallery and accesses its 72-inch wide glass door that also discharges to the exterior of the building.

Assuming the people are equally spaced throughout the front lobby and adjacent rooms, the longest travel distance to the discharge door exit is about 80 feet. It is assumed that there will be minimal queuing at the front exit door when only occupants in these spaces are considered. Movement times for the evacuation of the front lobby are estimated to be on the order of 119 seconds.

Main Theater, Platform/Stage, and Adjoining Supply Rooms

The main theater and its ancillary spaces are located just north of the front lobby and measure approximately 5,400 square feet. The maximum occupant load for this area was calculated at 358 people (see Appendix A). This value is higher than the occupancy loads experienced during non-production times. The main theater area has fixed seating that includes 170 loge-type seats on a progressively elevated, enclosed wooden

framework and up to 50 moveable seats that can be placed on the main floor in front of the elevated seating. A lounge area adjacent and north of the fixed seating section is available for visitors to get drinks and light food items prior to the start of a production. The occupant load of the lounge area and bar was calculated to be 48 people. During actual production events, people do not congregate in the lounge area but must be seated. Even so, the occupancy load of 48 was included in the maximum capacity analyzed in this evaluation. Lastly, the platform stage area and ancillary storage rooms have a maximum occupancy of 90 people. In total, the maximum occupancy load in the main theater is estimated at 358 people.

It is assumed that in the case of a fire, the people in the theater will divide in near-equal groups and head to one of the two, 72-inch wide exit doors for the theater. The rear exit discharge door in the north wall of the theater leads to a parking lot at the rear of the building. The front door leads into the front lobby and then to the front exit discharge door.

The raised, seating platform consists of seven rows of fixed seats with spring-loaded seat bottoms that lift when an occupant stands. After the seats rise, there is an approximately 18-inch wide path between rows of seats for people to walk through. There are two aisles of stairs for people to enter and leave the seating platform, one on each side. The average distance for a person to walk from their seat to the closest aisle is about 12 feet. The steps on these exit aisles each have treads of about 40 inches and risers of about 7 inches. They lead to sets of three steps at the bottom of each exit aisle

that in turn descend 21 inches to the main floor. For the last person to reach the ground floor by first traversing their seating row and then down the exit aisle and steps involves about 40 feet of horizontal travel plus the equivalent of about 6 feet of vertical descent from the top row.

Estimations were made of the movement times for evacuations using one or both exits. The movement times ranged between 2.6 minutes when both doors were available to 3.3 minutes when only one door could be used. Specific calculations are presented in Appendix A.

Rear Theater, Platform/Stage and Actor Areas

The rear theater, platform/stage area and actor spaces have a maximum occupant load of 110 people. The rear theater floor measures about 1,500 square feet. Of that, approximately 400 square feet is seating and the remainder includes the stage, the area between the audience and the stage, and the control room and actor areas. It is estimated that because of the room's size, the time to alert the people in this area of a fire will be minimal and that pre-movement times will be negligible.

A 72-inch wide door serves the rear theater. Most of the occupants (less actors in their spaces or people in the control room will have to pass this door when entering the theater through the 36-inch wide hallway from the rear lobby. It is assumed that most people will exit through the main door inside the rear theater rather than bypassing it in favor of the hallway (13 feet away) to return to the lobby to exit.

Of the maximum 110 people in the rear theater, about 60 people are expected to be seated on a tiered, seating platform, the highest point of which is 2 feet above the floor. Chairs there are portable and arranged together but unconnected nor affixed to the platform. According to the Section 1028.12 of the California Fire Code, “In places of assembly, the seats shall be securely fastened to the floor.” Exception 4 to that provision states, “In places of assembly where flexibility of the seating arrangement is an integral part of the design and function of the space and seating is on tiered levels, a maximum of 200 seats shall not be required to be fastened to the floor. Plans showing seating, tiers and *aisles* shall be submitted for approval.” Despite the possibility of the seats being tipped over leading to potential obstructions during an evacuation, this exception to the CFC allows for the seating in the rear theater to remain loosely positioned as long as the arrangement of those seats conforms to the plans submitted to the AHJ.

The furthest distance from the main door in the rear theater is about 40 feet of horizontal travel. That plus the travel distance on the seating platform makes the maximum distance anyone would have to travel on the order of 50 feet or less.

To reach the main exit door, occupants will have to pass through a narrowed walkway between the seating platform and the west wall. That walkway is about 52 inches wide. The south entrance to that walkway from the seating area and stage could become a chokepoint where queuing might be expected. Considering delays that might be experienced at that chokepoint if queuing occurred, it would take approximately 1.5

minutes for all 110 people to pass the chokepoint and leave through the main exit door once movement begins.

A second option for people to evacuate from the rear theater would be for some to pass through the unmarked doorway behind the platform/stage and on through the sprinkler control room exit to the exterior. The interior doorway is unmarked however and generally blocked from view and egress by the stage sets. Accordingly, the only people likely familiar with that route would be actors and those who regularly work in the theater. If 10 people were familiar with and used that route, it would only reduce the overall time to evacuate the theater by about 7 seconds to a total time of about 1 minute and 23 seconds.

Rear Lobby, Dressing Rooms and Restrooms

The rear lobby, dressing rooms and restrooms have a maximum occupant load of 48 people. The occupant load for the adjacent rear supply rooms is 3 people. The supply rooms are fitted with a 72-inch wide exit door and a 96-inch wide garage type roll-up door. Egress should not pose a problem from them and they will not be considered further.

The rear lobby has a 72-inch wide door that opens onto the parking lot. The door could accommodate a pass-through rate of 120 people per minute. Considering the maximum expected number of occupants, no queuing is expected. If egress through the

door was somehow blocked, occupants could also travel through a hallway or the dressing rooms into the rear theater and exit through the 72 inch door there.

If the lobby door is not blocked and all occupants exit through it, the time to evacuate will be approximately 24 seconds which includes the time to walk the maximum distance of about 50 feet to the exit.

Second Floor

The second floor occupancies are situated over the combination of the first floor lobby, adjacent rooms and the art gallery. They include a dance studio (with three dance rooms), a dressing room, offices and reception area, a sound studio, associated hallways, restrooms and a storage room. The total second floor space measures approximately 5000 square feet.

According to calculations shown in Appendix A, the maximum occupancy load of the second floor is 211 people. The second floor is fitted with two stair exits. One of the stairs serves as the main and typical entrance / exit to the second floor. It is entered from and discharges directly to a sidewalk at the front exterior of the building. A second stair designed to serve only as an emergency exit is located at the rear (north side) of the second floor at the reception area. It provides egress from the second floor down to the first floor inside the main theater adjacent to the main platform/stage. Once there, two exit paths can be chosen. One leads through a 36-inch door to the front dressing room and onto the front lobby and the other to a 36-inch doorway to the floor of the main

theater. The rear emergency exit door does not serve as a normal entrance to the second floor.

Travel over the front stairs includes a 12-foot vertical distance between the floors and approximately 20 feet of landings or level path between the door at the top of the stairs and the front, exit discharge door. The travel over the rear stairs also includes a 12-foot vertical distance between the floors and approximately 22 feet of landing or level path.

Since all of the people normally entering the second floor do so through the front stairs it is assumed most occupants will try to exit along the same path using the front stairs. Since the door to the rear stairs is located in the second floor reception area, some people who are there when a fire is detected might choose to evacuate via the rear stairs.

Movement times to exit the second floor were estimated for four different scenarios: 100% of occupants using the front stairs, 100% using the rear stairs, 50% using each of the stairs and 75% using the front and 25% using the rear. It is assumed that as long as neither exit is blocked by obstructions or fire, 75% of the second floor occupants (158 people) will use the front stairs and 25% (53 people) will attempt to use the rear stairs. Each of the scenarios results in slight queuing at the entrance doors to the stairs. If an evacuation of the first floor is already underway, any additional queuing of the second floor occupants once they reach the first floor would be dependent on things such as pre-movement times of the first floor occupants.

In general, movement times for the maximum number of people on the second floor (211) varies from 2.9 minutes if half the occupants use each set of stairs to 5.3 minutes if everyone is forced to use the rear stairs. If a fire in the main theater makes the rear stairs inaccessible, it would take 5.1 minutes of movement time to evacuate everyone through the front stairs.

Table 3 summarizes the calculated travel times from each space. The actual RSET times will be the sum of these times plus time to notification and pre-movement time.

Estimated Movement Times				
Area of Building	Maximum Occupancy	Special Conditions	Minutes	Seconds
Art Gallery	132		1.1	66
Front Lobby & Adjoining Rooms	199			
Main Theater	358	Both exits available	2.6-2.75	156-165
	358	One exit available	3.3	200
Rear Theater	110	Main exit available	1.5	90
Rear Lobby & Dressing Rooms	48		0.4	24
Second Floor	211	50% through each exit	2.9	174
	211	75% through front exit, 25% through rear	4.0	239
	211	100% through front exit	5.1	304
	211	100% through rear exit	5.3	318

Table 3: Estimated Movement Times

The calculations upon which these values are based are presented in Appendix A.

Water-based Suppression

Installed Automatic Sprinkler System

An automatic sprinkler system was installed in the building in 1993 when the building occupancy changed to include a gymnasium in what is now the main theater. The occupancy changed again around 2002 when it was converted to its current use as a performing arts center. At that time, the sprinkler system was not modified.

The sprinkler system installed into the building is a wet-pipe system designed to control a fire rather than extinguish it. Considering the assembly occupancy spaces in the building, system activation is designed to allow extra egress time for their safe evacuation.

When the sprinkler system was first installed, the building served primarily as a gymnasium and health-club type facility and the sprinkler system was classified according to an “Ordinary Hazard, Group 1”. If a new system were designed today, the dance school would likely maintain the OH-1 classification originally assigned when the system was installed or perhaps fall under a Light Hazard classification. The auditorium/theater areas apart from the platform stage would also be classified at Light Hazard but the platform/stage in the theater would be classified as Ordinary Hazard, Group 2.

The density/area criterion for which the sprinkler system was designed was 0.15 gpm/ft² over a 1,500-ft² area of sprinkler operation. For the areas such as the theater and

offices that could currently be classified Light Hazard by NFPA 13, the installed density/area criteria exceed what is needed since they require only was 0.10 gpm/ft² over a 1,500 ft² area. For an actual stage, the hazard classification would be Ordinary Hazard, Group 2. The required density/area coverage for OH-2 of 0.20 gpm/ft² over an area of 1,500 ft² would be slightly more than the existing coverage. The Center for the Arts production area is not officially a stage but rather a platform because the lack of hanging curtains over the front as well as hanging sets and props. It is uncertain whether the technical differences between a stage and a platform might allow for a less dense coverage than OH-2. In any case, the AHJ did not require an increase in the density after the conversion to a performing arts center.

Water Supply

The water supply for the building is supplied via city water mains of the local city. It is located at the rear of the building in underground mains that run along the street, immediately north of and perpendicular to the long axis of the building. The water is fed by a gravity feed from a water treatment facility located about one mile away at a higher elevation of several hundred feet.

According to records of recent tests conducted by the city's Public Works Department, the water supply for the Center for the Performing Arts' sprinkler system has a static pressure of 64 psi and a residual pressure of 54 psi at a flow rate of 2,400

gpm. The connection to the building's sprinkler system is underground at the far north end of the facility.

System Location and Layout

The sprinkler system riser enters the northernmost utility room of the building adjacent to a public street. The riser is made of 4 inch, Schedule 10 steel pipe. At the sprinkler room, the riser is fitted with two inline gate valves, a check valve, test line apparatus and a pressure gauge. The fire department's 4-inch connection is located above the check valve and tees into the riser. That FD connection is fitted with a check valve (prior to the "T") and extends to the exterior of the building to a single male fitting.

The riser climbs for an elevation of 18 feet where it ties via an elbow into a 3-inch, Schedule 10 steel feed main that leads south into the building. At the north end of the building in the single-story section which houses a "day theater", dressing rooms, waiting room and storage areas, branch lines are fed off the primary north-south supply. The feed main line tees off to a 3 inch cross main running east and west along the short axis of the building and which in turn supplies three branch lines that T and run to the north and to the south covering the length of the northern, one-story annex. Branch lines are a combination of 1-1/4" and 2 inch Schedule 40 piping.

Each of the cross main sections and branch line pipes is supported by a combination of adjustable swivel ring hangers and rigid pipe supports attached to the building's structural roof members.

The principle feed main travels for 152 feet to the south and enters the main portion of the building where it T's into another 3-inch cross-main. The secondary cross main spreads out across the full width of the building. Rising off that cross main are various 2 inch riser nipples, each rising to feed one of seven north-south running branch lines spaced 10 to 12 feet apart that are fitted with sprinkler heads for the main theater. These lines continue 76 feet to the south where they T into a downward leading pipe as well as extend further south at the same elevation into the second floor ceiling area (at the front of the building). The downward-flowing vertical pipes extend to just above the height of the first floor ceiling and then T again into horizontal pipes that supply the first floor at the front of the building.

Figure 26: Plan view of the sprinkler layout. The remote area shown here is located on the second floor in Dance Studio 1. North is to the left.

The sprinklers that are used for the system are a combination of ½ inch upright, brass pendants (k-factor = 5.6) or recessed, ½ inch pendants. Most of the sprinklers are 165 °F activated, standard response sprinklers that are the “A” model, manufactured by Central sprinklers. The sprinklers are not glass bulb activated sprinklers but instead have a fusible alloy sealed into the sprinkler’s brass activating rod that is held in place by a stainless steel ball.

The most remote area of the sprinkler system was determined to be sprinklers on branch lines on the second floor at the south end of the building. Second floor sprinklers were spaced 12 feet, 10.5 feet, or 10 feet apart (the system was initially approved with a non-symmetrical spacing to best fit room layouts) on the branch lines. It was determined that 12 heads would have to operate to cover the required 1,500 ft² area of operation. In order to determine the size requirement for the length of one size of the remote area, the formula, $L \geq 1.2 \sqrt{1500}$, was used. That gave a minimum length of 46.5 feet along a branch line. Further, the sprinkler system designer calculated the area of coverage by a particular sprinkler as 126 ft². Using that, it was determined to cover the minimum area of operation would require 12 sprinklers.

TABLE 8.6.2.2.1(b) Protection Areas and Maximum Spacing of Standard Pendent and Upright Spray Sprinklers for Ordinary Hazard

Construction Type	System Type	Protection Area		Maximum Spacing	
		ft²	m²	ft	m
All	All	130	12.1	15	4.6

Figure 27: NFPA 13 Table of Sprinkler Specifications for Ordinary Hazard Protection

Section 11.2.3.2.4 of the NFPA 13, the Standard for the Installation of Sprinkler Systems, 2010 edition, states that for sloped ceilings, like that in the Center for the Arts' main theater, "The system area of operation shall be increased by 30 percent without revising the density..." when spray sprinklers are used on sloped ceilings with a pitch exceeding 1 in 6, the equivalent of 15 degrees slope. The design area increase is based on the sprinkler tests and modeling conducted at FM Global. In those tests, slopes greater than 15 degrees resulted in erratic sprinkler operating patterns that could adversely affect sprinklers operating outside the design area. Heat accumulated near the peak and tended to activate sprinklers distant to the fire. The result was the potential for the sprinkler system to be overwhelmed by the activation of too many heads threatening the system with becoming ineffective at providing design area coverage. A 30 percent increase in the coverage of the 15-foot maximum spacing set forth in Table 8.6.2.2.1(b) would reduce the maximum spacing to 10.5 feet.

The slope of the ceiling near the sides of the main theater is approximately 25 degrees. In accordance with the provisions of Section 11.2.3.2.4 of NFPA 13, that slope would trigger the 30 percent increase in coverage. As can be seen by the hydraulic calculations prepared for the Center for the Arts building, the outer branch line spacing on each side of the building was in fact reduced by 30 percent. The maximum distance from the walls for the outer branch lines is established by Section 8.6.3.2.1 and Table 8.6.2.2.1(b), both of NFPA 13 as no more than half the distance between sprinklers, in this case 10.5 feet. Actual distance of the outer branch lines was measured at 5 feet out from the walls in adherence to this requirement.

Figure 28: Elevation view of the sprinkler system in the main theater looking south.

Figure 29: Elevation view of the sprinkler system in the main theater looking west.

Unfortunately, no known plans exist for the installed sprinkler system. A search of the records of the AHJ as well as by the Center for the Arts personnel failed to locate any copies. The designer is reportedly no longer in business. A copy of a computerized hydraulic calculation was available in the AHJ file. That record is presented in Appendix D. It shows the sizes of various pipes used in the calculations as well as fittings, elevations, and other related values. The computer calculations estimated a water supply demand at the base of the riser (BOR) of 245.8 gpm with a required pressure of 53.7 psi. That coupled with a 250-gpm hose demand led to an overall demand of 495.8 gpm at 53.7 psi.

Activation of 12 sprinklers could involve 6 sprinklers on each of the furthest 2 branch lines or 4 heads on each of the furthest 3 lines or a combination thereof. Not knowing which heads had activated in the computer calculations, hand estimates were

performed to identify possibilities. It was estimated that the most geographically remote heads would be on the furthest two or three branch lines to the west on the second floor. Hand calculations determined that the highest demand was created when 4 sprinklers opened on each of the 3 westernmost branch lines on the second floor. That demand was calculated to be 245.3 gpm at 49.0 psi at the base of the riser (BOR) (see Appendix D for calculations). The hose stream allowance for an Ordinary Hazard Group I occupancy is 250 gpm for 90 minutes. The total water demand for the building is therefore 495.3 gpm at 49 psi. These values were in reasonable agreement with those indicated in the computerized calculations.

Inspection, Testing and Maintenance

Several inspection, testing and maintenance (ITM) requirements for the sprinkler system in the Center for the Arts are set forth in NFPA 25, Inspection, Testing and Maintenance of Water-Based Fire Protection Systems and modified by Title 19 of the California Code of Regulations. NFPA 25 contains three tables that generally summarize ITM requirements. They are Tables 5.1.1.2, 6.1.1.2, and 13.1.1.2. Monthly observations of the sprinkler system are the responsibility of the staff of the Center for the Arts. A sprinkler contractor approved by the AHJ carries out annual inspections, testing and maintenance. A table synthesizing the inspection, testing and maintenance requirements for alarm systems set forth in NFPA 25 is included herein as Appendix E.

Alarm Detection and Notification System

History

Like with the automatic sprinkler system, the Center for the Arts building was not originally fitted with alarm detection or notification systems. The first alarm system components were installed sometime before the sprinkler system was required. The only known alarm system requirement for the Center for the Arts is for a waterflow alarm for the sprinkler system. That alarm and its ancillary components are currently in place. Other than that however, there are no requirements for any alarm detection or notification systems to be installed.

Requirements for Fire Detection and Alarm Systems

Neither the California Building Code (CBC), the California Fire Code (CFC) nor the Life Safety Code (LSC), NFPA 101, have established requirements for alarm systems to be installed into existing buildings like the Center for the Arts. Section 907 of the CFC specifies the rules and regulations regarding Fire Alarm and Detection Systems. The LSC requirements for Detection, Alarm and Communication Systems are set forth in Section 13.3.4.

LSC Section 13.3.4.1.1 states that “Assembly occupancies with occupant loads of more than 300 and all theaters with more than one audience-viewing room hall be provided with an approved fire alarm system... *unless otherwise permitted...*” (emphasis

added). Even though the Center for the Arts is an assembly occupancy with an occupant load of more than 300 in the main theater, it is covered by an exception to that requirement. Section 13.3.4.1.4 of the LSC states, “The requirement of 13.3.4.1.1 shall not apply to assembly occupancies where, *in the judgment of the authority having jurisdiction*, adequate alternative provisions exist or are provided for the discovery of a fire and for alerting the occupants promptly.” In this instance, the local fire department as the AHJ has deemed installation of most alarm systems unnecessary.

According to local fire inspectors with the AHJ, the Center for the Arts technically falls under the latter exclusion because of other provisions in Section 907.3 of the CFC entitled, “Where required in existing buildings and structures”. In that, it states that, “An approved fire alarm system shall be installed in existing buildings and structures where required in Chapter 46”. Section 4603 of that code addresses “Fire Safety Requirements for Existing Buildings.” In 4603, the only requirements for fire alarm systems in existing structure are for occupancy types other than those existing in the Center for the Arts. Further, it has been decided by local fire officials that the building’s full coverage sprinkler protection in effect adds heat sensors in the form of sprinkler heads. While the AHJ might recommend a fire notification system be installed throughout the building, under these provisions they cannot require such a system be installed.

If Center for the Arts personnel choose to upgrade the existing or install a different system to improve life safety conditions, they should first identify their goals

and objectives for the system. NFPA 72 offers various features and functions in Section 23.3.3.1 that owners may want to evaluate and consider as potentially applicable to the building.

Since the building is protected by a water sprinkler system, both the CFC and the LSC require that that system be monitored with a waterflow alarm. Section 903.4 of the CFC states, “All valves controlling the water supply for automatic sprinkler systems, pumps, tanks, water levels and temperatures, critical air pressures and water-flow switches on all sprinkler systems shall be electrically supervised by a listed fire alarm control unit.” Similarly, Section 9.6.2.1 of the LSC states, “Where required by other sections of this Code, actuation of the complete fire alarm system shall be initiated by, but shall not be limited to, any or all of the following means:

- (1) Manual fire alarm initiation
- (2) Automatic detection
- (3) *Extinguishing system operation* (emphasis added).

In meeting this requirement, the Center for the Arts installed a waterflow alarm system at the sprinkler riser.

Installed Alarm System

Currently, two independent alarm detection and notification systems are installed on the ground floor of the Center for the Arts. Each has its own fire alarm control panel. No alarm system is present on the second floor besides local smoke detectors or as related to activation of the waterflow alarm in the sprinkler system. Each of the two alarm systems for the Center of the Arts are of the Supervising Station type connected by telephone lines to a Central Station.

Though no documentation of installation could be found, the oldest of the two alarm systems appears to be around 20 to 25 years old. It originally consisted of a mixture of smoke detection and a burglar alarm system. Though the smoke detectors are still monitored by a central station, the burglar alarm portion of the system has been deactivated. The other system installed at the far north end of the building is located primarily in and around the sprinkler room. It is designed to serve as both a detection and notification system of sprinkler activation as well as detection and notification of fire related problems in the sprinkler room that could affect the sprinkler system. Unfortunately, no drawings or installation documentation for either of the two systems was available either at the Center for the Arts or at the local fire department or are even known to exist.

Front System Detectors and Notification Appliances

The smoke detection and alarm notification system in and around the front lobby currently covers only the first floor of the front portion of the building south of the main theater. The fire alarm control panel connected to the original system is an Optex Morse model SMDC-16 unit. It is also wired to an Optex Morse keypad and annunciator panel.

Figure 30: Optex Morse SMDC-16 Fire Alarm Control Panel keypad for the front alarm system

Those portions of the system designed to serve as a burglar alarm have been disconnected. The fire alarm control panel is monitored via telephone line by a central station monitoring service.

Five ionization smoke detectors are installed in the front portion of the building, two in the front lobby, one in the office, one in the actors' dressing "green" room, and one in the art gallery. Four are similar in appearance to older style General Electric 120V models although the exact model type could not be verified. The other appears to be a BRK model 120V detector. Each of the detectors appears to be about twenty years old. All of the front system smoke detectors are ceiling mounted except for that in the art gallery.

Figure 31: Smoke detector on the front lobby ceiling

The art gallery detector is wall mounted, 30 inches below a 12 foot 6 inch high ceiling. That location is not in compliance with NFPA 72. Sections 17.7.3.2.1 dictate that a smoke detector should be mounted within the top 12 inches of the room height.

Even if the detector was mounted at the correct height on the wall or on the ceiling, there would still be problems associated with having only one detector in the gallery. Because the upper part of the gallery is divided into three bays separated by deep solid beams, having only one detector in the room would not necessarily assure prompt activation unless the fire started directly below the bay in which the detector was mounted. If the fire started below another bay, then smoke would first have to fill that bay and then spill out and flow into the bay with the detector before activation would be assured. Under the current arrangement, all three bays will have to fill with smoke and then the level descend about six inches further to even reach the existing detector.

Figure 32: Smoke detector mounted low on the north wall of the art gallery

With regards to detector spacing in the front half of the building, since there was no mandate for these detectors to be in the building, according to Section 17.5.3.3.1 of NFPA 72, there is no prescribed spacing required for them. The existing arrangement seems somewhat arbitrary other than that it covers the largest spaces in the front area.

The only notification appliance in the front half of the building is an Amseco model BZ-54VT electric horn. It is mounted on the north wall of the lobby, 92 inches above the floor, immediately below the drop ceiling. That wall separates the lobby and the main theater. The mounting location does not fully meets the requirement of Section 18.4.8.1 even though it is located at least 90 inches above the finished floor. That section also requires that it must be 6 inches below the ceiling.

Figure 33: Amseco model BZ-54VT electric horn in the front lobby

The Fire alarm control panel for the front half of the building is also mounted on the north wall of the lobby just below the ceiling, about 10 feet west of the horn. The Optex Morse annunciator panel and keyboard is located further south on the west wall, approximately 25 feet inside and north of the main entrance doors.

Rear System Detectors and Notification Appliances

The rear portion of the alarm system serves only to detect and notify occupants of either sprinkler waterflow activation, or fire related problems in the sprinkler room that could affect the system's performance. The fire alarm control panel mounted there is a model MS-5012 fire control communicator manufactured by Fire Lite Alarms, Inc., a division of Honeywell. Telephone lines connect the system to the central station monitoring the system.

Figure 34: FireLite MS-5012 fire alarm control panel

The principal detection device of that system is a Potter model VSR-4 waterflow switch mounted in the sprinkler riser. Also installed in the sprinkler room is a 120V smoke detector mounted on the wall nine feet above the floor, directly over the fire alarm control panel. The smoke detector is a Federal Signal model FSF109, hardwired, photoelectric detector. Located immediately below the fire alarm control panel in the sprinkler room is a Fire Lite Model BG-12 pull station.

One of the notification appliances attached to the rear fire alarm control panel is a Gentex model GEC, 24-volt horn strobe with 75 cd and 70-82 dBA. That horn strobe is mounted inside and along the north wall of the rear day theater of the Center for the Arts. The unit is 86 inches above the floor but because of a temporarily stage set being used in

the theater, it may not be visible at the front (south) side of the stage, either by the audience or cast. The mounting height as well as the existing location behind a possible blockage such as a stage set do not meet the location requirements of Section 18.4.8 of NFPA 72.

Figure 35: Gentex Model GEC Horn Strobe

Attached outside on the north wall of the building, 12 feet above the ground, is a 10-inch vibrating bell manufactured by Potter Electric Signal Company, model MBA2410.

Figure 36: Potter Electric Signal Vibrating Bell

Fire Detection Scenarios

In order to estimate the time for detection in areas where smoke detectors are installed, three fire detection scenarios were examined. The time to detection was analyzed either with the computer zone fire model CFAST for wall mounted detectors or with the spreadsheet model, DETACT. The specific calculations and results are included in Appendix E.

Central Station Disposition of Alarm, Supervisory and Trouble Signals

The fire alarm system installed in the Center for the Arts is a Supervising Station alarm type monitored by a central station. Signals are passed to the central station via telephone lines installed at each of the two fire alarm control panels.

NFPA 72 dictates the requirements for central stations to respond to alarm signals. A synopsis of those signals and the corresponding actions to be taken are discussed in Appendix E.

Mass Notification System

The Center for the Arts does not have a Mass Notification System installed.

Secondary Power Requirements

Each of the two alarm systems installed in the Center for the Arts is required by NFPA 72 to have backup power sources to maintain the alarm systems in the event of a power outage. Both fire alarm control panels are outfitted with 8 amp-hour portable batteries for this purpose. Section 10.5.6.3.1 of NFPA 72 states that, “The secondary power supply shall have sufficient capacity to operate the system under quiescent load (system operating in a non-alarm condition) for a minimum of 24 hours and, at the end of that period, shall be capable of operating all alarm notification

appliances used for evacuation or to direct aid to the location of an emergency for 5 minutes...”

Accurate standby power requirements for the smoke detectors at the Center for the Arts could not be determined because there currently is no known documentation identifying the installed detectors. Accordingly, estimates of the power requirements for the smoke detectors were obtained for those of similar devices described in online references. The notification appliances needing to be powered include the horn in the front lobby and horn strobe and vibrating bell for the rear system. Power requirements for those notification appliances were either obtained off the individual appliances or off data sheets available from the suppliers.

Wiring for the rear circuits was readily accessible and determined to be 14 AWG copper size. The front system wiring was hidden in the walls and therefore not visible without removing the ceiling and/or disassembling the system. At the time of examinations, the Center for the Arts was open and conducting business. Accordingly no disassembly occurred. Instead, estimations of the power requirements for the front system have been made based upon similar wiring (14 AWG solid copper conductors) used elsewhere.

Front Alarm System Secondary Power Requirement

Item	Description	Qty	Standby Current per Unit (amps)	Total Standby Current (amps)	Alarm Current per Unit (amps)	Total System Alarm Current (amps)
A	Ionization Smoke Detector	5	0.0002	0.001	0.077	0.385
B	SMDC-16 FACP	1	0.113	0.113	0.20	0.20
C	SMDC-32 Annunciator	1	0.070	0.070	0.07	0.07
D	BZ-54VT Horn	1	None	None	0.12	0.12
TOTALS				0.184A		0.775A

Table 4: Front Alarm System Secondary Power Requirement

$$24 \text{ hours standby} \times 0.184\text{A} = 4.416 \text{ Ah}$$

$$0.0833 \text{ hours (5 mins) alarm} \times 0.775 \text{ A} = 0.065 \text{ Ah}$$

$$\text{Standby} + \text{Alarm power requirement} = 4.48 \text{ Ah}$$

$$\text{Power requirement} \times 1.2 \text{ (20\% Safety factor)} = 5.4 \text{ Ah}$$

Total Secondary Power Requirement for the front system is 5.4 Ah

Rear Alarm System Secondary Power Requirement

Item	Description	Qty	Standby Current per Unit (amps)	Total Standby Current (amps)	Alarm Current per Unit (amps)	Total System Alarm Current (amps)
E	MS-5012 FACP	1	0.01	0.01	0.005	0.005
F	FSF109 Smoke Det	1	0.0001	0.0001	0.13	0.13
G	BG-12 Pull Station	1	None	None	None	None
H	GEC Horn Strobe	1	None	None	0.137	0.137
I	MBA2410 Vib-Bell	1	None	None	0.060	0.060
J	VSR-4 WF Switch	1	0.010	0.010	0.010	0.010
TOTAL				0.0201A		0.322A

Table 5: Rear Alarm System Secondary Power Requirement

$$24 \text{ hrs standby} \times 0.0201\text{A} = 0.48 \text{ Ah}$$

$$0.0833 \text{ hrs (5 mins) alarm} \times 0.322 \text{ A} = 0.03 \text{ Ah}$$

$$\text{Standby} + \text{Alarm power requirement} = 0.51 \text{ Ah}$$

$$\text{Power Requirement} \times 1.2 \text{ (20\% Safety factor)} = 0.61 \text{ Ah}$$

Total Secondary Power Requirement for the rear system is 0.61 Ah

Both the front and rear alarm systems are supplied with 8.0 Ah batteries. In each case, the secondary power supply is sufficient to power the systems in accordance with Section 10.5.6.3.1 of NFPA 72.

Inspection, Testing and Maintenance

A local electric company maintains the Center for the Arts' alarm system and conducts all necessary inspections and testing. This is allowed under Section 14.2.2.3 of NFPA 72 if conducted pursuant to a written contract. None of the facilities or maintenance personnel at the Center for the Arts was familiar with specifics of the alarm system in terms of installation or the maintenance. Further, they stated that they have never seen any copies of installation diagrams or paperwork associated with either of the two alarm systems and do not know if any exists. They suggested copies might be available at either the alarm system contractor or the fire department. Checks with both organizations revealed neither have copies either installation diagrams or commissioning documentation.

Section 14.2.4 of the 2010 edition of NFPA 72 requires that "At the time of an acceptance test, the authority having jurisdiction and the system contractor must ensure that all documentation for the system installation has been completed and is presented to the owner or the owner's designated representative in a usable format." Whether this was ever done is uncertain. Documents suggested to be maintained by NFPA 72 include: Fire Alarm System Record of Completion, Point to Point Wiring Diagrams, Individual Device Interconnection Drawings, As-Built Drawings, Copy of Original Equipment Submittals, Operational Manuals, Manufacturer's Proper Testing and Maintenance Requirements, and a Device Address List/Conventional Device Location List.

Besides the documentation requirements, Sections 14.1 and 14.2 of NFPA 72 also sets forth the requirements for an inspection, testing and maintenance programs for new and existing alarm systems. Table 14.3.1, Visual Inspection Frequencies, prescribes the requirements for visual inspection. With regards to the installed equipment, the visual inspection requirements that apply to the Center for the Art's system are shown in Appendix E.

Structural Fire Protection

General Building Construction

The Center for the Arts was built of Type III construction, commonly referred to as “Ordinary Construction”. It occupies slightly less than 19,000 square feet. First floor space measures about 13,900 square feet while the second floor is approximately 4,750 square feet. The building’s maximum height is approximately 28 feet.

Table 503 of the California Building Code specifies maximum building heights and areas for various construction types. It specifies that a building of Type III-A construction can have a maximum height of 65 feet, contain three stories and for an Assembly, type A-1, occupancy (which includes theaters), have a maximum floor area of 14,000 square feet. Type III-B construction can be used to create a similar occupancy building with a maximum height of 55 feet, two stories and 8,500 square feet. (The other occupancy types found in the Center for the Arts are less restrictive for both Type III-A and III-B buildings and can include more area). Based upon area increase provisions set forth in Section 506 of the CBC, the presence of sprinkler protection and open frontage areas onto public ways increases the allowable per floor area of the building. For the Center for the Arts, the area allowed for Type III-A construction is more than 42,600 square feet per story and to 25,840 square feet per story for Type III-B. This is because the building is sprinklered and has almost 200 feet of its 670-foot perimeter opening onto an open area of more than 30 feet in width.

Calculations to determine the increase in the floor area for each type of construction are as follows:

Frontage Increase

$$I_f = [F/P - 0.25] W / 30$$

Where:

I_f = Area increase due to frontage (percent)

F = Building perimeter which fronts public way or open space having 20 foot minimum width.

P = Perimeter of the building.

W = Minimum width of public way or open space.

For the Center for the Arts:

F ~ 195 feet

P ~ 670 feet

W = 30 feet (since all open areas > 30 feet wide)

Therefore, the increase in floor space because of available public frontage is:

$$I_f = [195/670 - 0.25] 30 / 30$$

$$I_f = 0.04 \text{ or } 4\%$$

Sprinkler Increase

Section 506.3 of the CBC also provides for an area increase in buildings protected with an approved automatic sprinkler system. The increase, I_s is 200 percent for multi-storied buildings.

Section 506 of the CBC sets the calculation for the total area modification as:

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$$

Where:

A_a = Allowable building area per story (square feet).

A_t = Tabular building area per story in accordance with Table 503 (square feet).

For the most restrictive occupancy found in the Center for the Arts, Assembly (A-1), the tabular area is 14,000 sq. ft. for Type III-A and 8,500 sq. ft for Type III-B construction.

I_f = Area increase factor due to frontage as calculated in accordance with Section 506.2, in this case 4%.

I_s = Area increase factor due to sprinkler protection as calculated in accordance with Section 506.3.

For the Center for the Arts, the area modification for Type III-A construction is:

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$$

$$A_a = \{14000' + [14000' \times 0.04] + [14000' \times 2]\}$$

$$A_a = 42,560 \text{ sq. ft.}$$

For Type III-B, the area is:

$$A_a = \{A_t + [A_t \times I_f] + [A_t \times I_s]\}$$

$$A_a = \{8500' + [8500' \times 0.04] + [8500' \times 2]\}$$

$$A_a = 25,840 \text{ sq. ft.}$$

According to these area allowances and the permitted height and number of stories for both Type III-A and III-B construction, the Center for the Arts may be of either type.

Fire Resistance Ratings

Table 601 of the CBC (shown below) sets forth the minimum fire resistance building element requirements for various construction types. Type III-A construction requires a 2-hour fire resistance rating for exterior structural bearing walls, and a 1-hour fire resistance rating for interior bearing walls, floors and roof construction. Non-bearing interior walls and partitions require no fire resistance rating. Type III-B construction has no fire resistance requirement for any elements other than for exterior bearing walls which like in Type III-A is also 2 hours. Because there are no interior bearing walls, these requirements are met throughout the building.

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A ^d	B	A ^d	B	HT	A ^d	B
Primary structural frame ^g (see Section 202)	3 ^a	2 ^a	1	0	1	0	HT	1	0
Bearing Walls									
Exterior ^{f,g}	3	2	1	0	2	2	2	1	0
Interior	3 ^a	2 ^a	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior ^e	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and secondary members (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and secondary members (see Section 202)	1 ^{1/2} ^b	1 ^{b,c}	1 ^{b,c}	0 ^c	1 ^{b,c}	0	HT	1 ^{b,c}	0

Figure 37: Table 601, California Building Code, 2010 edition

For SI: 1 foot = 304.8 mm.

a. Roof supports: Fire-resistance ratings of primary structural frame and bearing walls are permitted to be reduced by 1 hour where supporting a roof only.

b1. Except in Group A, E, F-1, H, I, L, M, R-1, R-2, R-2.1 and S-1 occupancies, high-rise buildings, and other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

b2. For Group A, E, I, L, R-1, R-2, and R-2.1 occupancies, high-rise buildings, and other applications listed in Section 1.11 regulated by the Office of the State Fire Marshal, fire protection of members other than the structural frame shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

b3. One-story portions of Group A and E assembly occupancies the roof-framing system of Type II A or Type III A construction may be of unprotected construction when such roof-framing system is open to the assembly area and does not contain concealed spaces.

c. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.

d. An approved automatic sprinkler system in accordance with Section 903.3.1.1 shall be allowed to be substituted for 1-hour fire-resistance-rated construction, provided such system is not otherwise required by other provisions of the code or used for an allowable area increase in accordance with Section 506.3 or an allowable height increase in accordance with Section 504.2. The 1-hour substitution for the fire resistance of exterior walls shall not be permitted.

e. Not less than the fire-resistance rating required by other sections of this code.

f. Not less than the fire-resistance rating based on fire separation distance (see Table 602).

g. Not less than the fire-resistance rating as referenced in Section 704.10

Exterior Walls

The exterior walls of the Center for the Arts consist of 8-inch thick, filled, masonry block units except where there are windows or doors facing onto public areas more than 30 feet deep.

Fire Separation Requirements

The west wall of the Center for the Arts is approximately 8 feet from the closest building. The north end of the east wall is separated from an adjacent garage by less than 2 feet. At the building's south end, the nearest building lies 30 feet away from the east wall (see Figure 38).

Figure 38: Building Separation Layout

The Sections of Table 602 of the CBC dealing with the occupancy classifications for the Center of the Arts as shown below list the fire resistance ratings required of exterior walls based upon fire separation distance. For the Center for the Arts, this fire resistance rating is 1 hour.

FIRE SEPARATION DISTANCE = X (feet)	TYPE OF CONSTRUCTION	OCCUPANCY GROUP A, B, E, F-2, I, R,S-2^g, U^b
X < 5^c	All	1
5 ≤ X < 10	IA Others	1 1
10 ≤ X < 30	IA, IB IIB, VB Others	1 ^d 0 1 ^d
X ≥ 30	All	0

Figure 39: Calif. Building Code Table 602 - Fire-resistance rating requirements for exterior walls based on fire separation distance

The exterior walls of the Center for the Arts are grouted and filled concrete blocks. Determining the effective fire resistive thickness of a normally hollow unit such as a concrete block, one multiplies the thickness of the block by its solid percentage using the formula:

$$T_e = T_n * P$$

T_e = Equivalent Thickness

T_n = Nominal thickness of block

P = Percent solid

The 8-inch thick, exterior walls were examined by sounding and estimated to be completely solid. Section 721.3.1.4 of the CBC states that for airspaces and cells of

concrete block filled with loose-fill material, “The equivalent thickness of completely filled hollow concrete masonry is the actual thickness of the unit when loose-fill materials are: sand, pea gravel crushed stone or slag; pumices, scoria, expanded shale, expanded clay, expanded slate, expanded slag, expanded fly ash or cinders... or perlite or vermiculite...” Accordingly, the Center for the Art’s 8-inch exterior block walls are estimated to have an equivalent concrete thickness of 8 inches. According to Table 720.1(2) of the CBC, the minimum fire resistance rating for the 8-inch block wall is well over 4 hours.

The structural framing supporting the concrete block walls consisted of concrete block lintels attached to the inside of the exterior walls and positioned under the end of each roof truss (8 inch x 20 inch wooden, glulam arched trusses). It is presumed but could not be verified that the lintels contained structural steel within the concrete blocks. Because of their apparent construction, the fire resistance of the lintels is the same as the exterior walls.

Tables 601 and 602 shows that the exterior walls and the primary structural frame support of the Center for the Arts meet all fire resistance and fire separation distance rating requirements for both Type III-A and III-B construction.

Interior Walls

Interior walls throughout the second floor at the front of the building are wood framed walls covered with gypsum board. No plans for the as-built construction were

available for examination. The majority of interior walls appeared to be non-weight bearing and serving only as partitions. Based upon the wall thickness, the studs are estimated to be either 3-1/3 or 5-1/2 inches thick, the same thickness as nominal 2x4 or 2x6 wooden boards (presumably spaced 16 inches on center allowing for 20 minutes of protection). Sheetrock panels appear either 1/2 inch or 5/8 inch thick. The wall fire rating can be determined using Table 721.6.2(1) of the IBC. The ratings for 1/2 inch thick are 15 minutes for non Type X wallboard or 25 minutes 1/2 inch Type X. For 5/8-inch wallboard, the fire resistance is 30 minutes for non Type X wall board or 40 minutes for Type X. Calculations using the component additive method show the following fire resistance:

<u>Wallboard Type</u>	<u>Combined Fire Resistance (mins)</u>
1/2 inch regular + wood studs	35 mins
1/2 inch Type X + wood studs	45 mins
5/8 inch regular + wood studs	50 mins
5/8 inch Type X + wood studs	60 mins

To meet Type III-A fire resistance requirements, all interior, bearing walls would be required to have at least 5/8 inch Type X sheetrock on wooded studs 16 inches on center if no sprinkler system was installed. With the sprinkler system however, a 1-hr rating can be achieved because of the sprinkler thus alleviating the need for a more robust

fire resistance rating based on structural member types alone. The presence of the sprinklers raises the Center for the Arts construction type from what would normally be a Type III-B building to Type III-A.

The first floor interior walls in the front half of the building are of various construction types. Original wall sections appear to be lath and plaster while later additions look like sheetrock on wooden or steel studs. Again, no plans for the as-built construction were available for examination. Those that might potentially be weight bearing walls appeared to be sheathed in plaster instead of sheetrock. Those walls must have a 1-hour rating for Type III-A construction but with Type III-B construction have no fire resistance requirements. The presence of the sprinkler system automatically meets the 1-hour requirement for interior walls.

The two-story wall separating the main theater from the front of the building is approximately 7 inches thick. It has several unsealed penetrations for HVAC ducting, piping, a double door and single door. With Type III-B construction no fire resistance rating is required for the wall and these open penetrations are permissible. For Type III-A however, the wall, doors and penetrations would each have to have a 1-hour fire resistance rating. If the wall and door in the wall did in fact meet a 1-hour fire rating, the double door could be used as a horizontal exit from the main theater. While the presence of a sprinkler offers a 1-hour resistance rating in general, it does not elevate the condition of the wall to meet the requirements of a horizontal exit.

The rear (north) wing of the complex has three spaces separated by 8-inch thick,

concrete block bearing walls. Two of the spaces are used for storage of theater props and equipment and one contains a day theater, waiting room, dressing rooms and restrooms. The smaller rooms have partition walls of sheetrock over 2x4 studs. The north wing meets the previously discussed fire resistance requirements for both Type III-A and III-B construction.

Roof

The roof framework in the southern half of the building consists of wooden planking on an arched, wooden truss framework. On the second story at the front of the building, trusses are bolted with metal bolts. Over the main theater space, the framework is of laminated wooden arched trusses measuring 8 inches wide by 20 inches deep. The trusses over the theater do not have a bottom chord. The roof decking for a Type III-A building requires a 1-hour fire resistance rating. There is no roofing fire resistance requirement for a Type III-B building. Like with other sections of the building, there were no drawings to examine roof specifications. Roof construction appeared to be tongue and groove planks supported on the trusses and covered on the exterior with a rolled, aluminized tar and gravel covering. Paper-sided fiberglass insulation batts are suspended under the roof planks and exposed from below.

The construction of the Center for the Arts' roof appears to meet both Type III-A and III-B fire resistance requirements based upon section 721.6.2(4) of the CBC.

Floors

The first floor throughout the structure is concrete either on grade or supported in a perimeter concrete foundation. Various floor coverings are installed over the concrete. The second story floor at the front of the building appears to be poured concrete slabs supported by plaster encased beams of an unknown type. Table 601 of the CBC calls for a 1-hour fire resistance floor rating for Type III-A construction. No such rating is needed for Type III-B. Though no plans were available to view, the flooring for the second story appears to offer at least a 1-hour rating. Again, the presence of the sprinkler system automatically can be substituted for a 1-hour fire resistance rating except for exterior walls.

Structural Fire Protection Summary

The Center for the Arts meets the size, height, and area requirements of Type III-B construction throughout. With the existing sprinkler protection, it also meets the Type III-A requirements. The only fire resistance rating requirements needed to achieve this construction type classification is a 2-hour rating for the exterior bearing walls. The 8-inch, filled, concrete block walls easily meet this requirement.

Performance Based Analysis

Tenability Analysis

Fire protection in the Center for the Arts relies predominantly on fire prevention as well as prompt and safe egress of occupants. Though installed, the automatic sprinkler system is not designed to extinguish a fire, but simply to control one should it occur until local firefighters can respond. Sprinklers do not guarantee complete safety to occupants. Instead they are intended to add extra time to that available for safe egress. One question that must be addressed is how much additional time is provided.

In conducting a performance-based analysis on the Center for the Arts to evaluate RSET vs. ASET, four fire scenarios were considered. Three were in the main theater and one was in the rear theater. These locations were selected because of the likelihood they would have the biggest impact on the greatest number of people in terms of evacuation.

Section 5.2 of the Life Safety Code specifies the types of performance criteria that can be used to evaluate fire protection designs. One of the aspects to be examined in such analyses is whether the particular facility can meet tenability performance criteria. To do so, one must demonstrate that any occupant not intimate with a fire's ignition will not be exposed to instantaneous or cumulative untenable conditions as specified in Section 5.2.2.

One of the methods suggested by the Life Safety code for estimating whether a building or design meets tenability-related performance criteria is to determine for specific design fire scenarios, whether each room will be fully evacuated before the smoke or toxic gas layer descends to within 6 feet above the floor. This method involves evaluation of the location, behavior and movements of occupants as well.

This method was used in conducting the performance-based tenability analysis of the Center for the Arts. Initial reviews showed that for each of several design fire scenarios, smoke levels would likely descend within minutes to below 6 feet above the floor or other walking surfaces on which people would be located. Accordingly, the required evacuation times (RSET) for maximum occupant loading in the theaters were examined based on specific tenability criteria at or below 6 feet above the floor.

Tenability limits are often specified in terms of four criteria: visibility, temperature, radiant exposure and combustion gas toxicity. Determining the level of exposure to each can be based on somewhat subjective evaluations. For this analysis, untenable conditions were determined to exist when the following values of each criteria were reached:

Visibility	< 10 meters
Temperature	>120°C in dry conditions >60°C in moist conditions
Radiant Flux	>2.5 kW/m ²
Carbon Monoxide	>1,200 ppm

The visibility tenability value selected for passage through smoke such as in corridors or other escape routes was based on work done by Sherfig¹³ and Hadjisophocleous¹⁴. In their research, they suggest a visibility limit of at least 10 meters. This value agrees with suggested values obtained from various documents such as the SFPE Handbook and the International Fire Engineering Guidelines for large enclosures. As Hadjisophocleous points out, in a primary room such as an office or familiar living space, this value may be dropped down to 3 meters. Purser in the SFPE Handbook suggests a limit of 5 meters in smaller spaces. Certainly the larger value provides a safety margin for less confusion during egress.

With regards to temperature, a maximum air temperature of 120°C was considered since that is the point at which skin exposed to dry, convected air will start to feel pain or burn in more than 60 seconds¹⁴⁻¹⁵. The corresponding value for moist air is actually lower, closer to 60°C. After conducting computer-modeling runs of fire scenarios in the Center for the Arts, it became clear that for people not in intimate contact with fires in the scenarios, exposure to temperatures in excess of 120 °C value was unlikely. 60°C was reached in some of the scenarios and since it usually occurred after sprinkler heads activated, the air was moist with suppression water. Accordingly, that value was chosen to represent untenability.

Similarly, the tenability limit for radiant heat flux was set at 2.5 kW/m². Babrauskas is listed in the SFPE Handbook¹⁶ as choosing a maximum heat flux of 2.5 kW/m² as a tenability limit for radiant exposure. That is a commonly accepted

level at which bare skin will generally feel pain. Conditions of lower intensity should limit the onset of burns over a short period of time as well as limit damage to the respiratory tracts of people trying to escape.

The CO level of 1,200 ppm was chosen because at that level, a 30-minute exposure will cause incapacitation¹⁶. Shorter time exposures such as the RSETs that might be expected for areas through the Center for the Arts might be allowed to go higher. A 5-minute exposure at 6,000 ppm would be expected to cause incapacitation so a lower value of 4,000-ppm exposure as a tenability limit for small spaces would be appropriate. In evaluating the various design fire scenarios for the Center of the Arts, CO levels remained well within acceptable levels by the time other factors became untenable.

The performance based analysis conducted for this evaluation of the Center for the Arts was not done in order to evaluate a particular or specific fire protection system. It was instead done to ascertain available safe egress times and compare it with the required safe egress times identified for various locations in the building. The analyses were conducted using Fire Dynamics Simulator (FDS), Version 5, a computer fire model published by the National Institute of Standards and Technology. FDS is capable of estimating tenability limit values. Because of the complex building geometry associated with the arched roofs and vertical fuels such as stage curtains, Pyrosim, a graphical user interface for FDS was also used to import computer aided drawing (CAD) files created during this effort. Pyrosim then converted the drawing files into the necessary computer

input coding needed required to run the FDS model.

Four design fire scenarios were developed for the performance-based analysis. Each was chosen based upon realistic fire possibilities that were identified after visiting the Center for the Arts. Criteria discussed in Section 5.5 of the Life Safety Code were used to select appropriate scenarios specific to this facility. The selections were made to simulate both high and low consequence fires as well as a special problem identified in the theater. Available fuels as well as potential ignition sources were evaluated and selected based upon their likelihood of occurring as well as the threat to life safety. Each fire scenario involved a T-squared fire growing at rates associated with other fire tests.

The first three scenarios are set in the main theater. The fourth scenario occurs in the rear theater. It should be stressed that the fire growth rates are based upon the time a fire would grow after established burning occurred. A slow incipient phase during which a fire initially burned with very small flames until starting to grow more rapidly would result in a longer fire growth. In an actual fire, it is often difficult to estimate the time leading to established burning. Such a delay actually benefits the occupants of a particular scenario because it tends to increase the ASET for evacuation to safety.

Scenario 1

Scenario 1 involves a fire that starts at the south end of the main theater underneath stacks of chairs used by the Center for the Arts staff for portable seating. The chairs are a mix of thermoplastic molded chairs as well as metal and wood framed chairs

with polyurethane foam padding in the seat and covered with a synthetic fabric. Chairs often stacked 10 high have been seen stored alongside the south edge of the fixed seating platform in the eight foot wide space between the seating and the south wall of the theater.

Figure 40: Space south of the main theater fixed seating platform and the south wall of the theater. This area is commonly used to stack portable chairs for storage.

A fire was selected that starts under the stacks of chairs near the east wall, perhaps through human means. A peak heat release rate of 1,500 kW was chosen based upon familiarity with fires involving similar fuels in various test fires or examined in previous investigations. A 60 second growth rate was selected based upon the configuration of the fuels. Stacked plastic commodities have been shown to achieve such high growth rates.

This fire is consistent with Design Fire Scenario 1 specified in the Section 5.5.3.1 of the Life Safety Code.

Scenario 2

The second scenario fire also occurs in the main theater. Upholstered sofas are situated in the lounge area at the north of the fixed seating and south of the northern storage rooms. They are available for visitors' use before or after productions. A fire was selected that occurred adjacent to one of the sofas and peaked at 100 kW in about 30 seconds similar to a trash can fire. Again, these values were selected as reasonable based upon personal experience with fire testing related to various investigations. Material properties were chosen for upholstered furniture with polyurethane foam cushions that have been shown in previous fire modeling efforts to be reasonable in terms of supporting ignition from open flaming as well as flame spread across the item.

This fire is consistent with Design Fire Scenario 5 specified in the Section 5.5.3.5 of the Life Safety Code although it involves a smaller fire threat. While it is not completely shielded from suppression systems, the location of the fire between two sprinklers on a sloped roof reveals the concern with sprinkler activation elsewhere than over the fire.

Figure 41: View of the main theater lounge area and upholstered sofas

Scenario 3

The third scenario fire is also in the main theater but on the platform/stage. Two relatively large gymnasium-type mats are stored at the northwest corner of the platform/stage between the separating wall to the northwest storage rooms and the northernmost three stage curtains. The mats measure approximately six foot long by five feet wide and about four feet high. Clamp on portable, electric lights have been seen positioned directly above the mats. Additionally, several strands of power to both lighting fixtures and audio accessories are often run above the stage. A catastrophic failure in one of the lighting fixtures or other electrical equipment above and dropping

onto the mats is the presumed fire cause.

A peak heat release rate of 2,000 kW was selected along with an ultra-fast growth rate. Full-scale fire tests by Professor Mowrer conducted several years earlier to examine the fire growth of gymnasium mats were relied upon to estimate this fire curve²⁰. It was decided that sprinkler activation would likely occur not long after ignition because of the relatively small 8-foot distance between the top of the mat and the closest sprinkler head. Again, the uncertainty in the fire growth rate with regards to prediction of available safe egress time makes the establishment of an actual ASET value difficult. Even so, it still provides an indication of anticipated fire and smoke spread as well as the sprinkler system response.

Figure 42: Polyurethane foam gym mats stored at the north side of the platform/stage

As with the sofa in Scenario 2, material properties for the mats were chosen based upon common values for polyurethane foam that has been shown in previous fire modeling efforts to be reasonably accurate. Identifying specific material properties would involve actual testing of the material, perhaps in a cone or full-scale oxygen consumption calorimeter to determine the peak heat release rate, burning rate and flame spread characteristics. This fire is consistent with Design Fire Scenario 6 specified in the Section 5.5.3.6 of the Life Safety Code. It is perhaps the most severe, rapidly developing fire possible at the Center of the Arts affecting a large number of occupants.

Scenario 4

In scenario 4, a fire starts at the rear of the seating platform in the rear theater adjacent to the production control booth. The seats used in the rear theater are loosely situated on the platform but are generally touching to maximize seating capacity. As in the portable chairs used in the main theater, the chairs consist of a metal frame and a wooden seat cushioned with polyurethane foam padding and covered with a synthetic fabric. Numerous electrical lines run in and around the control booth to control the lighting and sound inside the theater. While a specific failure mode was not identified, an accidental ignition by one of these power sources was presumed.

Fire modeling was conducted based on a fire growth curve with a 400 kW peak in 60 seconds. Material properties for the chairs were the same as those selected for similar chairs stacked in the main theater in scenario 1. This fire is also consistent with Design

Fire Scenario 5 specified in the Section 5.5.3.5 of the Life Safety Code. While the fire is not completely shielded from suppression systems, the location of the fire at the rear of the seating platform below the seats represents limitations of sprinkler effectiveness when water is shielded from the base of a fire. Water from the closest sprinkler head is blocked in part both by the theater control booth as well as the chairs.

Figure 43: Rear theater seating platform and the adjacent theater control booth behind it

The following assumptions were made in evaluating each of the four scenarios:

- That the automatic sprinkler system is fully functional.
- That theatrical productions are underway at the times of the fires. The theaters are darkened with sound at production levels higher than normal, ambient conditions.

- That only a single fire start occurs in each instance rather than multiple, concurrent fire sets that might result from an intensive and aggressive act of arson.
- That the rooms in which the fires start are at maximum occupancy levels.
- That once fire-room occupants start evacuating, word of the fire spreads between people throughout the building and that evacuations of other rooms also commence.
- That in the first three scenarios in the main theater, occupants of the second floor discharge through the front exit onto the street and not through the theater.

Computer Fire Modeling – Design Fire Simulations

Scenario 1

A 1,500 kW peak HRR fire with a 60 second growth rate burns below the rear stacks of chairs south of the main theater fixed seating near the east wall. The fire is centered under four adjacent stacks of chairs. The first sprinkler activates at around 69 seconds at the closest head to the south wall of the theater on the easternmost and lowest branch line. A grid size of between 0.2 m and 0.22 m on a side was used throughout the main theater domain.

Figure 3-1.18. HRR of stackable chairs, polypropylene with steel frame, no padding.

Figure 44: HRR Curve from SFPE Handbook for stackable, polypropylene chairs

Figure 3-1.19. HRR of metal-frame, upholstered stacking chairs.

Figure 45: HRR Curve from SFPE Handbook for stackable, metal-framed, upholstered chairs

Figures 44 and 45 were examined to determine an appropriate growth rate for the scenario. The growth of the scenario was based upon the assumption that established burning would occur at time = 0. Though that might be an overly aggressive assumption considering the variety of ignition sources that might start more slowly, the result is representative of a worst-case condition. The peak heat release rate for the fire scenario was based upon the heat release rate of a such a fire at the time of sprinkler activation determined by the model.

Figure 46: Heat release rate for scenario 1. Sprinkler activation occurs at about 69 seconds

A graph of the heat release rate calculated by the model and affected by the sprinkler activation shows that even though the fire was spreading through and involving the chairs, the effects of the sprinkler controlled the fire to a HRR just above 1,500 kW. This is consistent with expected fire growth in stacked commodities where water may not reach lower, protected fuels to extinguish fires, but still controls the fire, limiting further growth.

Since there are no fire alarms or notification devices in the main theater, the detection and notification times can only be estimated. Certainly the activation of a sprinkler head at the southeast corner of the theater would serve to notify people there. Smoke from the fire would also likely alert people seated near the south end of the fixed seating even before sprinkler activation. Detection time was estimated as 30 seconds

after ignition. Since the fire is not located near the stage, it is unlikely that visitors would confuse it as being part of a production and will begin moving soon after recognizing the threat. Presumably they would begin warning others and the production staff would raise the lighting and cut sound to hasten notification. Under these circumstances, the combination of detection/Notification and pre-movement times estimated at 1 minute.

According to the movement calculations shown under the egress section, the minimum time needed to evacuate the main theater if both exit doors are available is 2.6 - 2.75 minutes. If only one door is available, then the time is closer to 3.3 minutes. It was assumed that both exit doors would be opened for Scenario 1 at about 30 seconds after ignition and would remain open for the entire simulation.

With all times combined, the RSET for this scenario is approximately 3.6 minutes to 4.3 minutes. A review of the ASET for Scenario 1 shows that the limiting factor for tenability is visibility. Thermal conditions and CO concentrations remained satisfactory beyond the time that visibility dropped. The maximum temperatures at 6 feet above the floor other than at the actual fire were below 40°C. The maximum CO concentration in the simulation was about 100 parts per million, about 1/10th of untenable levels. Similar trends occurred in scenarios 2 and 3.

Figure 47: Scenario 1 - View from south wall of main theater. Stacked chairs are shown to the right in green and tan.

Figure 47 is a representation of the FDS output as generated by the Smokeview graphics program. Perimeter wall sections have been rendered invisible for easier viewing. The blue sections at the left of the graphic represents the theater curtains on the platform/stage. The arched roof and other structural elements are depicted in white and grey. Because FDS is based upon a rectilinear format (squares, rectangles and boxes), the shape of curved surfaces such as the arched roof of the Center for the Arts are

estimated by creating numerous rectangular sections and stepping them in an offset fashion from adjacent blocks.

Smokeview 5.6.3 – Dec 27 2010

Frame: 317

Time: 69.9

Figure 48: Time = 69.9 seconds just after initial sprinkler activation

Figure 48 shows that shortly after 1 minute of burn, the buoyant smoke has reached the opposite side of the theater, its momentum driving it below the arched roof level. Note that the rear exit from the second floor, the top landing of which can be seen in white in front of the dark blue theatrical curtains, is already engulfed in smoke over its upper section. A person attempting to egress down those stairs, even though it's unlikely

they would have been alerted to a fire within a minute, would be immersed in smoke upon opening the door.

Smokeview 5.6.3 – Dec 27 2010

Frame: 485

Time: 119.7

Figure 49: Time = 2 minutes after fire start. Two sprinkler heads activated.

Within two minutes after ignition, smoke levels descend to near floor level along the south side of the fixed seating platform. Suppression water not only limits the fire growth but also cools the smoke, thus reducing its buoyancy. The second floor rear exit stairs are visible towards the left side of the graphic, with the top half of them enveloped in smoke.

Figure 50: Slice file depicting the visibility 6 feet above the theater floor

The slice file in Figure 50 displays visibility conditions 6 feet above the floor two minutes after ignition, the same time as the previous figure. The dark smoke has been removed from the graphic to enhance the view. Areas shown in light and dark blue represent locations where the visibility has fallen below the selected tenability limit of 10 meters.

Figure 51: Northern view slice file showing visibility at a 6 foot height above the floor

This slice shows conditions about 229 seconds after ignition. Visibility over much of the elevated seating platform is well below 10 meters. Some of the area above the fixed seating is actually less than 6 feet above the platform aisles since the 6 foot measurement is referenced to the theater floor.

Fire Timeline – Scenario 1	
Approx. Time	Conditions Visible in Smokeview
30 seconds	Estimated Detection / Notification time
36 seconds	Smoke descends to the top of the 2nd floor rear exit door. Visibility near the top of the exit door at about 12 meters
50 seconds	Smoke reaches west (opposite) wall and starts to flow downward from momentum
60 seconds	Estimated completion of pre-movement time. Upper half of 2nd floor rear exit stairs have visibility <10 meters at 6 feet above steps
64 seconds	Smoke reaches north wall and starts to bank down.
68 seconds	1st sprinkler activates directly overhead burning chairs. Momentum of smoke flow across theater slows. Heat flux adjacent to the fire at the upper portion of the south aisle to fixed seating exceeds 2.5 kw/m ²
71 seconds	Smoke descends to 6 foot height at the north exit door of main theater. Visibility about 20 meters
82 seconds	Smoke at north theater door risen to about 8 feet above floor but smoke is thick at 6 feet above floor in NE corner of theater
85 seconds	Visibility on the upper level, north end of the fixed seating platform is < 10 meters
90 seconds	Visibility for the entire north aisle of fixed seating at 6 foot height is 10 meters or less. Visibility around the bar area of the lounge is below 10 meters.
98 seconds	2nd sprinkler head activates on next branch line up towards roof peak
100 seconds	East half of double exit doors at south end of theater are immersed smoke with visibility < 10 meters. Smoke down to about 6 feet above floor. Entire aisle at south end fixed seating has <10 meters visibility at 6 feet above floor. Much of area at south of theater has visibility <10 meters. Temperature at the 2nd floor rear exit about 60 °C. Onset of pain or burns from moist air possible.
110 seconds	Visibility in smoke at upper reaches of fixed seating near south end around 10 meters or less at 6 feet above floor
125seconds	The south doorway to the theater has visibility of only about 2 meters.

140 seconds	3rd sprinkler head activates. Head next one north on easternmost branch line
155 seconds	Visibility at the base of the upper fixed seating near the south end is < 2 meters
158 seconds	4 th sprinkler head opens in the center of the ceiling bay between first two trusses
165 seconds	Southeastern portion of fixed seating has visibility well below 10 meters. Visibility south of platform/stage < 10 meters, 6 feet above the base floor level.
195 seconds	5th head opens on second branch line adjacent to south side of the 2nd truss.
220 seconds	The entire southern half of the main theater has visibility < 10 meters 6 feet above floor
300 seconds	Visibility still > 10 meters at north exit, 6 feet above floor. Temperatures in south aisle of fixed seating and throughout main body of room 6 feet above the floor remain < 40° C throughout the theater except in the fire. CO levels < 100 ppm.

Table 6: Fire Timeline for Scenario 1, fire in stacked chairs in main theater south of fixed seating

Visibility at the southern exit door fell to below the 10-meter tenability limit at about 2 minutes after the start of the fire. Visibility for the entire southern half of the theater fell below this limit in about 220 seconds. Visibility at the northern exit door was still above 10 meters until 280 seconds into the simulation. At that point, egress was limited to a single exit, which would necessitate a longer required egress time. Occupants throughout the theater other than in the immediate vicinity of the fire would not have reached untenable limits for temperature, heat flux or carbon monoxide exposure during the 5-minute simulation.

The evaluation of Scenario 1 in terms of ASET vs. RSET shows that while many occupants would be able to evacuate from the theater, there was no safety factor for the time needed for a complete evacuation. RSET exceeded ASET because of deteriorating visibility.

There is uncertainty in a few variables in Scenario 1 including the fire's growth rate as well as the estimated detection and pre-movement times. There is also a question as to whether the FDS simulation accurately modeled whether the flammable ceiling finish throughout the main theater space would have ignited. Depending on the actual flammability of that finish, it is possible that the ceiling may ignite causing fire to sweep across the underside of the ceiling trapping some occupants inside in a cloud of burning, falling debris. Temperature at the ceiling directly above the fire is estimated to have peaked at 200 °C at 100 seconds after ignition. Burning brands carried aloft to the ceiling are possible but could not be modeled.

Figure 52: Visibility vs. Time, Scenario 1

SCENARIO 1 – Fire in Stacked Chairs

Figure 53: ASET vs RSET graph for main theater occupants in Scenario 1

Second floor occupants were presumed to have required longer detection/notification and pre-movement times. Because of the lack of a coordinated detection network throughout the building, a fire in the main theater may not have been noticed on the second floor until smoke was circulated through the HVAC system (for which the air return is located above the second floor spaces) to the second floor. The extent of that circulation is unknown.

The rear exit to the second floor would have been rendered impassable by smoke within one minute of ignition. It seems doubtful that anyone on the second floor would

even have noticed the fire by that time. Detection notification times there may have taken several minutes, however an exact time is likely dependent upon the state of the HVAC system at the time as well as natural leakage between the spaces. Pre-movement times would likely take another one to two minutes in the ensuing confusion. If second floor occupants opened the rear exit door to investigate, an initial flow of hot smoke through the door would have occurred.

Fortunately, most productions in the main theater take place after hours and on weekends when the second floor occupancies levels are minimal. Travel times of 100% of the second floor occupants through the front exit stairs is estimated at 5.1 minutes. That coupled with detection/notification times along with pre-movement times suggests evacuation of the second floor may take on the order of 10 minutes or more. Quick thinking occupants of the second floor who open windows at the front of the building to allow descending smoke to flow out may extend their available egress time.

Scenario 2

A 100 kW peak HRR fire with a 30 second growth rate, similar in size and growth to a trash can fire, starts on one of two upholstered sofas in the lounge area at the north of the main theater. The fire impinges upon the upper back seating portion of the sofa. FDS calculates the initial sprinkler head activation at around 80 seconds. The grid size used was again between 0.2 m and 0.22 m on a side. It was assumed that both exit doors would be opened about 30 seconds after ignition and remain open for the entire fire simulation.

Figure 3-1.102. HRR of several upholstered furniture items tested at NIST.²

Figure 54: HRR Curve from SFPE Handbook for various upholstered furniture items

Figure 54 was considered in determining an appropriate growth rate for the scenario. The growth of the scenario was based upon the assumption that established burning would occur at time = 0. Though such an assumption might be overly aggressive in light of the variety of ignition sources that might start more slowly, the fire represents a worst-case condition.

A graph of the heat release rate calculated by the model shows that unlike in scenario 1, this fire continued to grow in size even after activation of the first sprinkler. This is in part due to the fact that the first sprinkler to activate is located “upslope” from the fire plume. The second sprinkler head that activates is actually “downslope” and closer to the outer wall, some 20 feet away. Neither of these sprinklers appears to have provided the typical control that might be expected of a fire under or near a sprinkler head. This type of situation with sloped ceilings is discussed in NFPA 13 in Section 11.2.3.2.4 and calls for a 30% increase in sprinkler coverage if the ceiling slope exceeds 1 in 6. Sprinkler designers for the Center for the Arts added that extra coverage near the east and west walls of the building between the outermost branch lines. Even so, the water from the sprinkler did not appear to limit this fire’s growth to the heat release rate level at the time of sprinkler activation.

Figure 55: Scenario 1 HRR. Sprinkler activation occurs at about 69 seconds

It is assumed like with scenarios 1 and 3, the fire occurs during a theatrical production and that lights are dimmed and sound is possibly elevated. During such times, the lounge area north of the fixed seating typically is empty of patrons. Because of this, the time to fire detection and notification will likely be somewhat extended unless light from flames catches someone's attention. Otherwise, the detection and notification time is estimated at about one minute. Pre-movement time is again estimated at an additional 30 seconds. It is unlikely that visitors would confuse a fire in the lounge area as being part of a theatrical production.

Figure 56: View from north shortly after 1st sprinkler activation at 80 seconds

This view from the north of the theater to the area of fire origin clearly shows activation of the first sprinkler head several feet laterally removed from the smoke plume. It also shows the plume leaning over somewhat to the east away from the open sprinkler head.

Frame: 239

Time: 52.5

Figure 57: View from south even before 1st sprinkler activation showing second floor exit immersed in smoke and untenable visibility conditions

Figure 58: View from north shortly after 3rd sprinkler activation at 107 seconds

As shown in Figure 58, three sprinkler heads activate in just under two minutes yet none of them is directly above the seat of the fire in this instance. This certainly limits outward flame spread but has little extinguishing effect on the original fire.

Figure 59: View from north shows visibility < 10m at north door 6 feet above the floor

By 157 seconds, the visibility 6 feet above the floor at the north exit door has fallen well below 10 meters making visibility conditions untenable at that door. Elsewhere in the southern portion of the theater, visibility is still adequate for egress. This causes the overall movement time for complete evacuation to increase to somewhere between 2.6 and 3.3 minutes calculated in Appendix A.

Figure 60: View from south. Visibility at 6 feet height by the exit door < 10 m

By 275 seconds, occupants are subject to untenable visibility conditions 6 feet above the floor at the south exit door. Smoke has caused visibility to fall well below 10 meters.

Figure 61: View from north. Temperatures are below 60 °C at 6 foot height throughout

By the end of the simulation, temperatures 6 feet above the floor remain below even the 60 °C level of untenability throughout the theater. Temperatures at the rear exit to the second floor passed this point at about 90 seconds into the fire shortly after that area was already rendered untenable by low visibility.

Fire Timeline – Scenario 2	
Approx. Time	Conditions Visible in Smokeview
50 seconds	Visibility untenable at 2 nd floor rear exit door
60 seconds	Estimated Detection & Notification time
65 seconds	Smoke at 6 feet above the south aisle of fixed seating temporarily drops to < 10 meters
69 seconds	Smoke in upper rows at southern part of fixed seating temporarily drops the visibility to < 10 meters
80 seconds	1 st sprinkler head activates.
81 seconds	Visibility 6 feet above top level of fixed seating < 10 meters
90 seconds	Estimated pre-movement time complete. Temperature untenable at 2 nd floor rear exit door
99 seconds	Smoke at south end of fixed seating rises and visibility > 10 meters
105 seconds	2 nd sprinkler head activates at lowest branch line to east
107 seconds	3 rd sprinkler head activates closer to roof peak, further from fire plume
158 seconds	Visibility untenable at north exit, 6 feet above the floor
230 seconds	Visibility untenable at south exit, 6 feet above the floor
300 seconds	Temperatures at 6 feet above floor throughout the theater remain below 60 °C

Table 7: Fire Timeline for Scenario 2, fire in sofa in lounge area of main theater

Figure 62: Visibility vs. Time, Scenario 2

SCENARIO 2 – Fire on Sofa in Theater Lounge

Figure 63: ASET vs RSET graph for main theater occupants in Scenario 2

The ASET vs. RSET graph for Scenario 2 shows that the required safe egress time from the main theater would be expected to be on the order of 4 to 4.5 minutes. The difference between the two is dependent upon whether or not some of the people could evacuate through the north exit door prior to visibility there becoming untenable at 158 seconds. If so, then it's possible the ASET is sufficient since visibility at the south exit door is generally adequate until about 230 seconds after the fire start. Temperature, heat flux and carbon monoxide exposures remained tenable throughout the entire period. If

the detection/notification and pre-movement times can be shortened by about a minute than those estimated here, the likelihood of a successful evacuation improves. If the flammable ceiling finish becomes involved in fire and upper level flames spread throughout the theater, the chances of injuries or fatalities increase. Regardless, even though this fire is relatively small in size, this scenario again shows there is little chance of a complete evacuation of the main theater even with sprinkler activation unless early notification occurs.

As with Scenario 1, egress of occupants of the front lobby areas and art gallery along with those in the second floor spaces was not studied. Even though the fire in this scenario starts at the north end of the theater opposite these spaces, rapid smoke filling throughout the theater makes the second floor rear exit unusable in less than a minute, very similarly to a fire burning at the south end of the theater adjacent to these spaces. Successful evacuation of the second floor will again rely on 100% evacuation through the front exit door. Second floor evacuation times are again estimated at up to ten minutes depending on the number of people there at the time.

Scenario 3

The third fire scenario occurs on the platform/stage. Two large gymnasium-type mats kept there are presumed to ignite and burn, possibly started by a malfunction in nearby electrical equipment. A peak heat release rate of 2,000 kW was chosen with an ultra-fast growth rate. Testing conducted several years ago in full-scale fire tests by Professor Mowrer to examine the fire growth of gymnasium mats were considered in estimating this fire curve. It was concluded that sprinkler activation would likely follow not long after ignition because of the relatively close distance between the top of the mat and the sprinkler. Reducing the growth rate in the model to provide for a slower fire development would significantly increase calculation time and likely not add substantially to the understanding of smoke layer development and spread or the response by the automatic sprinkler system. It might provide a more conservative estimate of the ASET. A similar mesh size of between 0.2 m and 0.22 m like those for scenarios 1 and 2 was again used.

Figure 54 (shown above on page 124) was again used to determine an appropriate growth rate for this scenario since the major mass of the gym mat is polyurethane foam. The growth of the scenario was once again based upon the assumption that established burning would start at the very onset of the scenario. Though such an assumption might be overly aggressive in light of the variety of ignition sources that might start more slowly, the fire represents a worst-case condition and minimizes unnecessary model calculation time.

Figure 64: Heat release rate for scenario 3. Sprinkler activation occurs at about 73 seconds.

The estimated growth rate of the fire seemed reasonable in comparison to actual testing. Though there was the potential for a much higher peak heat release rate without sprinklers, the peak rate in the model was consistent with a sprinkler activation that controlled the fire growth but did not extinguish the blaze.

Detection and notification times were estimated to be on the order of 60 seconds. It would be expected to be less if the platform/stage was occupied at the time. The gym mat is generally not observable by the audience. If the platform/stage was occupied as in a performance, back-stage actors and stagehands would be expected to notice the fire and

give directions to visitors. This would reduce pre-movement time to approximately 45 seconds. As with Scenarios 1 and 2, movement time for evacuation of the main theater is estimated at between 2.6 or 2.75 minutes when both exit doors are accessible to 3.3 minutes for only one door. In this scenario, both doors should have remained accessible for equal periods of time. Both exit doors are assumed to be opened about 30 seconds after ignition and to remain open for the entire fire simulation.

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Figure 65: View of west side of main theater. Gym mats shown to left with green top.
The white space to the right of the mat depicts the rear side of the theater screen.

Figure 65 is the Smokeview output of the layout of Scenario 3 in the main theater. The graphic depicts the theater prior to ignition. As before, wall sections have been rendered invisible for ease of viewing. The blue sections represent the curtains on the platform/stage. Structural elements are generally depicted in white.

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Frame: 311

Time: 75.0

Figure 66: View from west of main theater shortly after 1st sprinkler activation at 75 seconds

The first sprinkler activates at about 73 seconds after the fire start. The estimated HRR at the time is about 2,000 kW. Smoke levels have already enveloped the rear exit

door from the second floor and have descended approximately one-third the depth from floor to ceiling.

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Figure 67: View from southwest shortly after 1st sprinkler activation at 75 seconds

Figure 68: View from southeast after 4th sprinkler activation at 95 seconds

Because of the intensity of the fire and the elevated position of the gym mats in relation to the sprinklers, four sprinkler heads activate within 22 seconds of each other. By the time the 4th head activates, smoke levels descend below a level 6 feet above the upper fixed seating platform.

Frame: 426

Time: 109.5

Figure 69: Visibility slice at the southern aisle of the seating platform at 110 seconds.

By 110 seconds, the visibility at 6 feet above the upper platform in the fixed seating is well below 10 meters. Overall smoke layer stability is nearly uniform throughout the main theater and still descending.

Frame: 661

Time: 180.0

Figure 70: View from north at 180 seconds. Visibility 6 feet above the floor < 10 meters

By 180 seconds into the fire, at least five sprinklers have activated including one at the peak of the roof, approximately 35 feet laterally distant from the main fire. The number of activations not only tax the sprinkler system's ability to control the fire by adding increased water demand but they also cool the smoke sufficiently to drop visibility levels at 6 feet above the theater floor to less than 10 meters.

Frame: 861

Time: 240.0

Figure 71: Visibility slice shown from the northeast at 240 seconds. Visibility at 3 feet above the floor < 10 meters

Figure 72: Chart of sprinkler element temperature vs. time showing activations for Scenario 3

The magnitude of the gym mat fire reveals that in addition to creating untenable conditions for occupants in terms of visibility, it also severely challenges the sprinkler system. By four minutes into the fire, at least eight sprinkler heads activate. The sprinkler system was designed to fully operate with up to five heads activating.

Figure 73: View of gas temperatures at 270 seconds into the fire

Throughout the fire, though smoke levels drop close to the floor, temperature exposures at a level 6 feet above the highest seating level do not reach above 60 °C. Although the fire conditions become untenable in terms of visibility, they do not become untenable due to temperature exposure.

Fire Timeline – Scenario 3	
Approx. Time	Conditions Visible on Smokeview
48 seconds	Visibility < 10 meters at 2nd floor rear exit
60 seconds	Estimated Detection / Notification time
64 seconds	Smoke reaches east side of theater
68 seconds	Visibility near zero at base of 2nd floor rear exit upper landing
73 seconds	1st sprinkler head activates above fire
84 seconds	2nd and 3rd sprinkler heads activate
84.3 seconds	4th sprinkler head activates
95 seconds	5th sprinkler head activates
96 seconds	Visibility < 10 meters at north end, top of fixed seating
105 seconds	Estimated completion of pre-movement time
110 seconds	Visibility < 10 meters at south end, top of fixed seating
155 seconds	6th sprinkler head activates
200 seconds	7th sprinkler head activates Visibility < 10 meters throughout theater at about 6 feet above floor
205 seconds	8th sprinkler head activates
230 seconds	Visibility < 10 meters throughout theater; rolls out north door
240 seconds	Visibility < 10 meters throughout theater; rolls out south door

Table 8: Fire Timeline for Scenario 3, fire in gym mat on main theater platform/stage

Figure 74: Visibility vs. Time, Scenario 3

The visibility at 6 feet above the floor at the south doors, north doors and stage temporarily drops to below the 10-meter tenability limit at about 50 seconds at the south and 170 seconds at the north and stage. These are short-lived instances however and the visibility quickly raises to tenable levels. Not until around 200 seconds does the visibility at all three areas become untenable for an extended period of time. Accordingly, the ASET based upon visibility was estimated at 200 seconds after ignition. It should be noted that in this instance, as in Scenarios 1 and 2, the visibility at the second floor rear exit becomes untenable in less than a minute.

SCENARIO 3 – Fire on Gym Mat on Stage

Figure 75: ASET vs RSET graph for main theater occupants in Scenario 3

As seen by the ASET vs. RSET graph for Scenario 3, though the required safe egress time from the main theater would be expected to be on the order of 4.5 minutes, visibility of more than 10 meters at a point 6 feet above the floor lasted slightly more than 3 minutes. Temperature, heat flux and carbon monoxide exposures remained well below the tenability limits throughout the entire period. The maximum temperature outside the immediate fire area at 6 feet above the floor was about 40 °C. Maximum CO levels again reached only about 100 ppm, 10 times less than untenable conditions.

Once again like in the first two scenarios, only the egress of occupants from the main theater was examined. And like with the first two scenarios, the second floor rear exit became untenable in less than a minute. The uncertainty in the detection/notification times on the second floor is high. The available safe egress time from the second floor is unknown and a matter of speculation. What is likely however is that the required safe egress time using conservative estimates of detection/notification and pre-movement times is on the order of 10 minutes after ignition depending on the occupancy load of the second floor at the time of the fire.

In order to improve the ASET vs. RSET conditions for Scenario 3, the detection/notification and pre-movement times must be decreased. Even if they were decreased to on the order of 30 seconds, a full safe evacuation of the maximum occupancy load of the theater even with sprinkler activations is questionable. If the estimated fire growth rate used in the model is faster than an actual fire would grow, some time cushion would result. If actual sprinkler activations followed the pattern revealed in the model, then its possible that the entire system might be overwhelmed. Residual water supply pressure and supply may be sufficient to handle the additional load but a new hydraulic calculation should be performed to verify that.

Scenario 4

Scenario 4 involves a fire in the rear theater. It starts behind the rear row of audience seats at the top of platform, adjacent to the production control booth. The movable seats used in the rear theater consist of a metal frame and a wooden seat cushioned with polyurethane foam padding and covered with a synthetic fabric. Numerous electrical power lines run in and around the control booth to operate the lighting and sound inside the theater. While a specific failure mode to cause this fire was not identified, an accidental ignition by one of these power sources was presumed.

Fire modeling was conducted based on a fire growth curve of an initial fuel with a 400 kW peak in 60 seconds. The fire spreads to other fuels including chairs in the area of origin before the sprinkler system activates. Material properties selected for the chairs are the same as those selected for similar chairs stacked in the main theater in scenario 1. The initial fire was designed to start decaying after 60 seconds.

Figure 3-1.64. HRR of a typical wood pallet stack (1.22 m × 1.22 m high).

Figure 76: HRR Curve from SFPE Handbook for stacked wood pallets

Figure 76 was considered in estimating an appropriate growth rate for the scenario. The fire started under the chairs on the rear side of the platform and would initially involve openly configured, vertical and horizontal wood members. The growth of the scenario was based upon two assumptions. The first was that established burning would occur at time = 0 and the second was the involvement of the fire on the wooden items would be at a rate consistent with Figure 76. The peak heat release rate was based upon estimations of the amount of wood that would be burning as well as upholstered cushions on the chairs by the time of sprinkler activation.

This scenario again assumes that the fire occurs during a theatrical production and that lights are dimmed and sound is possibly elevated. Because of the relatively small size of the theater and the location of the fire near the audience, detection and notification times would likely be on the order of 30 seconds or less if the platform/stage is occupied at the time. The first audience members to notice the fire would be expected to notify others and begin moving. Pre-movement time is estimated at 30 seconds after notification. Since a smoke detector is mounted in the normally open sprinkler control room at the rear of the theater, it is expected that detector would sound within one minute of the onset of the fire and activate the horn-strobe notification device. Additionally, once a sprinkler head opens, the outside vibrating bell will sound.

Movement time for evacuation of the rear theater is estimated at 1.5 minutes. People in the rear lobby at the time of the fire would be notified by the horn strobe sounding or when actors or theater personnel in the dressing rooms move to the lobby door to evacuate. The main exit door to the theater is assumed to be opened 20 seconds after the start of the fire and to remain open. The sprinkler control room door and the rear lobby exit door are assumed to be opened at 60 seconds after ignition and to remain open.

Unlike the fires in the three main theater scenarios, this fire decays almost as quickly as it grows. Any ignition of the chairs is quickly controlled and extinguished in part due to the closer proximity of the low sprinkler heads in this theater as compared to those in the main theater.

Figure 77: Heat release rate for scenario 3. Sprinkler activation occurs at about 73 seconds.

Figure 78: View of rear wing from northwest. West wall made invisible for viewing.
Seating on the seating platform is shown in olive green.

Figure 79: Close-up view of the rear theater 30 seconds after ignition. Detection by occupants presumed to happen by this time.

By 30 seconds after ignition, an established smoke plume likely would alert occupants in the seating area as well as theater personnel in the control booth immediately behind the seating.

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mesh: 1

Frame: 342

Time: 74.1

Figure 80: Sprinkler head activates above control room at 73 seconds

Smokeview 5.6.3 - Dec 27 2010

mesh: 1

Frame: 389

Time: 87.0

Figure 81: By 87 seconds visibility throughout seating area is untenable

mesh: 1

Frame: 390

Time: 87.3

Figure 82: Wider view of rear theater at 87 seconds. Smoke has reached the sprinkler room.

By 87 seconds after ignition, the smoke level had enveloped much of the seating area and has flowed into the sprinkler room. The smoke detector there would have activated by this time alerting people outside the building of a fire within.

Figure 83: Visibility slice file 6 feet above floor showing untenable conditions in blue

Though the platform/stage area still has adequate visibility a minute and a half after ignition, the rear seating area is mostly enveloped in smoke causing visibility to drop to below untenable conditions. If the doorway behind the platform/stage is clearly marked and visible with open access, some patrons will likely move towards it and into the sprinkler room exiting through its door into the parking lot.

Smokeview 5.6.3 - Dec 27 2010

Frame: 338

Time: 101.4

Figure 84: Vertical slice at 101 sec. The stage is to the left and seating to the right. Visibility about 6 feet above floor is less than 10 meters.

By 101 seconds, the visibility throughout the rear theater at 6 feet above the floor is reduced to untenable conditions. The fire size has decayed to around 200 kW, that of a moderate trash can fire.

Time: 120.6

Though visibility conditions from even a small fire such as this worsened rapidly and became untenable within a minute and a half, temperatures in the theater remained moderate. This slice shows temperatures at 6 feet above the floor at their near-maximum

levels in the fire. Subsequently, as the fire decays, temperatures quickly drop. Maximum CO levels of about 140 ppm occur at 200 seconds and thereafter drop. At about the time the sprinkler activates, heat fluxes reach approximately 3 kW/m² at the backs of the second row of chairs from the top row as the fire grows under the rear seats. Thereafter it drops to well below the untenable limit of 2.5 kW/m². Heat fluxes outside the area of actual fire also remain low.

Fire Timeline – Scenario 4	
Approx. Time	Conditions Visible on Smokeview
30 seconds	Estimated Detection and Notification time
60 seconds	Estimated completion of pre-movement time
73 seconds	1st sprinkler head activates above fire
75 seconds	The bottom of the smoke layer had descended to about 6 feet above top level of seating platform
87 seconds	Visibility is untenable at 6 feet above the eastern 2/3 of seating platform
101 seconds	Visibility is untenable at 6 feet above the floor throughout the theater
120 seconds	Peak temperatures of about 30 °C at 6 feet above the floor

Table 9: Fire Timeline for Scenario 3, fire in gym mat on main theater platform/stage

SCENARIO 4 – Fire on Seating Platform in Rear Theater

Figure 86: ASET vs RSET graph for rear theater occupants in Scenario 4

The ASET vs RSET graph for Scenario 4 clearly demonstrates that with even a small fire controlled by sprinkler activation, occupants of the rear theater would be exposed to untenable visibility conditions before a full evacuation could be expected. By 101 seconds, visibility at six feet above the floor is less than 10 meters throughout the theater. At this time, visibility near the floor would be adequate but would require evacuees to bend down below normal standing height or crawl from the theater. Fortunately, temperatures in this scenario at 6 feet above the floor and below never peak

much above about 30 °C except in the fire plume reducing thermal exposure from such a small fire controlled by sprinkler activation.

Even so, this scenario clearly demonstrates the need for alternate exits out of the rear theater in accordance with the remoteness requirements contained in Sections 7.5.1.3.1 and 7.5.1.3.2 of the Life Safety Code. They state in part that multiple, accessible exits must be located no closer to each other than one half the diagonal measurement of a room. For the rear theater, that minimum separation distance between exits is on the order of 28 feet.

Comments and Recommendations

The prescriptive and performance-based analyses of the Center for the Arts building identified various factors related to both major and minor fire safety issues that might affect the life safety of the building occupants. Computer fire modeling simulations showed that with regards to four design fire scenarios created to examine ASET vs. RSET, that even with an automatic sprinkler suppression system activating, maximum occupancy loads face significant hurdles in achieving safe egress and that incomplete evacuations are likely.

Possible corrective measures are discussed below that could either decrease the required time needed for safe egress allowing for a greater margin of safety or increase the available safe egress time. Some are relatively easy to accomplish while others may require more intense and perhaps costly efforts.

History has shown that when fires occur in buildings with similar, unaddressed issues, large losses of life and numerous injuries to occupants can result. Two notable examples of fires that led to tremendous loss of life in the past 40 years were the Station Nightclub fire in 2003 in which 100 people died and more than 200 more were injured and the Beverly Hills Supper Club fire in 1977 that resulted in 164 deaths and more than 200 injuries.

Alarm System

The Center for the Arts is not required by code to have an alarm system besides that installed in the sprinkler control room. Even so, the performance-based analyses presented herein have shown the benefit of modification and extension of the existing system. NFPA 72 states that, "Fire alarm systems intended for life safety should be designed, installed, and maintained to provide indication and warning of abnormal fire conditions. The system should alert building occupants and summon appropriate aid in adequate time to allow for occupants to travel to a safe place and for rescue operations to occur. The fire alarm system should be part of a life safety plan that also includes a combination of prevention, protection, egress, and other features particular to that occupancy."

The Life Safety Code sets forth as one of its principal objectives, the idea of occupant protection. In it is states, "A structure shall be designed, constructed, and maintained to protect occupants who are not intimate with the initial fire development for the time needed to evacuate, relocate, or defend in place." Many of the occupants of the Center for the Arts are expected to be first time or occasional visitors not totally familiar with the building and its system and layout. Accordingly, the above objective contained in the LSC seems particularly applicable to the Center for the Arts.

The water flow alarm for the sprinkler system is connected to only two notification appliances, a horn/strobe mounted in the rear theater adjacent to

the sprinkler room and a vibrating bell mounted on the exterior, north end of the building, also adjacent to the sprinkler room. According to the building staff, even if either of those notification appliances should activate, they may not be heard under normal circumstances in the main part of the building that includes the main theater, the front lobby and offices or in the second floor spaces.

During a performance in the main theater, attendees there might never hear the notification appliances sounding because of the sound levels from ongoing presentation. The potential evacuation delays could have deadly consequences. Attendees would likely be delayed in starting their departure making a safe, timely and full evacuation even more difficult to achieve.

Modifications and additions to the existing alarm system could greatly enhance the protection of theater occupants from such an event. First and relatively easily, the existing notification appliance system for the waterflow alarm could be extended to the main theater, front lobby and the second floor occupancies. This simple improvement would reduce detection/notification and probably pre-movement times significantly. Further, commercially available devices could link the alarm system with the theater's sound and lighting systems. In the event of a fire during a performance, theatrical sound levels would be automatically reduced to allow fire notification appliances to be heard and lighting levels in the darkened theater would be raised. Provisions for such systems are discussed in Section 18.4.3.1 of NFPA 72.

Where acceptable to the authority having jurisdiction, reducing the background noise is a viable alternative to providing a fire alarm notification system with high level audio output. NFPA 72 states that in some situations, such as nightclubs, concert halls, and theaters, an advisable action is to stop the background noise and control the lighting to create a sudden and noticeable change in the environment to get people's attention. This would serve to alert both visitors and employees.

It is also recommended to extend the smoke detection system to under the ceiling in the main theater to provide additional notification time to occupants. While detection throughout the theater is recommended, even a line of detectors at the top of the arched ceiling would be a significant improvement. In the performance-based scenarios, the time to detection was wholly based on occupant detection. Although a wet pipe sprinkler system is installed, it is clear that large amounts of smoke can be produced and spread throughout the theater before a sprinkler head activates. Any reduction in the time of detection and notification adds a safety margin to RSET.

Another alarm system improvement that would minimize smoke flow throughout the Center for the Arts would be connecting the fire detection system to the HVAC air movers. Once a detection signal was sensed, power to the fans would be shut off thus minimizing forced circulation of smoke into the first and second floor spaces at the front of the building. An air return located near the peak of the

south wall of the main theater routes air into cooling equipment located in a portion of the ceiling/attic space above the second floor. Disabling air movement through this system during a fire would slow the smoke flow out of the theater to a rate wholly dependent on leakage rather than forced air flow.

The AHJ previously opined that the Center for the Arts is relieved of the onus of Section 13.3.4.1.1 of the Life Safety Code (requiring an alarm system in existing assembly spaces with occupant loads of more than 300) since a sprinkler system is installed therein. The reasoning was that a sprinkler head can act as a form of heat detector and serve to alert occupants of fire danger. As the performance based analyses showed, by the time sprinklers do activate, smoke can be widespread throughout the main theater and visibility levels quickly dropping.

A series of smoke detectors and notification devices installed in the main theater would provide earlier alerts to fire there than would the activation of a sprinkler head. Since the existing sound and visual appliances connected to the waterflow alarm are located well outside the theater, it should be presumed they might be completely ineffective in alerting occupants of fire danger.

In addition to adding an alarm system to the main theater, addition of detection and notification appliances on the second floor should also be considered. Since the second floor occupancies do not share common areas or activities with the rest of the building with the exception of HVAC, a fire starting elsewhere could easily go unnoticed on the second floor for a significant time. That

along with the fact that one half of the second floor egress capacity passes through the main theater makes it crucial to provide second floor occupants with early notification. As is evident with each of the three fire scenarios in the main theater, the second floor rear exit can become impassable within one minute of fire ignition at ground level in the theater.

Lastly, though perhaps minor in comparison to the other alarm issues, the existing smoke detector arrangement in the art gallery is insufficient and does not meet code requirements with regards to placement. Sections 17.5.2 and 17.5.3 of NFPA 72, the National Fire Alarm and Signaling Code dictate that smoke detectors should be mounted within the top 15% of the room height. In the art gallery, that distance is within 22.5 inches of the ceiling. The existing detector is 30 inches below. Even if mounted at the correct height on a wall or on the ceiling, the existing detector might still not provide adequate smoke detection. The upper part of the gallery is divided into three bays separated by deep, solid beams. A single smoke detector will only lead to timely activation if a fire starts directly below the bay in which the detector is mounted. If it started below another bay, then smoke would first have to fill that bay and then spill out and flow into the bay with the detector before activation would be assured. Currently, all three bays will have to fill with smoke and then the smoke layer will have to descend about six more inches before reaching the existing detector. Although fire detection is not required in the art gallery, to make the current system adequate will require

repositioning the existing detector higher in the room and addition of at least two more detectors in the adjacent ceiling bays.

Horizontal Exit

The performance based scenarios in the main theater all showed that in the event of a fire there, the rear emergency exit for the second floor becomes unusable within seconds of the fire's start. With that exit unavailable, little option is left to those on the second floor with regards to egress other than full evacuation through the front exit. An expensive and challenging option to alleviate this problem would be addition of an additional exit that opened directly from the second floor to the exterior of the building. Another option would be to separate or isolate the existing second floor rear exit stairs from the rest of the main theater by enclosing it behind fire rated walls and doors, thus qualifying it a horizontal exit. Without some modification however, the current rear exit should be considered as unreliable in the event of a fire starting in the main theater, front lobby or adjacent spaces. It could still be effective should a fire start in the second floor spaces.

The wall separating the main theater from the first and second floors to the south could serve as a horizontal exit into the front lobby with some modifications. The doors between the lobby and theater would have to be upgraded to fire rated doors limiting smoke flow through ample leakage paths around the existing door. Additionally, penetrations through the wall from piping or ducting would also have to be filled or

enclosed to prevent smoke and fire migration through the wall. HVAC ducts extending between the first and second floors could be enclosed in chases surrounded by fire resistant rated walls.

Administrative Controls - Storage

Two of the fire scenarios examined for the performance based analyses involved stored items as the main fuel source. Stacked chairs, either upholstered or plastic and the gym mats on the platform/stage can result in fires with readily high heat release rates that would not only lead to rapid fire spread, but which could overwhelm the existing sprinkler system. Prompt consideration should be given to eliminating the chair storage from alongside the south edge of the theater's fixed seating and relocating it to enclosed storage areas such as at the north end of the theater. Though the fire danger from the sum of the chairs when unstacked is relatively insignificant, once stacked, the geometry of the stacks makes them a serious fire danger to occupants. If ignited, even sprinkler activation may prove ineffective at fire control since many of the chairs' burning surfaces may be shielded from falling droplets. Further, a fire in a stacked arrangement tends to generate significantly more toxic smoke than if the same number of chairs burned separately.

The gym mat on the platform stage also poses a serious fire danger if ignited. As shown in Scenario 3, the mass of foam in the mat has enough energy to overwhelm the theater's sprinkler system in minutes. If alternative storage is unavailable due to the size of the mats, then they should at least be enclosed under fire resistant materials or

protected from the possibility of ignition from failures in nearby, overhead electrical circuits and equipment. The current location of the mat openly exposed to potential ignition sources poses an unnecessary risk.

Interior Finish

Ceilings throughout most of the Center for the Arts, on both the first and second floors, are lined with insulation with the facing exposed. That facing has been shown to easily ignite with a small flame. Section 13.3.3.3 of the LSC requires that in existing buildings with general assembly areas having occupant loads of more than 300, interior wall and ceiling finish materials shall be rated Class A or Class B as determined by standardized testing. No records of applicable testing or flammability ratings of the material are known to exist. Unofficial flammability tests that exposed the material to small flames suggests the ceiling finish will likely not meet existing Class A or B requirements.

A documentation review for similar products for sale by major insulation suppliers suggests most analogous materials do not meet the interior finish rating requirements set forth in the Life Safety Code for existing occupancies. One need only review the results of major fire catastrophes such as the Station Nightclub Fire, the Beverly Hills Supper Club and others in which the contribution of flammable interior finish led to multiple fatalities to realize the significance of this issue. If ignited, flame

spread over the exposed ceiling facing would be rapid. Such a fire could quickly overwhelm the sprinkler system and rain flaming debris down onto the occupants below.

Reducing this fire danger will likely require that the material either be removed, covered or treated. It could be protected from fire exposure from below by covering it with gypsum board or another material with low-combustibility or Class B finish ratings. There might also be approved fire resistant coatings that could be used to cover the facing.

Rear Theater Exits

The existing arrangement of exits in the rear theater does not appear to meet the requirements of the Life Safety Code in terms of exit arrangement or visibility of exits. At present, most occupants to the rear theater would likely attempt to evacuate through the main exit in the event of a fire. Though a second exit behind the platform/stage that leads into and through the sprinkler control room has been thought by Center staff to be a satisfactory alternative, it is neither visible from the main part of the theater nor is it clearly marked and accessible. The AHJ should be consulted with regards to available alternatives. At a minimum, the secondary exit must be clearly visible from throughout the space and access to it unimpeded. Whether that would be an acceptable alternate exit based upon its required egress travel through the sprinkler control room is a matter to be decided by the AHJ.

Appendix A

Egress - Occupancy Load Determinations

The following four pages show maximum occupancy load spreadsheet calculations for the Center for the Arts building that are based upon the occupancy loading criteria of Table 7.3.1.2 of the Life Safety Code.

Center for the Arts

Occupancy Loading

MAIN THEATRE (INCLUDING STORAGE), FRONT LOBBY AND BUSINESS AREAS						
Space/Room	Length	Width	Area	Occ. Category	OLF	Occ. Load
Front Office A	26	18.75	487.5	Business	100	5
Front Office B	16	18.75	300.0	Business	100	3
Reception	24.75	17.5	433.1	Assembly	15	29
Coffee serving	13.33	6	80.0	Business	100	1
Main waiting area A (Note 3)	42	25	1050.0	Assembly/Conc use	7	150
Front Dressing Room	27	17	459.0	Business	100	5
Hallway/Restrooms	27	23	621.0	Business	100	6
Fixed Theatre Seating			0.0	Fixed Seating	Note 1	170
Area in front of seating	57	19	1083.0	Assembly	Note 2	50
South side of fixed seating	7	42.5	297.5	Assembly	Note 3	0
Lounge seating/theatre(Note 3)	33	21	693.0	Assembly-low	15	46
Bar area - theatre	21	10	210.0	Assembly	100	2
Platform/Stage and staging	52	25	1300.0	Assembly	15	87
Storage A (main level)	25	19	475.0	Storage	500	1
Storage A (second level)	25	19	475.0	Storage	500	1
Storage B/C	20	30	600.0	Storage	500	1
Total People in Main Floor Theatre & Waiting Area:						557
Total People in Front Lobby/Waiting Areas						199
Total People in Main Theater and Main Storage						358

ART GALLERY						
Space/Room	Length	Width	Area	Occ. Category	OLF	Occ. Load
Art Gallery	33	28	924.0	Assembly/conc use	7	132
Total People in Main Floor Art Gallery						132

Center for the Arts

Occupancy Loading

REAR THEATER, WAITING AND STORAGE AREAS

Space/Room	Length	Width	Area	Occ. Category	OLF	Occ. Load
Sprinkler room	10	5	50.0	Business	100	1
Behind theatre staging	4.25	20	85.0	Assembly	15	6
Rear actor hallway	42	3	126.0	Assembly	15	8
Rear theatre platform/stage	27.5	18.5	508.8	Assembly	15	34
Between seats and platform	10	27.5	275.0	Assembly (note 5)		0
Control Booth	7.33	17	124.7	Business	100	1
Rear theatre seats	12	23.75	285.0	Fixed Seating (note 1)		60
Rear entry/waiting	30	20	603.4	Assembly	15	40
Rear hallway	15	4	60.0	Assembly	15	4
Rear dressing rooms	11.75	18.75	220.3	Business	100	2
Rear restrooms	15	11	165.0	Business (note 4)		2
Storage D	29	30	870.0	Storage	500	2
Storage E	14.66	18.2	266.4	Storage	500	1

**Total People in Rear Theatre, Waiting
and Storage Areas 161**

First Floor Max Occupancy 850

Center for the Arts

Occupancy Loading

SECOND FLOOR							
Space/Room	Length	Width	Area	Occ. Category	OLF	Occ. Load	
Reception	15	23	345.0	Business	100	3	
Hallway	4	47.25	94.3	Assembly	15	6	
Offices	15	11.75	176.3	Business	100	2	
Dressing Room	18	10.75	193.5	Assembly	15	13	
Sound Studio	22.45	14	314.3	Business	100	3	
Restrooms	12.25	12.75	156.2	Business (note 4)		3	
Dance Studio 1	48	28	1344.0	Assembly	15	90	
Dance Studio 2	26	24	624.0	Assembly	15	42	
Dance Studio 3	30	24	720.0	Assembly	15	48	
Storage	12.75	21	267.8	Storage	500	1	
Second Floor Max Occupancy						211	
First Floor Front Theatre Area Max Occupancy						557	
<i>(Main Theatre/Storage Max Occupancy)</i>						<i>358</i>	
<i>(Front Waiting Area Max Occupancy)</i>						<i>199</i>	
Art Gallery Max Occupancy						132	
Rear Theatre, Waiting and Storage Rooms Max Occupancy						161	
MAXIMUM FIRST FLOOR OCCUPANCY						850	
MAXIMUM SECOND FLOOR OCCUPANCY						211	
MAXIMUM BUILDING OCCUPANCY						1061	

Center for the Arts

Occupancy Loading

(Note 1) These numbers are based upon fixed seating

(Note 2) No one is supposed to be in these areas after people are seated except 50 additional seats on ground floor

(Note 3) No one is to remain in this area during a performance

(Note 4) These values are based on number of stalls, sinks, and urinals +25%

(Note 5) No one is to be allowed in front of the front seats during a performance

<i>Likely reductions in first floor max during productions</i>	-198
<i>(when theatre fully occupied, front waiting and lounge seating unoccupied)</i>	
<i>Likely max occupancy 1st floor south half during productions</i>	755
<i>(when theatre fully occupied, front waiting and lounge seating unoccupied)</i>	

Hand Calculations Of Estimated Movement and Required Safe Egress Times (RSET)

Art Gallery

Exit Discharge Door	72-inch
Door to Lobby	72-inch
Maximum occupancy	132 persons
Maximum Specific Flow thru Door	24.0 persons/min/foot eff. width (Table 3-14.5, SFPE 3 rd).

Effective width of 72 inch doors $72'' - 12'' = 60''$ or 5 feet.

Maximum calculated flow through each doorway at ideal density would be:
 $24 \text{ persons/minute/foot effective width} \times 5 \text{ feet} = 120 \text{ persons/minute}$

Assuming everyone is equally spaced through the art gallery and heads to the exit at about the same time, it is estimated that to discharge 132 people from the art gallery will take $132 \text{ people} / 120 \text{ people/minute} = 1.1 \text{ minutes (66 seconds)}$.

Front Lobby and Adjacent Rooms (less main theater population)

Maximum occupancy	199 persons
Exit discharge door	72-inch wide
Door to Art Gallery	72-inch wide
Maximum flow through 72" door	120 persons/minute
The time to discharge 199 people:	

$199 \text{ persons} / 120 \text{ persons per min} = 1.66 \text{ minutes (99 seconds)}$

Longest distance to discharge door Approx. 80 feet.

Maximum travel rate on flat surface	235 feet/minute (Table 3-13.4 SFPE 4 th)
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Time to reach exit door:	80 feet/235 feet per min = 0.34 minutes (20 seconds)
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Assume minimal queuing at the front exit door when just considering these occupants.

Evacuation of the front lobby and adjacent rooms = 119 seconds.

Main Theater, Platform/Stage, and Adjoining Supply Rooms

Maximum occupant load	358 people* 170 fixed seats 50 moveable seats 48 people in lounge 90 people in platform/storage areas.
Exit doors	Two, 72-inch wide
Space between fixed seat rows	18-inch
Average distance seat to closest aisle	~12 feet.
Aisle steps	Treads ~ 40" Risers 7" Three step bottom of each aisle
Height of steps	21" to main floor.
Horizontal travel	40 feet average
Vertical descent	6 feet from top row
Stair travel for 7/11 stair	1.85 x vertical distance 1.85 x 6 = 11 feet (Table 3-14.5, SFPE 4 th).
Total distance (horiz. + stairs)	51 feet for furthest seated person

Speed on stairs is calculated using the equation:

$$S = k - akD$$

Where: S = speed along line of travel
D = density (persons/unit area) (0.175 for ideal flow, SFPE Handbook Figure 3-14.5)
K and *a* = constants (Table 3-14.2, SFPE 3rd ed.)
K = 212 for stairs,
a = 2.86 for speed in feet/min

Therefore, speed of travel on the stairs = $212 - (2.86)(212)(.175)$
Approximately 106 feet / minute

Exit stairs width	36"
Effective width	24" (36" – 2x6")

Eff. width x 18.5 persons/minute/foot e.w. = 37 people/minute

Assume 170 people in fixed seats divide equally between sets of steps

170 people / 37 people per min = 2.3 minutes (140 seconds)
to get people out of fixed seating and onto the main floor.

Travel distance / speed on stairs = Travel time

51 feet / 106 feet/min on stairs = 0.48 minutes (29 seconds)

A queue may form at the bottom three steps making the stair passage the limiting factor.

Time to clear fixed seating = 170 people / 37 people per min
Time = approximately 2.3 minutes (140 seconds)

Distance to the rear (north) exit	21 feet
Distance to the rear (north) exit	9 feet

Travel speed on flat floor	235 feet/minute (Table 3-14.4, SFPE, 3 rd)
Travel time to north exit	6 seconds
Travel time to south exit	3 seconds

Remaining occupant load of
(stage hands/performers/lounge/
temp seating) 188 people

It is assumed these 188 people will divide evenly sending 94 people to each of the two exit doors.

Maximum travel distance 50 feet approx.

Travel time to exits $50' / 235' \text{ per min} = 0.33 \text{ minutes (20 seconds)}$

Width of Main Theater Doors 72-inches wide.

At maximum flow thru doors,

Time to pass thru doors 94 people / 120 people per minute

Time to pass = $0.78 \text{ minutes (47 seconds)}$

Time to travel to/thru exit doors = 47 secs + 20 secs = 67 seconds (1.1 mins)

That should be sufficient time for the 94 people to pass through each door before the additional two groups of 85 people each to clear their respective sides of fixed seating and head to the doors. Therefore, 179 people will likely not cause a queue to form.

It is assumed the 179 people exiting through the front lobby (85 from the fixed seating and 94 from the stage) will possibly form a slight queue at the front exit discharge door when joining the people from the front lobby.

The second double door to the art gallery may cause minor queue if any will form at the front exit discharge door since it will only take 106 seconds to fully evacuate the front lobby.

$$\text{Time from theater to front exit doors} = 70 \text{ feet} / 235 \text{ feet per min} = 18 \text{ seconds}$$

Time to evacuate fixed seating	140 seconds (longest period)
Time to evacuate platform/stage or temporary floor seating	67 seconds (to either door)
Time from north steps to north exit door	6 seconds
Time from north steps to south exit door	2 seconds
Time to pass from south theater door to front exit discharge	18 seconds

Total time to clear the main theater to rear exit or to front lobby (using both theater exit doors) will be approximately 2 minutes and 25 seconds after people start moving.

Additional time to reach front exit = 18 seconds

**Time to evacuate main theater after movement starts = 2 mins 25 secs thru rear exit
2 mins 45 secs thru front exit**

*This value is likely higher than occupancy loads experienced under normal use during productions.

Rear Theater and Platform/Stage

Storage Rooms

Max occupant load rear supply room	3 people
Exit Doors	72-inch man door 96-inch roll-up door

Rear Theater, Platform/Stage Area, Actor Spaces

Max occupant load	110 people
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Rear Lobby, Dressing Rooms And Restrooms

Max occupant load	48 people.
Total Rear Wing Occupancy Load	161 people

REAR THEATER

Exits	72-inch 36-inch hallway 36-inch doorway into/thru sprinkler room
Seating on platform	60
Max Platform Height	2 feet above floor.
Max Horizontal travel	40 feet
Max travel distance	~ 50 feet
Width of walkway to exit door	52 inches**
Boundary layer widths of walkway	8" (Table 3-13.1, SFPE Hbk 4 th)
Effective width of walkway	36" (52" – 2x8")
Max Specific Flow	24 persons/min/foot eff. width (Table 3-13.5, SFPE 4 th)

Flow thru walkway = 36" eff. width x 24 persons/min/ft eff. width
= 72 people/minute.

Time to pass thru walkway = 110 persons / 72 persons per min
= 1.5 minutes

Average distance to main exit door 50 feet
Time to reach rear exit = 50 ft / 235 ft per min
= 13 seconds

Limiting flow would be through the narrowed corridor next to the seating area.

Alternate option

Some people exit thru unmarked doorway behind the platform/stage into sprinkler control room exit to the exterior.

The rear doorway is unmarked and typically blocked from the audience by the stage sets. The only people likely familiar with that route are actors and theater workers.

If 10 people used the rear exit route through the sprinkler control room, it would only reduce the time for the remainder of the people to evacuate via the main exit door by about 7 seconds

Total alternative time of about 1 minute and 23 seconds.

Based on this information, is estimated the total time to evacuate the rear theater using just the 72 inch main exit door will be approximately 1.5 minutes.

** This opening could serve as a chokepoint where queuing might be expected.

Rear Lobby, Dressing and Restrooms

Max occupant load	48 people
Exit Door	72-inch
Exit Door Capacity	120 people/minute
Time to evacuate thru door =	48 people / 120 people per minute
Time to evacuate thru door =	0.4 minutes (24 seconds)
Maximum travel distance	~ 50 feet
Time to cover max distance	~ 13 seconds

Time to evacuate the rear lobby, dressing rooms and restrooms will be 24 seconds after all pre-movement is complete if people are equally spaced in these rooms.

Second Floor Spaces

Max occupancy load	211 people
Exit Doors	36-inch at top of front stairs 36-inch bottom of front stairs 36-inch at top of rear stairs
Stair width	44 inches at front 44 inches at rear
Eff. Width of doors	24 inches (Table 3-13.1 SFPE 4 th)
Flow thru doors	48 persons/minute (24 people/min/ft eff width) (Table 3-13.5, SFPE 4 th)
Flow on 7 / 11 stairs	18.5 persons/min/ft eff width (Table 3-13.5, SFPE 4 th)
Eff. Width of stairs	32 inches (44" – 12")

Flow down stairs 49.4 people/minute

Therefore, limit to flow in each staircase based upon size of doorways

Speed of travel on the stairs 106 ft / min
For ideal density of people on stairs

$$\text{Stair speed} = 212 - (2.86)(212)(0.175)$$

Calculated using the equation:

$$S = k - akD$$

where: S = speed along line of travel
D = density (persons/unit area) (= 0.175 for ideal flow, SFPE Figure 3-13.8)
K and *a* = constants (*as per table 3-12.2, SFPE 4th*)
K = 212 for stairs, and
a = 2.86 for speed in feet / min

Vertical distance over stairs 12-foot
Landings or level path on stairs 20 feet
Travel distance over front stair
& 12-foot vertical distance

Calculated using the equation:

$$\text{Distance} = 12' \times 1.85 = 22.2' \text{ on treads} + \text{dist. on landings} \\ (\text{Table 3-13.5, SFPE 4th}).$$

$$22.2 \text{ ft} + 20 \text{ ft} = 42.2 \text{ ft.}$$

Total front stairway travel distance between floors = 42.2 feet

Travel speed on stairs 106 feet/min

Time on stairs

24 secs down front stairs

25 secs down rear stairs

Since people entering second floor do so through the front stairs, assumed most will attempt to also exit along the same path. Since the door to the rear stairs is entered from the second floor reception area, some people in that area might choose the rear stairs to evacuate.

Weighted averages of time to the nearest door entrance to the top of the stairs are calculated based upon the number of occupants of each room and the longest distance from any compartment to that door traveled at a speed of 235 feet/min on the level corridors (*SFPE 4th, Table 3-13.4*).

Second Floor Egress Distances

Max Walking Time to Top of Front Stairs					
	Max Occupants	Distance ft	Speed ft/min	Time (secs)	Weighted Ave
Dance Studio 1	90	108	235.0	28	11.76
Dance Studio 2	42	28	235.0	7	1.42
Dance Studio 3	48	38	235.0	10	2.21
Dressing Room	13	58	235.0	15	0.91
Office	2	78	235.0	20	0.19
Reception	3	35	235.0	9	0.13
Sound Studio	3	38	235.0	10	0.14
Storage	1	20	235.0	5	0.02
Hallway	6	25	235.0	6	0.18
Restrooms	3	8	235.0	2	0.03

**16.99 secs
average**

Max Walking Time to Top of Rear Stairs					
Dance Studio 1	90	40	235.0	10	4.36
Dance Studio 2	42	35	235.0	9	1.78
Dance Studio 3	48	56	235.0	14	3.25
Dressing Room	13	28	235.0	7	0.44
Office	2	25	235.0	6	0.06
Reception	3	10	235.0	3	0.04
Sound Studio	3	55	235.0	14	0.20
Storage	1	50	235.0	13	0.06
Hallway	6	25	235.0	6	0.18
Restrooms	3	42	235.0	11	0.15

**10.52 secs
average**

Table 10: Calculations of weighted average to reach second floor stairs

Assumed 75% (158 people) use the front stairs and 25% (53 people) use rear stairs

Time to front stairs 18 secs

Time down front stairs 24 secs

Limiting flow at upper doorway 48 people/minute

24 seconds after the first person enter the stairs, they will pass through the exit discharge. As the first person reaches the exterior, there will be 19 people in the stairway

(24 seconds to travel stairs x 48 people per minute through the door) with 138 more queued up at the top. From that point on it will take 2.9 minutes (138 people remaining / 48 people per minute to pass through door) to get the rest of the people in that queue out the front door.

Thus, to evacuate 75% of the people out the front stairs will take:

- 17 seconds for first person to reach stairs
- + 24 seconds for that person to reach exit discharge door
- + 2.9 minutes to get all people in the queue into the stairs
- + 24 seconds for the last person to reach the exit discharge.

= 4.0 minutes (239 seconds) to clear 75% of the maximum occupant load through the front exit once they start moving.

Rear Stair Analysis

Number of people	53 people (25% of max)
Time to reach stairs	11 secs
Time on stairs (see above)	25 secs

At that time, there will be 19 people in the stairs and a queue of 33 at the top of the stairs. It will take an additional 41 seconds (33 people / 48 people per min) for the remaining people to enter the stairs at the top and then 25 more seconds for the last person to reach the bottom. Then assuming there are no queues or bottlenecks of flow on the ground floor, it will take the last person an additional 18 seconds to walk the remaining approximately 70 feet to one of the exit discharge doors.

As with above, this totals:

- 11 seconds for first person to reach stairs
- + 25 seconds for that person to reach the bottom of the stairs
- + 41 seconds to get all those queued up into the stairs
- + 24 seconds for the last person to reach the bottom of the stairs
- + 18 seconds for the last person to reach the exit discharge.

Travel Time = 119 seconds after pre-movement time to clear 25% of the max occupant load through the rear, emergency exit and out of the building.

100% of 2nd Floor Max. Occupancy Load Uses the Rear Exit Door

- 11 seconds for first person to reach stairs
- + 25 seconds for that person to reach the bottom of the stairs
- + 4 minutes to get the 192 people queued up at the top door into the stairs (19 people already on the stairs)
- + 24 seconds for the last person to reach the bottom of the stairs
- + 18 seconds for the last person to reach the exit discharge.

Travel Time = 5.3 minutes (318 seconds) after pre-movement time to clear 100% of the maximum second floor occupant load through the rear, emergency exit and out of the building.

50% of 2nd Floor Max. Occupancy Load Uses Each Exit Door

Time to reach ground floor thru rear door 36 secs

50% of the people out the front stairs will take:

- 17 seconds for first person to reach stairs
- + 24 seconds for that person to reach exit discharge door
- + 1.8 minutes to get the 87 people in the queue into the stairs
- + 24 seconds for the last person to reach the exit discharge.

Travel Time = 2.9 minutes (174 seconds) after pre-movement time to clear 50% of the maximum occupant load through the front exit outside the building.

50% of the people out of the rear exit door & stairs:

- 11 seconds for first person to reach stairs
- + 25 seconds for that person to reach the bottom of the stairs
- + 1.8 minutes to get the 87 people queued up at the top door into the stairs (19 people already on the stairs)

- + 18 seconds for the last person to reach the exit discharge.

Travel Time = 3.1 minutes (187 seconds) after pre-movement time to clear 50% of the maximum occupant load through the rear exit and out of the building.

If an evacuation of the first floor is already underway, any queuing of the second floor occupants once they reach the first floor is dependent on things such as pre-movement times on the first and second floors.

It will take 4.0 minutes (239 seconds) to clear 75% of the max occupant load departing through the front exit and about half that time, 2.0 minutes (119 seconds) to clear 25% through the rear, emergency exit and out of the building. In order to shorten the overall evacuation time from the second floor, more people should be urged to use the rear emergency exit to minimize queuing at the front stairs.

100% of 2nd Floor Max. Occupancy Load Out of the Front Exit Door

If occupants of the second floor determine early on that there is a fire in the main theater space or that the rear exit stairs are unusable, then all 211 people on the upper floor will be forced to use the front stairs. Using a similar analysis as shown above, the time to evacuate all 211 people through the front stairs will be:

- 17 seconds for first person to reach stairs
- + 24 seconds for that person to reach exit discharge door
(191 people will remain queued at the top doorway)
- + 239 seconds to get the remaining people into the stairs
- + 24 seconds for the last person to reach the exit discharge.

Travel Time = 304 seconds (5.1 minutes) to clear all of the second floor maximum occupant load through the front exit after movement begins

Appendix B

‘Center for the Arts’ Plans

During the evaluation of the Center for the Arts, no plans were located either with the AHJ or with the onsite staff showing a detailed layout of the building. The following drawings were generated from on-site inspections to offer a general idea of the arrangement of the building as well as the fire protection systems. These do not portray at a level of accuracy with which to make engineering decisions or judgments but only to give the reader a general idea of how the building existed at the time of the review.

Floor Plans

Figure 87: First floor, south half layout of the Center for the Arts

Figure 88: First floor, north half floor layout of the Center for the Arts (expanded)

Figure 89: Second floor layout for the Center for the Arts (expanded)

Exit Configuration and Travel Paths

Figure 90: First floor (front half) exit layout

Figure 91: First floor (front half) evacuation travel paths

Figure 92: First floor (rear half) exit layout

Figure 93: First floor, rear theater evacuation travel paths

Figure 94: First floor, rear lobby & dressing room evacuation travel paths

Figure 95: Second floor exit layout

Figure 96: Second floor evacuation travel paths

Sprinkler System Layout

Figure 97: Plan view of the sprinkler system including most remote area

Figure 98: Elevation view of the sprinkler system looking east

Figure 99: Elevation view of the sprinkler system in the main theater looking south

Figure 100: Elevation view of the sprinkler system in the main theater looking west

Alarm Detection and Notification System

Figure 101: Fire alarm detection and notification system in the first floor front

Figure 102: Fire alarm detection and notification system in the first floor rear wing

Structural Wall Design Types/Ratings

Figure 103: Wall types in the front portion of the first floor

Figure 104: Wall types in rear portion of the first floor

Figure 105: Wall types on the second floor

Appendix C

‘Center for the Arts’ Photos

Figure 106: View of between seat rows on fixed seating platform in main theater

Figure 107: Additional view of seat rows on fixed seating platform in main theater

Figure 108: View of exit aisle on fixed seating platform in main theater

Figure 109: View of ventilation ducting and grills penetrating south wall of main theater

Figure 110: Example of sealed penetration through south wall of main theater

Figure 111: Example of unsealed penetrations

Figure 112: View of exposed rear exit from second floor entering main theater

Figure 113: View of rear exit from second floor taken from main platform/stage

Figure 114: View of steps from fixed seating and north exit from main theater

Figure 115: View of steps from fixed seating and south exit from main theater

Figure 116: Alternate view of stacked chairs stored alongside south wall of main theater

Figure 117: Panorama of front lobby taken from south exit door of main theater

Figure 118: Exit door from front lobby entrance of the Center for the Arts

Figure 119: View of main exit doorway from art gallery

Figure 120: View of rear theater doorway opening from behind the platform/stage into the sprinkler control room

Figure 121: Fire Department supply connection into sprinkler control room

Figure 122: Sprinkler riser faceplate with hydraulic system requirements

Figure 123: Sprinkler system riser valve arrangement

Figure 124: Sprinkler head arrangement adjacent to arched roof trusses

Appendix D

Automatic Sprinkler System

Computerized Hydraulic Sprinkler Calculations

The following six pages are copies of computer calculations that were located in the files of the local fire department. No copies of sprinkler design plans were available to compare these calculations with a particular layout or the as-built arrangement. Nonetheless, copies have been provided as reference. Backup hand calculations were also performed. The results were quite close.

The water supply requirements calculated by the computer program were 495.8 gpm (including a 250 gpm hose allowance) at 53.7 psi. Hand calculations estimated the requirements to be 495.3 gpm at 49 psi. The available city water supply was 2400 gpm at residual pressure of 60 psi.

SPRINKLER SYSTEM HYDRAULIC ANALYSIS

Page 1
ANN1201

ate: 06/08/92
JOB TITLE:
WATER SUPPLY DATA

(D.H.I.)

SOURCE NODE TAG	STATIC PRESS. (PSI)	RESID. PRESS. (PSI)	FLOW @ (GPM)	AVAIL. PRESS. @ (PSI)	TOTAL DEMAND (GPM)	REQ'D PRESS. (PSI)
25	64.0	54.0	2400.0	63.5	495.8	53.7

AGGREGATE FLOW ANALYSIS:

TOTAL FLOW AT SOURCE	495.8 GPM
TOTAL HOSE STREAM ALLOWANCE AT SOURCE	250.0 GPM
OTHER HOSE STREAM ALLOWANCES	0.0 GPM
TOTAL DISCHARGE FROM ACTIVE SPRINKLERS	245.8 GPM

NODE ANALYSIS DATA

NODE TAG	ELEVATION (FT)	NODE TYPE	PRESSURE (PSI)	DISCHARGE (GPM)
1	18.0	- - - -	28.7	- - -
2	26.5	K= 5.60	13.4	20.5
3	26.5	K= 5.60	13.0	20.2
4	26.5	K= 5.60	13.0	20.2
5	26.5	K= 5.60	13.3	20.5
6	18.0	- - - -	19.7	- - -
7	18.0	- - - -	20.9	- - -
8	26.5	K= 5.60	13.5	20.6
9	26.5	K= 5.60	13.1	20.2
10	26.5	K= 5.60	13.1	20.2
11	26.5	K= 5.60	13.5	20.5
12	18.0	- - - -	19.9	- - -
13	18.0	- - - -	29.5	- - -
14	26.5	K= 5.60	13.9	20.9
15	26.5	K= 5.60	13.5	20.5
16	26.5	K= 5.60	13.5	20.5
17	26.5	K= 5.60	13.9	20.9
18	18.0	- - - -	20.4	- - -
19	18.0	- - - -	30.7	- - -
20	18.0	- - - -	21.5	- - -
21	18.0	- - - -	32.4	- - -
22	18.0	- - - -	22.2	- - -
23	18.0	- - - -	35.0	- - -
24	1.0	- - - -	52.4	- - -
25	0.0	SOURCE	53.7	245.8
26	18.0	- - - -	34.4	- - -
27	18.0	- - - -	22.6	- - -
28	18.0	- - - -	34.3	- - -
29	18.0	- - - -	22.7	- - -

FROM:

SPRINKLER SYSTEM HYDRAULIC ANALYSIS

Page 2

JOB TITLE:
PIPE DATA

(B.H.1)

PIPE TAG END NODES	ELEV. (FT)	NOZ. (K)	PT (PSI)	DISC. (GPM)	DI (GPM) VEL (FPS)	DIA (IN) HW (C) F.L./FT	LENGTH (FT)	PRESS. SUM. (PSI)
Pipe: 1					41.5	1.380 PL	76.00	PF 11.6
1	18.0	0.0	28.7	0.0	8.9	120 FTG	2T	PE 3.7
2	26.5	5.6	13.4	20.5		0.132 TL	88.00	PV 0.5
Pipe: 2					21.0	1.380 PL	12.00	PF 0.5
2	26.5	5.6	13.4	20.5	4.5	120 FTG	----	PE 0.0
3	26.5	5.6	13.0	20.2		0.038 TL	12.00	PV 0.1
Pipe: 3					0.9	1.380 PL	12.00	PF 0.0
3	26.5	5.6	13.0	20.2	0.2	120 FTG	----	PE 0.0
4	26.5	5.6	13.0	20.2		0.000 TL	12.00	PV 0.0
Pipe: 4					-19.3	1.380 PL	12.00	PF 0.4
4	26.5	5.6	13.0	20.2	4.1	120 FTG	----	PE 0.0
5	26.5	5.6	13.3	20.5		0.032 TL	12.00	PV 0.1
Pipe: 5					-39.7	1.380 PL	10.00	PF 2.7
5	26.5	5.6	13.3	20.5	8.5	120 FTG	2T	PE 3.7
6	18.0	0.0	19.7	0.0		0.122 TL	22.00	PV 0.5
Pipe: 6					41.5	2.157 PL	10.50	PF 0.2
7	18.0	0.0	28.9	0.0	3.6	120 FTG	----	PE 0.0
1	18.0	0.0	28.7	0.0		0.015 TL	10.50	PV 0.1
Pipe: 7					41.6	1.380 PL	76.00	PF 11.7
7	18.0	0.0	28.9	0.0	8.9	120 FTG	2T	PE 3.7
8	26.5	5.6	13.5	20.6		0.133 TL	88.00	PV 0.5
Pipe: 8					21.0	1.380 PL	12.00	PF 0.5
8	26.5	5.6	13.5	20.6	4.5	120 FTG	----	PE 0.0
9	26.5	5.6	13.1	20.2		0.038 TL	12.00	PV 0.1
Pipe: 9					0.8	1.380 PL	12.00	PF 0.0
9	26.5	5.6	13.1	20.2	0.2	120 FTG	----	PE 0.0
10	26.5	5.6	13.1	20.2		0.000 TL	12.00	PV 0.0
Pipe: 10					-19.4	1.380 PL	12.00	PF 0.4
10	26.5	5.6	13.1	20.2	4.2	120 FTG	----	PE 0.0
11	26.5	5.6	13.5	20.5		0.032 TL	12.00	PV 0.1
Pipe: 11					-40.0	1.380 PL	10.00	PF 2.7
11	26.5	5.6	13.5	20.5	8.6	120 FTG	2T	PE 3.7
12	18.0	0.0	19.9	0.0		0.123 TL	22.00	PV 0.5
Pipe: 12					39.7	2.157 PL	10.50	PF 0.1
12	18.0	0.0	19.9	0.0	3.5	120 FTG	----	PE 0.0
6	18.0	0.0	19.7	0.0		0.014 TL	10.50	PV 0.1
Pipe: 13					83.2	2.157 PL	10.50	PF 0.6
13	18.0	0.0	29.5	0.0	7.3	120 FTG	----	PE 0.0
7	18.0	0.0	28.9	0.0		0.054 TL	10.50	PV 0.4

SPRINKLER SYSTEM HYDRAULIC ANALYSIS

Page 3

JOB TITLE: (O.H.I)
PIPE DATA (cont'd)

PIPE TAG	END	ELEV.	NOZ.	P1	DISC.	VEL (FPS)	DIA (IN)	LENGTH	PRESS.	SUM.
NODES	(FT)	(K)	(PSI)	(GPM)		ELL/FT		(FT)	(PSI)	(PSI)
Pipe: 14						42.0	1.380	PL 76.00	PF	11.9
13	18.0	0.0	29.5	0.0	9.0		120	FTG 2T	PE	3.7
14	26.5	5.6	13.9	20.9		0.135	TL	88.00	PV	0.5
Pipe: 15						21.1	1.380	PL 12.00	PF	0.5
14	26.5	5.6	13.9	20.9	4.5		120	FTG ----	PE	0.0
15	26.5	5.6	13.5	20.5		0.038	TL	12.00	PV	0.1
Pipe: 16						0.5	1.380	PL 12.00	PF	0.0
15	26.5	5.6	13.5	20.5	0.1		120	FTG ----	PE	0.0
16	26.5	5.6	13.5	20.5		0.000	TL	12.00	PV	0.0
Pipe: 17						-20.0	1.380	PL 12.00	PF	0.4
16	26.5	5.6	13.5	20.5	4.3		120	FTG ----	PE	0.0
17	26.5	5.6	13.9	20.9		0.034	TL	12.00	PV	0.1
Pipe: 18						-40.9	1.380	PL 10.00	PF	2.8
17	26.5	5.6	13.9	20.9	8.8		120	FTG 2T	PE	3.7
18	18.0	0.0	20.4	0.0		0.128	TL	22.00	PV	0.5
Pipe: 19						79.7	2.157	PL 10.50	PF	0.5
18	18.0	0.0	20.4	0.0	7.0		120	FTG ----	PE	0.0
12	18.0	0.0	19.9	0.0		0.050	TL	10.50	PV	0.3
Pipe: 20						125.2	2.157	PL 10.50	PF	1.2
19	18.0	0.0	30.7	0.0	11.0		120	FTG ----	PE	0.0
13	18.0	0.0	29.5	0.0		0.116	TL	10.50	PV	0.8
Pipe: 21						27.3	1.380	PL 122.00	PF	9.2
19	18.0	0.0	30.7	0.0	6.0		120	FTG 4T	PE	0.0
20	18.0	0.0	21.5	0.0		0.063	TL	146.00	PV	0.2
Pipe: 22						120.6	2.157	PL 10.50	PF	1.1
20	18.0	0.0	21.5	0.0	10.6		120	FTG ----	PE	0.0
18	18.0	0.0	20.4	0.0		0.108	TL	10.50	PV	0.8
Pipe: 23						152.9	2.157	PL 10.50	PF	1.8
21	18.0	0.0	32.4	0.0	15.4		120	FTG ----	PE	0.0
19	18.0	0.0	30.7	0.0		0.168	TL	10.50	PV	1.2
Pipe: 24						29.5	1.380	PL 122.00	PF	10.2
21	18.0	0.0	32.4	0.0	6.3		120	FTG 4T	PE	0.0
22	18.0	0.0	22.2	0.0		0.070	TL	146.00	PV	0.3
Pipe: 25						92.8	2.157	PL 10.50	PF	0.7
22	18.0	0.0	22.2	0.0	8.2		120	FTG ----	PE	0.0
20	18.0	0.0	21.5	0.0		0.067	TL	10.50	PV	0.4
Pipe: 26						182.4	2.157	PL 1.00	PF	2.6
23	18.0	0.0	35.0	0.0	16.0		120	FTG T	PE	0.0
21	18.0	0.0	32.4	0.0		0.232	TL	11.00	PV	1.7

SPRINKLER SYSTEM HYDRAULIC ANALYSIS

Page 4

JOB TITLE: [REDACTED] (C.H.I.)
 PIPE DATA (cont'd)

PIPE TAG	END	ELEV.	NOZ.	PT	DISC.	VEL (FPS)	DIA (IN)	LENGTH	PRESS.
	NODES	(FT)	(K)	(PSI)	(GPM)			(FT)	SUM.
									(PSI)
Pipe: 27						-245.8	3.260 PL	152.00	PF 10.1
23		18.0	0.0	35.0	0.0	9.4	120 FTG	3EGA	PE 7.4
24		1.0	0.0	52.4	0.0		0.054 TL	187.00	PV 0.6
Pipe: 28						-245.8	4.280 PL	35.00	PF 0.8
24		1.0	0.0	52.4	0.0	5.5	140 FTG	ETG	PE 0.4
25		0.0	SRCE	53.7	(N/A)		0.011 TL	78.00	PV 0.2
Pipe: 29						-63.4	2.157 PL	9.50	PF 0.6
26		18.0	0.0	34.4	0.0	5.6	120 FTG	T	PE 0.0
23		18.0	0.0	35.0	0.0		0.033 TL	19.50	PV 0.2
Pipe: 30						31.9	1.380 PL	122.00	PF 11.8
26		18.0	0.0	34.4	0.0	6.8	120 FTG	4T	PE 0.0
27		18.0	0.0	22.6	0.0		0.081 TL	146.00	PV 0.3
Pipe: 31						63.4	2.157 PL	10.50	PF 0.3
27		18.0	0.0	22.6	0.0	5.6	120 FTG	----	PE 0.0
22		18.0	0.0	22.2	0.0		0.033 TL	10.50	PV 0.2
Pipe: 32						-31.5	2.157 PL	10.50	PF 0.1
28		18.0	0.0	34.3	0.0	2.8	120 FTG	----	PE 0.0
26		18.0	0.0	34.4	0.0		0.009 TL	10.50	PV 0.1
Pipe: 33						31.5	1.380 PL	122.00	PF 11.6
28		18.0	0.0	34.3	0.0	6.8	120 FTG	4T	PE 0.0
29		18.0	0.0	22.7	0.0		0.079 TL	146.00	PV 0.3
Pipe: 34						31.5	2.157 PL	10.50	PF 0.1
29		18.0	0.0	22.7	0.0	2.8	120 FTG	----	PE 0.0
27		18.0	0.0	22.6	0.0		0.009 TL	10.50	PV 0.1

NOTES:

- Calculations were performed by the HASS 5.5.0 computer program under license no. 327L117 granted by HRS Systems, Inc. 2193 Ranchwood Dr., N.E. Atlanta, GA 30345
- The system has been balanced to provide an average imbalance at each node of 0.005 gpm and a maximum imbalance at any node of 0.128 gpm.
- Velocity pressures are printed for information only, and are not used in balancing the system. Maximum water velocity in any pipe is 16.0 ft/sec.

Hand Calculations

The following two pages are hand calculations to verify the water supply requirements at the Center for the Arts based upon visual observations of the installed system. Since no copies of actual plans were available and the applicability of the computerized calculations could not be verified as to the final installation, this backup calculation was performed.

HYDRAULIC CALCULATIONS

CONTRACT NAME

STEVE CARMAN FPE 523

SHEET 1 OF 1

NOZZLE IDENT. AND LOCATION	FLOW IN GPM	PIPE SIZE	PIPE FITTINGS AND DEVICES	EQUIV. PIPE LENGTH	FRICTION LOSS PSI/FT	PRESSURE SUMMARY	NORMAL PRESSURE	NOTES
1 BL1	q	1 1/4"		L 12	C=120	Pt 11.4	Pt	K=5.6 PER HEAD 126 FT ² x 0.15 gpm/ft ² = 8 g = 18.9 gpm P = (18.9/5.6) ² = 11.4 psi
	Q 18.9	5-40	T-6	F 6	P=0.03	Pe	Pv	
		1.38"	T 18			Pf 0.5	Pn	
2 BL1	q 19.3	1 1/4"		L 12	120=0	Pt 11.9	Pt	g = √(11.9 x 5.6) g = 19.3
	Q 38.2	1.38"		F -		Pe	Pv	
			T 12		0.11	Pf 1.3	Pn	
3 BL1	q 20.3	1 1/4"		L 12	C=120	Pt 13.2	Pt	g = √(13.2 x 5.6) = 20.3 gpm
	Q 58.5	1.38"		F -		Pe	Pv	
			T 12		0.25	Pf 3.0	Pn	
4 BL1	q 22.5	2"		L 94	C=120	Pt 16.2	Pt	g = √(16.2 x 5.6) g = 22.5 18' DROP IN ELEV.
	Q 81.0	5-40	3T-10	F 30		Pe 7.8	Pv	
		2.067		T 124	0.06	Pf 7.4	Pn	
	q			L		Pt 31.4	Pt	Q = 81 VP = √(31.4) = K _{BL1} K = 14.5
				F		Pe	Pv	
	Q			T		Pf	Pn	
CM ₁₋₂	q	3"		L 10.5	C=120	Pt 31.4	Pt	
	Q	5-10	1T-15	F 15.0		Pe	Pv	
		3.26		T 25.5	0.01	Pf 0.3	Pn	
CM ₂₋₃	q 81.6	3"		L 10.5	C=120	Pt 31.7	Pt	g = √(31.7 x 14.5) = 81.6 gpm
	Q 162.6	3.26"	1T-15	F 15		Pe	Pv	
			T 25.5		.03	Pf 0.8	Pn	
FM	q 82.7	3"	E-7	L 152	C=120	Pt 32.5	Pt	g = √(32.5 x 14.5) = 82.7
	Q 245.3	3.26"	3T-15	F 52		Pe	Pv	
			T 204		0.05	Pf 10.2	Pn	
R	q	4		L 21	C=120	Pt 42.7	Pt	12' ELEV DROP
	Q 245.3	4.26	*	F 85		Pe 5.2	Pv	
			T 106		.01	Pf 1.1	Pn	
BOR	q			L		Pt 49.0	Pt	245.3 gpm 49.0 psi
	Q			F		Pe	Pv	
				T		Pf	Pn	
	q			L		Pt	Pt	
				F		Pe	Pv	
	Q			T		Pf	Pn	
						Pt

American Fire Sprinkler Association
12750 Mard Drive, Suite 250, Dallas, Texas 75251
Tel: 214.343.5965
Fax: 214.343.6998
www.fire sprinkler.org

RISER FITTINGS

* 2-G @ 2' 1-L @ 6'
1-T @ 20' 1-C @ 22'
1-E @ 20' 1-A @ 13' (supplied by INSTAUCO)

CENTER FOR THE ARTS
NO: STEVE CARMAN FFE 523 WINTER 2012

Automatic Sprinkler System Inspection, Testing & Maintenance Requirements of NFPA 25

<u>MAJOR COMPONENT</u>	<u>INSPECTION, TESTING, MAINTENANCE ITEMS</u>	<u>FREQUENCY</u>	<u>NFPA 25 Reference</u>
CONTROL VALVES	Open/Test	Annually	12.3.3.1
	Verify as accessible	Monthly	12.3.2.1
	Wrenches/hand wheel available	Monthly	
	Operated/Lubricated	Annually	12.3.3.1
	Verify valve is free of leaks / locked	Weekly/ Monthly	13.3.2.1
	Identified with signs	Annually	5.2.6.1
	Valve maintenance	Annually	12.3.4
RISER	Inspect gauges	Monthly	5.2.4.1
	Gauges in good working order	Quarterly 5 year test/replace	5.2.6
	Name plate attached	Quarterly	5.2.7
	Seismic bracing checked	Annually	
	3 foot clear space	Quarterly	

	Main drain test	Annually	12.3.3.4, 12.2.2.6 13.2.5, 13.3.3.4
FIRE DEPT. CONNECTION	<p>Connection visible and accessible</p> <p>System back-flushed</p> <p>Couplings checked for smooth rotation/undamaged</p> <p>Couplings gaskets in place / undamaged</p> <p>ID signs in place</p> <p>Verify valves are free of leaks</p> <p>Check valve components. Inspect internally. Clean, repair/replace</p>	<p>Quarterly</p> <p>Every 5 years</p> <p>Quarterly</p> <p>Quarterly</p> <p>Quarterly</p> <p>Quarterly</p> <p>Every 5 years</p>	13.7.1
WATERFLOW ALARM PANEL, SUPERVISORY AND TAMPER SWITCHES AND DEVICES	<p>Inspect to verify system is free of damage</p> <p>Waterflow alarm test</p> <p>Test system - Audible alarm / visual signals activate within 90 seconds.</p> <p>Test system – Alarm company receives signals</p>	<p>Quarterly</p> <p>Quarterly</p> <p>Annually</p> <p>Quarterly</p>	<p>5.2.5</p> <p>5.3.3.1, 13.2.6</p> <p>5.3.3 / 12.2.7</p>
ABOVE GROUND PIPES,	Free of leaks and corrosion	Annually	5.2.2

FITTINGS, AND SUPPORTS	Verify proper alignment	Annually	5.2.3
	Verify free of external loads	Annually	
	Verify hangers and seismic bracing installed and undamaged	Annually	
	Verify water filled pipes not exposed to routine freezing	Every 5 years	14.2
	Obstructions and internal inspection of piping		
SPRINKLERS	Free of corrosion, foreign materials, paint and damage	Annually	5.2.1
	Verify installed with correct orientation	Annually	
	Verify unobstructed flow	Annually	
	Verify proper spacing from walls	Annually	
	Verify proper distance between sprinklers	Annually	
	Verify proper deflector distance from ceilings and to storage below	Every 5 years	
	Verify if sprinklers are less than 50 years old	Annually	
	Verify if there is a spare		

	sprinkler head box with the correct number of spare sprinklers available Verify spare sprinklers are the same as used in system		
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Appendix E

Alarm System

Central Station Disposition of Alarm, Supervisory and Trouble Signals

Section 3.3.240.1 defines an Alarm Signal as, “A signal indicating an emergency condition or an alert that requires action.” Section 26.3.7.1.2 states that the central station shall perform the following actions:

“(1) Immediately retransmit the alarm to the communications center.

(2) Dispatch a runner or technician to the protected premises to arrive within 2 hours after receipt of a signal if equipment needs to be manually reset by the prime contractor. Except where prohibited by the authority having jurisdiction, the runner or technician shall be permitted to be recalled prior to arrival at the premises if a qualified representative of the subscriber at the premises can provide the necessary resetting of the equipment and is able to place the system back in operating condition.

(3) Immediately notify the subscriber.

(4) Provide notice to the subscriber or authority having jurisdiction, or both, if required.”

NFPA 72 states that central station operators must perform these actions in the order given and must do so to properly respond to the intended levels of urgency implied by an alarm activation. One exception in this case is that a runner might not be needed if a contractor needs to manually reset equipment at the premises. If the subscriber or another trained individual from the Center for the Arts or elsewhere is trained to check and reset the system and is directed to do so, then the central station is not needed to respond. It should also be noted that if the alarm results from a prearranged test, then the above actions are clearly not necessary.

Similar to the mandated response to alarm signals, NFPA 72 dictates the requirements for how supervisory signals will be handled by the central station. Section 3.3.240.6 defines a supervisory signal as “a signal indicating the need for action in connection with the supervision of guard tours, the fire suppression systems or equipment, or the maintenance features of related systems.” Section 26.3.7.3 states that, “Upon receipt of a supervisory signal from a sprinkler system, other fire suppression system(s), or other equipment, the central station shall perform the following actions:

“(1) Communicate immediately with the persons designated by the subscriber and notify the fire department or law enforcement agency, or both, when required by the authority having jurisdiction

(2) Dispatch a runner or maintenance person to arrive within 2 hours to investigate *Exception: Where the supervisory signal is cleared in accordance with a scheduled procedure determined by 26.3.7.3(1).*

(3) Notify the authority having jurisdiction when sprinkler systems or other fire suppression systems or equipment have been wholly or partially out of service for 8 hours

(4) When service has been restored, provide notice, if required, to the subscriber or the authority having jurisdiction, or both, as to the nature of the signal, the time of occurrence, and the restoration of service when equipment has been out of service for 8 hours or more.

Exception: If the supervisory signal results from a prearranged test, the actions specified by 26.3.7.3(1), (3), and (4) shall not be required.”

In addition to the above provisions, NFPA 72 also provides guidance for the central station to respond to a trouble signal which it defines in Section 3.3.240.7 as “A signal initiated by a system or device indicative of a fault in a monitored circuit, system, or component.” Section 26.3.7.4 dictates the requirements for trouble signals by stating, “Upon receipt of trouble signals or other

signals pertaining solely to matters of equipment maintenance of the alarm systems, the central station shall perform the following actions:

- “(1) Communicate immediately with persons designated by the subscriber,
- (2) Dispatch personnel to arrive within 4 hours to initiate maintenance, if necessary.
- (3) When the interruption is more than 8 hours, provide notice to the subscriber and the fire department if so required by the authority having jurisdiction as to the nature of the interruption, the time of occurrence, and the restoration of service.”

Since trouble signals alert the central station to the alarm system being in some state of being partially or completely out of service, it is imperative that the central station takes action to assist in getting the system back in working order. Paragraph (2) above shows the importance placed on insuring that a technician trained in the particular system is dispatched to the site to get the system back up into working condition within the 4 hour limitation.

Inspection, Testing and Maintenance – Alarm System

COMPONENT	FREQUENCY
Control equipment including equipment monitored for alarm, supervisory and trouble signals including: a) fuses, b) interfaced equipment, c) Lamps and LEDs, and d) Primary power supply	Annually
Sealed Lead Acid Batteries	Semi-Annually
Fire Alarm Unit Trouble Signals	Semi-Annually
Remote Annunciators	Semi-Annually
Manual Fire Alarm Boxes	Semi-Annually
Smoke Detectors	Semi-Annually
Waterflow Devices	Quarterly
Alarm Notification Devices such as bells, horns and horn strobes	Semi-Annually

Figure 125: Table 14.4.5, NFPA 72, Testing Frequencies

The following testing requirements from Table 14.4.5 apply to the Center for the Art's system.

COMPONENT	FREQUENCY
Control equipment including equipment monitored for alarm, supervisory and trouble signals including: a) fuses, b) interfaced equipment, c) Lamps and LEDs, and d) Primary power supply	Annually
Sealed Lead Acid Batteries used as Secondary Power Supplies	<p>Replace within 5 years after manufacture or more frequently as needed.</p> <p>Charge and discharge tests should be conducted annually.</p> <p>Load voltage tests should be conducted semi-annually</p>
Fire Alarm Unit Trouble Signals	<p>Annually. The actual testing should be in accordance with Reference 10 of Table 14.4.2.2 of NFPA 72</p>

Remote Annunciators	Annually. The actual testing should be in accordance with Reference 11 of Table 14.4.2.2 of NFPA 72
Manual Fire Alarm Boxes	Annually
Smoke Detectors	Annually
Waterflow Devices	Semi-Annually
Alarm Notification Devices such as bells, horns and horn strobes	Annually. The actual testing should be in accordance with Reference 15 of Table 14.4.2.2 of NFPA 72

Section 14.5.2 of NFPA 72 states very generically that the frequency of maintenance and cleaning of system equipment shall depend on the type of equipment and the local ambient conditions. The emphasis of the section is on cleaning of the equipment which it suggests be conducted in accordance with manufacturer's published guidelines.

Fire Detection Scenarios

Three fire detection scenarios were examined for fires occurring at places in the Center for the Arts currently outfitted with alarms. The times estimated for alarm activation were determined using either the computer zone fire model CFAST or a spreadsheet analysis following the DETACT model. The specific calculations follow.

First Fire Detection Scenario

The first scenario is a fire presumed to occur in the fire sprinkler control room. The chance that a fire would occur in that room is small considering the limited fuels there. One potential fire could result from a malfunction in the electrical system powering the fire alarm control panel. A medium growth rate fire was assumed. The following additional assumptions are made for this scenario:

Ambient temperature	20°C
Fire growth rate	Slow
Ceiling height varies with slope. Max Height =	16 feet.
Height at sidewall:	11 feet.
Room size:	Approx. 70 square feet (5 feet x 14 feet)
Height of wall mounted smoke detector:	94 inches (2.4 m)
Average temperature rise to correlate with a PVC fire source: (According to Table B.4.7.5.3 NFPA 72)	7.2 °C

The zone fire model CFAST was run to estimate the time of detector activation from a medium growth rate fire. The DETACT model was not appropriate for use since the detector is wall mounted and DETACT applies to ceiling mounts. Although the ceiling was slanted, an average height of 13.5 feet (4 m) was used to estimate upper

layer filling time. The time for the upper layer to descend down to the smoke detector (94 inches, 2.4 m) with a slow growth fire was about 18 seconds. By that time, the temperature of the upper layer would only have raised about 1 °C. Increasing the temperature of the upper layer to 27.2 °C would take about 55 seconds. At 55 seconds, the heat release rate of the fire would be approximately 10 kW.

Second Fire Detection Scenario

The second theoretical fire is located in the front lobby area of the Center for the Arts. Two smoke detectors in the main lobby were evaluated for the time needed for detection. The following assumptions are made for this scenario:

Ambient temperature	20°C RTI – Smoke Detectors
Fire growth rate	Medium
Ceiling height	8 feet (2.4m) under drop ceiling. Ceiling mounted smoke detectors
Radial distance	Detector 1 = 20 feet (6.1 m) Detector 2 = 31 feet 8 inches (9.6 m)

According to Table B.4.7.5.3 of NFPA 72, the highest temperature rise associated with the activation of an ionization detector is with a wood fire source. That occurred with a rise of 13.9 °C. For other fuels such as PVC or Polyurethane, the rise would be 7.2 °C. In an effort to determine a conservative time for alarm activation, the higher value of 13.9 °C was evaluated.

According to calculations completed with the spreadsheet for the model DETACT, under these conditions, the detector located 20 feet away would activate at about 95 seconds after ignition when the heat release rate was about 100-110 kW. The second smoke detector, 31 feet away from the fire would be expected to activate 40 seconds later at 135 seconds when the heat release rate was around 220 kW. If PVC or synthetic fuels such as polyurethane were involved, the closest detector would activate at 27.2°C about 60-65 seconds after ignition. At that time, the heat release rate would be about 55 kW. The furthest detector would activate at about 75 seconds when the heat release rate was around 70 kW.

Third Fire Detection Scenario

The third theoretical fire is located in the art gallery of the Center for the Arts. The fire is estimated to start in a large, high-density polyethylene (HDPE) trash container stored in the main gallery space for visitors' use. The fire is estimated to

be a medium growth rate fire. The wall-mounted smoke detector in the gallery was evaluated for detection. The following assumptions are made for this scenario:

Ambient temperature	20°C
Room size	884 sq. ft. (82.3 sq. meters)
Fire growth rate	Medium
Ceiling height	12 feet, 6 inches (3.6 m) with three bays, each 24 inches deep
Wall mounted smoke detector	30 inches (0.75 m) below ceiling
Necessary temperature rise	7.2 °C

Because the detector is wall mounted, the typical DETACT analysis is not appropriate. Instead, CFAST was used to determine the amount of time until the smoke layer descended to the height of the detector. The fire source was based on NIST tests of a HDPE trash can fire documented in figure 3-1.101 of the SFPE Handbook (4th ed.).

According to Table B.4.7.5.3 of NFPA 72, the temperature rise associated with the activation of an ionization detector from a synthetic fuel source would be 7.2 °C. CFAST was used to determine the length of time it would take for an upper layer of smoke to descend to the height of the smoke detector, 10 feet (3.0 m) above the floor and to be at a minimum of 27.2°C. With a medium growth rate fire, the upper smoke layer would descend to 9.3 feet (2.8 m) above the floor at 50 seconds. Even so, at that time

the temperature of the upper layer was estimated to only be 24 °C (assuming an ambient of 20°C). The 7.2 °C increase in the smoke layer temperature was not achieved until approximately 65 seconds after ignition when the upper layer was estimated to have descended to 7.9 feet (2.4 m) above the floor. At 50 seconds, the HRR was estimated to be 30 kW. At 65 seconds, it would be approximately 50 kW.

Appendix F

Sample FDS Input File

Scenario 1

The following is a sample of code used as an FDS5 input file to simulate Scenario 1 for a fire burning in stacked chairs in the main theater. Because of the complexity of the file, only a partial sample is included. The actual file's more than 3,000 lines of obstruction definitions were removed along with other repetitive data.

MainTheater3-spr.fds

Generated by PyroSim - Version 2012.1.0605

Apr 13, 2013 6:30:18 PM

&HEAD CHID='MainTheater3-spr', TITLE='Main Theater Fire 3 Plastic Chairs-sprinklered'/

&TIME T_END=300.0/

&DUMP RENDER_FILE='MainTheater3-spr.ge1', DT_RESTART=15.0/

&MESH ID='MESH', FYI='Outer Mesh', IJK=112,135,40, XB=0.0,22.5,0.0,29.0,0.0,9.0/

&REAC ID='POLYURETHANE',
FYI='NFPA Babrauskas',
C=6.3,
H=7.1,
O=2.1,
N=1.0,
SOOT_YIELD=0.1
CO_YIELD=0.05/

&MISC CO_PRODUCTION = .TRUE. /
-----SPRINKLER LINES-----

&PART ID='Water',
WATER=.TRUE.,
AGE=60.0,
SPECIFIC_HEAT=4.184,
MELTING_TEMPERATURE=0.0,
VAPORIZATION_TEMPERATURE=100.0,
HEAT_OF_VAPORIZATION=2259.0/

&PROP ID='Default_Water Spray02',
QUANTITY='SPRINKLER LINK TEMPERATURE',
ACTIVATION_TEMPERATURE=74.0,
PART_ID='Water',
K_FACTOR=21.0,
OPERATING_PRESSURE=0.9,
DROPLET_VELOCITY=5.0/

PROP ID='Default_Water Spray',
QUANTITY='SPRINKLER LINK TEMPERATURE',
ACTIVATION_TEMPERATURE=74.0,
PART_ID='Water',
FLOW_RATE=1.0,
DROPLET_VELOCITY=5.0/

&DEVC ID='SPRK', PROP_ID='Default_Water Spray02', XYZ=20.4,2.2,5.0,
ORIENTATION=0.0,0.4,1.0/

&DEVC ID='SPRK02', PROP_ID='Default_Water Spray02', XYZ=17.0,2.2,6.6,
ORIENTATION=0.0,0.3,1.0/

Additional repeating sprinkler definition lines removed for brevity

&DEVC ID='TIMER', QUANTITY='TIME', XYZ=0.0,0.0,0.0, SETPOINT=30.0,
INITIAL_STATE=.TRUE./

-----MATERIAL PROPERTY LINES-----

&MATL ID='CONCRETE',
FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
SPECIFIC_HEAT=1.04,
CONDUCTIVITY=1.8,
DENSITY=2280.0/

&MATL ID='YELLOW PINE',
FYI='Quintiere, Fire Behavior - NIST NRC Validation',
SPECIFIC_HEAT=2.85,
CONDUCTIVITY=0.14,
DENSITY=640.0/

&MATL ID='PAPER',
SPECIFIC_HEAT=1.4,
CONDUCTIVITY=0.05,
DENSITY=85.0,
HEAT_OF_COMBUSTION=1.6E4/ Material to represent insulation facing

&MATL ID='FABRIC',
FYI='Covering for Upholstery',
SPECIFIC_HEAT=1.0,
CONDUCTIVITY=0.1,
DENSITY=100.0,
HEAT_OF_COMBUSTION=2.0E4,
REFERENCE_TEMPERATURE=280,
HEAT_OF_REACTION=1000,
N_REACTIONS=1,
NU_FUEL=1/

&MATL ID='FOAM',
FYI='Caution: Reaction Rate Not Validated, remaining data from Jukka Hietaniemi,
et al., "FDS simulation of fire spread..."',
SPECIFIC_HEAT=1.0,
CONDUCTIVITY=0.05,
DENSITY=60.0,
HEAT_OF_COMBUSTION=2.54E4,
N_REACTIONS=1,
HEAT_OF_REACTION=1250.0,
NU_FUEL=1.0,
REFERENCE_TEMPERATURE=280.0/

```
&MATL ID='GLASS',  
    SPECIFIC_HEAT=0.84,  
    CONDUCTIVITY=50.0,  
    DENSITY=2700.0/
```

```
&MATL ID='CURTAIN',  
    SPECIFIC_HEAT=1.0,  
    CONDUCTIVITY=0.1,  
    DENSITY=50.0,  
    HEAT_OF_COMBUSTION=1.0E4,  
    HEAT_OF_REACTION=2500,  
    REFERENCE_TEMPERATURE=400,  
    N_REACTIONS=1,  
    NU_FUEL=1/ Representing theatrical curtains. Estimated values
```

```
&MATL ID='HDPE',  
    SPECIFIC_HEAT=2.0,  
    CONDUCTIVITY=0.4,  
    DENSITY=750.0,  
    HEAT_OF_COMBUSTION=3.5E4,  
    REFERENCE_TEMPERATURE=350,  
    HEAT_OF_REACTION=1500,  
    NU_FUEL=1,  
    N_REACTIONS=1/ Representing plastic material for thermoplastic chairs.  
                        Estimated values
```

-----SURF LINES-----

```
&SURF ID='CONCRETE',  
    COLOR='GRAY 80',  
    MATL_ID(1,1)='CONCRETE',  
    MATL_MASS_FRACTION(1,1)=1.0,  
    THICKNESS(1)=0.2/
```

```
&SURF ID='WOOD',  
    RGB=51,51,0,  
    MATL_ID(1,1)='YELLOW PINE',  
    MATL_MASS_FRACTION(1,1)=1.0,  
    THICKNESS(1)=0.01,  
    IGNITION_TEMPERATURE=250/
```


&SURF ID='PAPER',
COLOR='GRAY 80',
BACKING='INSULATED',
MATL_ID(1,1)='PAPER',
MATL_MASS_FRACTION(1,1)=1.0,
THICKNESS(1)=0.001/ Exposed facing of insulation on ceiling finish

&SURF ID='UPHOLSTERY',
RGB=204,153,0,
MATL_ID(1,1)='FABRIC',
MATL_ID(2,1)='FOAM',
MATL_MASS_FRACTION(1,1)=1.0,
MATL_MASS_FRACTION(2,1)=1.0,
THICKNESS(1:2)=0.003,0.1/

&SURF ID='GLASS',
COLOR='CYAN',
MATL_ID(1,1)='GLASS',
MATL_MASS_FRACTION(1,1)=1.0,
THICKNESS(1)=0.005,
THICKNESS=.005/

&SURF ID='CURTAIN',
RGB=0,0,153,
MATL_ID(1,1)='CURTAIN',
MATL_MASS_FRACTION(1,1)=1.0,
THICKNESS(1)=0.006/ Representing theatrical curtains. Estimated values

&SURF ID='BURNER',
COLOR='RED',
HRRPUA=1500.0,
TAU_Q=-60.0/

&SURF ID='PLASTIC',
RGB=0,204,51,
MATL_ID(1,1)='HDPE',
MATL_MASS_FRACTION(1,1)=1.0,
THICKNESS(1)=0.01/

-----OBSTRUCTION LINES-----

&OBST XB=18.75,19.0,24.25,24.5,0.0,0.5, SURF_ID='UPHOLSTERY'/ Upholstery
&OBST XB=18.5,18.75,24.25,24.5,0.0,0.5, SURF_ID='UPHOLSTERY'/ Upholstery
.
.
.

Approximately 3,000 additional obstruction lines removed for brevity.

-----DOORWAY LINES-----

&HOLE XB=7.0,7.9,20.225,20.625,2.5,4.5/ Doorway to N stage high storage
&HOLE XB=10.3,10.9,1.5,2.25,10.2,10.6/ Hole

-----BURNER LINE-----

&VENT SURF_ID='BURNER', XB=19.7,20.7,2.4,3.4,0.2,0.2, IOR=3, RGB=255,0,51/
Burner

-----OUTPUT LINES-----

&BNDF QUANTITY='BURNING RATE'/
&BNDF QUANTITY='GAUGE HEAT FLUX'/
&BNDF QUANTITY='WALL TEMPERATURE'/

&SLCF QUANTITY='TEMPERATURE', PBX=10.5/
&SLCF QUANTITY='TEMPERATURE', PBX=13.0/
&SLCF QUANTITY='TEMPERATURE', PBX=20.0/
&SLCF QUANTITY='TEMPERATURE', PBX=2.5/
&SLCF QUANTITY='TEMPERATURE', PBX=4.5/
&SLCF QUANTITY='TEMPERATURE', PBX=12.0/
&SLCF QUANTITY='TEMPERATURE', PBX=18.5/
&SLCF QUANTITY='TEMPERATURE', PBZ=1.8/

&SLCF QUANTITY='VISIBILITY', PBX=10.5/
&SLCF QUANTITY='VISIBILITY', PBX=13.0/
&SLCF QUANTITY='VISIBILITY', PBX=20.0/
&SLCF QUANTITY='VISIBILITY', PBX=2.5/
&SLCF QUANTITY='VISIBILITY', PBX=4.5/
&SLCF QUANTITY='VISIBILITY', PBX=18.5/
&SLCF QUANTITY='VISIBILITY', PBX=1.8/

&DEVC XYZ = 13.0, 1.9, 1.8, ID='South6fttemp', QUANTITY= 'TEMPERATURE'/
&DEVC XYZ = 13.0, 1.9, 1.8, ID='South6ftvis', QUANTITY= 'VISIBILITY'/
&DEVC XYZ = 13.0, 1.9, 1.88, ID='South6ftCO', QUANTITY= 'VOLUME
FRACTION', SPEC_ID='carbon monoxide'/

&DEVC XYZ = 10.0, 24.6, 1.8, ID='North6fttemp', QUANTITY= 'TEMPERATURE'/
&DEVC XYZ = 10.0, 24.6, 1.8, ID='North6ftvis', QUANTITY= 'VISIBILITY'/
&DEVC XYZ = 10.0, 24.6, 1.8, ID='North6ftCO', QUANTITY= 'VOLUME
FRACTION', SPEC_ID='carbon monoxide'/

&DEVC XYZ = 6.5, 1.9, 5.5, ID='Upper6fttemp', QUANTITY= 'TEMPERATURE'/
&DEVC XYZ = 6.5, 1.9, 5.5, ID='Upper6ftvis', QUANTITY= 'VISIBILITY'/
&DEVC XYZ = 6.5, 1.9, 5.5, ID='Upper6ftCO', QUANTITY= 'VOLUME FRACTION',
SPEC_ID='carbon monoxide'/

&DEVC XYZ = 4.4, 12.0, 2.4, ID='Stage6fttemp', QUANTITY= 'TEMPERATURE'/
&DEVC XYZ = 4.4, 12.0, 2.4, ID='Stage6ftvis', QUANTITY= 'VISIBILITY'/
&DEVC XYZ = 4.4, 12.0, 2.4, ID='Stage6ftCO', QUANTITY= 'VOLUME
FRACTION', SPEC_ID='carbon monoxide'/

&DEVC XYZ = 17.0, 2.9, 6.75, ID='CeilingWestofPlume', QUANTITY=
'TEMPERATURE'/
&DEVC XYZ = 20.2, 2.9, 5.3, ID='CeilingatPlume', QUANTITY= 'TEMPERATURE'/

&TAIL /

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