RECONSTRUCTING THE STATION NIGHTCLUB FIRE – MATERIALS TESTING AND SMALL-SCALE EXPERIMENTS

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ABSTRACT

On February 20, 2003, during a band performance, pyrotechnics ignited foam insulation lining the walls and ceiling of the platform that was being used as a stage in The Station nightclub, Rhode Island, USA. The fire spread quickly along the foam lined walls and ceiling, smoke emerged from the exit doorways in less than one minute, smoke dropped quickly to near the dance floor, and flames broke through the roof in less than five minutes. One hundred people lost their lives in the fire and hundreds were injured. In order to simulate this fire, small-scale experiments were conducted on different interior finish materials to better understand how those materials performed under fire conditions. Oxygen depletion calorimetry, differential scanning calorimetry, and thermal gravimetric analysis were used to collect material property data on a range of interior finishes including polyurethane foam, both non-fire retardant and fire retardant, wood paneling, acoustic ceiling tiles, and carpet flooring. Polyurethane foam typically ignited in 3 s to 14 s and reached its peak heat release in less than 45 s. The wood paneling and carpet flooring typically required up to 41 s and 54 s to ignite, respectively. The polyurethane foam, wood paneling, and carpet flooring all exhibited peak heat release rates between 400 kW/m^2 and 1400 kW/m^2. The foam would have contributed to a quick initial fire growth, but typically would not have had sufficient mass to carry the fire past the initial stages. Wood and the carpet flooring had greater mass and were a larger source of energy than the foam, although the wood and carpet required longer times to ignite. Once ignited, both the wood and carpet would release a substantial amount of the energy during the fire. The ceiling tiles would have released relatively little energy compared to the other fuel components. Experiments also examined the thermal characteristics of discharging pyrotechnic devices similar to those that were ignited in the nightclub. Pyrotechnic devices were discharged onto walls covered with gypsum board, wood paneling, and polyurethane foam. The experiments that involved discharging pyrotechnic devices against a foam-covered wall demonstrated that the shower of sparks could ignite non-fire retardant polyurethane foam, but that the sparks were not able to ignite fire retardant polyurethane foam, wood paneling or gypsum board within the 15 s discharge period. The ignition of the non-fire retardant polyurethane foam was similar to the ignition sequence observed in the video recorded inside the nightclub on the night of the fire.

INTRODUCTION

As part of its technical investigation of The Station nightclub fire[1], the National Institute of Standards and Technology (NIST) utilized a computer fire model to reconstruct the fire development within the nightclub. The model simulation required data on the ignition source, fuel load, the material properties of the various interior finishes, vent locations, and event timelines. Dimensions, construction materials, and window and door locations were collected from pre- and post-fire photographs, site visits, interviews, and floor plans. Fire growth and ventilation opening timelines were developed from videos recorded inside and outside the nightclub by a television camera operator[2], and fire department radio communications. The reconstruction also required the ignition and thermal properties of the interior materials. Lacking adequate literature values, the essential fire properties were obtained from small scale tests on wood paneling, carpeting, ceiling tile, and polyurethane foam. These material properties, such as thermal conductivity, heat capacity, density, and heat of combustion are utilized by a fire model to predict if and when a component will ignite and how much energy or heat will be released as the component burns. The ignition and subsequent release of energy causes the fire to grow and spread throughout a structure.

In addition to the small-scale tests, a series of real-scale experimental mockup burns of a portion of the nightclub were conducted to collect additional data on fire growth and smoke movement[3]. The mockup burns, each which involved about 20% of the nightclub interior, included both non-sprinklered and sprinklered configurations. The non-sprinklered mockup experiment led to flashover conditions within the drummer's alcove in approximately 60 s. The resulting high temperatures, low oxygen, high carbon monoxide, and high hydrogen cyanide levels all suggest that conditions in the un-sprinklered test became untenable in less than 90 s. In the mockup experiment with sprinklers, near ambient temperature and oxygen levels were maintained 1.5 m above the floor throughout the experiment.

Modeling the mockup experiments with the Fire Dynamic Simulator (FDS) fire model[4] offered an opportunity to compare the computer model results with a known fire, prior to applying the model to the actual nightclub geometry. Since the FDS model was successful in simulating the fire spread and smoke movement in the mockup burns, it was then used to examine the conditions in the entire nightclub as reported by Bryner et. al[5]. The material property data from the small-scale tests and the ignition and fire spread data from the pyrotechnic experiments led to an improved set of input data for the combustion model used in predicting the behavior of the fire and allowed a better understanding of the parameters that affected the performance of the computer simulation of the entire nightclub.

In addition to reconstructing the fire that occurred in the nightclub, FDS was also used to investigate the impact that automatic sprinklers may have had on the fire. Computer fire models are a tool that can not only help to fill in critical details of a specific fire incident, but can also be used to demonstrate the value of alternative building designs and fire safety measures.

POLYURETHANE FOAM CHARACTERIZATION

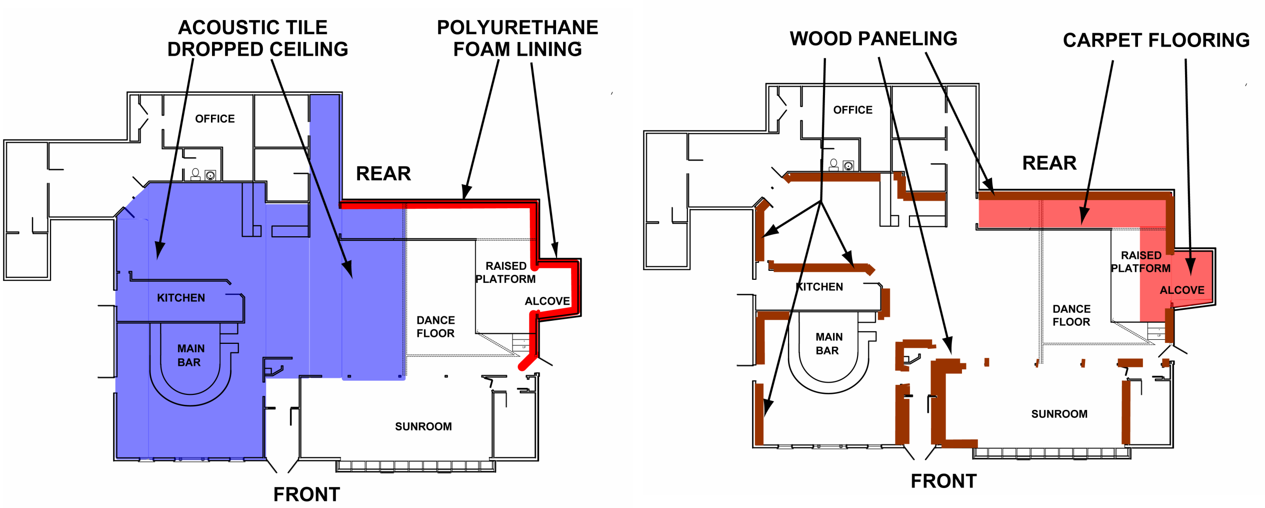
Polyurethane foam (PUF) had been installed on the rear wall, platform wall, and in the alcove as a sound attenuation material (Figure 1). The foam was installed on the vertical surface of the platform wall from the raised floor of the platform to the raised ceiling. The rear wall featured a vertical section and a sloped section. Wood paneling covered the lower portion of the rear wall while the upper portion of the vertical wall and the sloped ceiling were covered with foam.

Both non-fire retardant polyether polyurethane foam (PUF-NFR) and fire retardant polyester polyurethane foam (PUF-FR) were purchased in several lots from a distributor who unfortunately, could not identify the manufacturer of the foam nor ensure the lots were from the same manufacturer. Typically, the sheets of convoluted or "egg crate" foam were 1.22 m wide x 2.44 m long and approximately 0.04 m and 0.01 m at its thickest and thinnest dimensions, respectively.

The cone calorimeter was used to determine the heat release rate of the foams and the test protocol detailed in ASTM E 1354[6] was used for these experiments. A test plus two replicates of each sample (total of three tests) were conducted with the convoluted side exposed to external heat fluxes from 20 kW/m^2 to 70 kW/m^2. The data are tabulated in Table 1. The non-flame retardant NIST samples have a peak heat release rate of around 600 kW/m^2 when exposed to an incident radiant flux of 35 kW/m^2. This compares to a peak heat release rate of 453 kW/m^2 for the flame retardant NIST sample at the same external flux.

The time to sustained ignition is another measure of the fire hazard posed by a material. Both lots A and B of the NIST non-fire retardant PUF needed 6 to 7 seconds for sustained ignition when exposed to 35 kW/m^2 of radiant heat. The fire retardant NIST sample resisted ignition for 13 seconds. The

Figure 1. Portion of Nightclub with Polyurethane Foam (thick red line), Acoustic Ceiling Tile (shaded region), Carpet Flooring (shaded region), and Wood Paneling (thick brown line).



time to ignition in the cone calorimeter is governed by the ignition temperature, the imposed radiant flux, and the effective thermal inertia, kρc, of the material, where k is the thermal conductivity, ρ is the density, and c is the specific heat averaged over the heating period. The time to ignition is inversely related to the square of the imposed radiant flux and directly related to the effective thermal inertia. From the measured ignition temperature and ignition delay at 35 kW/m^2, kρc is estimated to be about 0.075 $(kW/m^2\text{-}^{\circ}C)^2\text{-}s$ for the NIST (lot B) non-fire retardant polyurethane foam.

The heat of vaporization is a measure of the amount of energy that is necessary to convert a material from a condensed to a vapor phase. Differential scanning calorimeter (DSC) and thermal gravimetric analysis (TGA) techniques were used by NIST to calculate the heat of vaporization for samples of non-fire retardant, flexible polyether polyurethane foam. These instruments yielded a range of heats of vaporization between 1000 and 1600 kJ/kg. The ignition temperature was determined by

Table 1. Cone Calorimeter Results for Foam, Ceiling Tile, Wood Panels, and Carpet Flooring.

Sample ID	External Radiant Flux, kW/m^2	Time to Sustained Ignition, Average, seconds	Time to Peak Heat Release, Average, seconds	Peak Heat Release Rate, Average, kW/m^2
PUF-FR	35	13	36	453
PUF-NFR- Lot A	35	7	30	605
PUF-NFR-Lot B	20	14	45	450
	35	6	30	586
	40	4	29	820
	60	3	24	1154
	70	3	21	970
Ceiling Tile	35	Did not ignite		
	70	8	20	57
Wood Paneling	35	41	129	437
	70	15	85	526
Carpet Flooring	35	54	192	627
	70	20	78	1371

Southwest Research Institute using ASTM D 1929[7]. The piloted ignition temperature of non-fire retardant flexible polyurethane foam was found to be 370 °C +/- 5 °C.

Using the properties of either foam, the fire is predicted to spread rapidly, with the foam acting as an ignition source for the wood layer underneath. The contribution from the foam to the total heat release in the fire was much less than from the wood, once the wood was ignited by the burning foam.

CHARACTERIZATION OF FINISH MATERIALS

Experiments were conducted on other finish materials similar to what was thought to be in the nightclub including wood paneling, carpet flooring, and ceiling tiles. Two external heat fluxes were examined in cone calorimeter experiments to account for the changing conditions experienced by the materials in the actual fire. Each test provided time to ignition, peak heat release rate, time to peak heat release rate, total heat release rate, specimen total mass loss, average mass loss rate, average effective heat of combustion, average smoke extinction area, average carbon dioxide yield, and average carbon monoxide yield for each of the finish materials (Additional details are included in the investigation report[1]).

A suspended ceiling of acoustic tiles had been installed in the nightclub except for in the sunroom, the platform area, and the dance floor areas (Figure 1). Each panel, 610 mm x 1219 mm x 16 mm, had been dropped into a metal support grid. Labeling found on a surviving acoustic tile indicated that that the tile was a mineral fiber type; samples of 942B acoustical tiles were purchased for these tests. In all tests, the painted side of the tile was exposed to the thermal flux.

When exposed to 35 kW/m^2 of external flux, the tiles did not ignite and each test was stopped after 3 minutes of exposure when none of the three samples ignited. As the flux was increased to 70 kW/m^2, ignition did occur and the samples reached their peak heat release rate in approximately 20 s. The ceiling tiles produced an average peak heat release rate of 57 kW/m^2 at the highest incident flux.

Wood paneling had been installed in the nightclub around the platform area, around the sunroom, back bar area, and entry way (Figure 1). A veneer type paneling which utilizes a plywood substrate was selected as being representative of the fuel load contributed by the paneling. The wood paneling was purchased in 1.22 m x 2.44 m sheets. A 0.3 mm birch veneer was laminated to a 6 mm thick three-ply Luan mahogany backer layer. In all tests, the veneer side was exposed to the thermal flux.

When irradiated with 35 kW/m^2, the wood paneling reached its average peak heat release rate, 440 kW/m^2, in approximately 130 s. At the lower thermal flux, each sample required about 40 s to achieve sustained ignition. At the higher flux, 70 kW/m^2, the wood panel samples required much less time to sustained ignition, resulted in a higher average peak heat release rate of 530 kW/m^2, and required substantially less time, 85 s, to achieve the peak value.

Carpet flooring had been installed in the nightclub on the elevated section along the rear wall and around the platform area (Figure 1). A closed-loop olefin carpet with a binding layer was selected as representing the fuel load contributed by the carpeting. In all tests, the olefin pile side was exposed to the thermal flux.

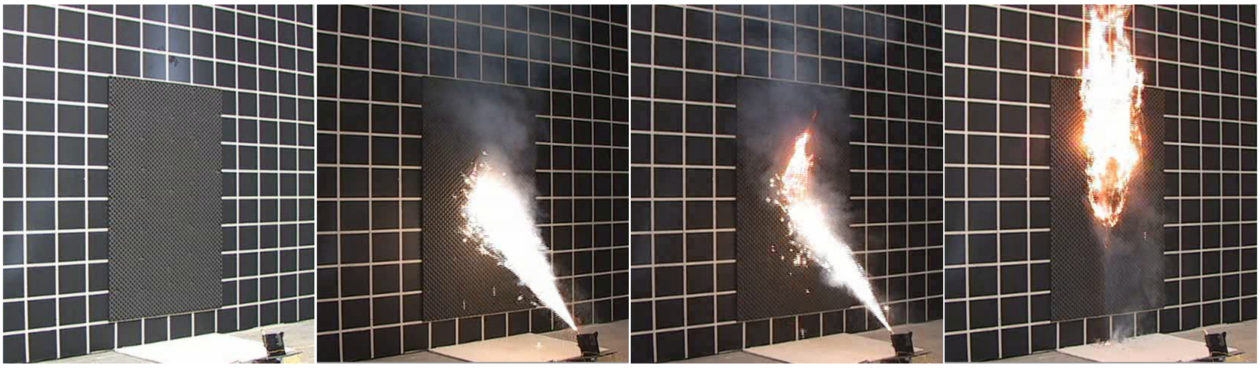
When exposed to 35 kW/m^2 of external heat flux, the average peak heat release rate for the three carpet samples was 627 kW/m^2. The carpet required about 54 s, on average, to achieve sustained ignition, and approximately 190 s to reach its peak heat release rate (Table 1). When exposed to the higher external heat flux of 70 kW/m^2, the carpeting reached its peak heat release rate in about half the time. Peak heat release rates for all three carpet samples averaged 1370 kW/m^2.

PYROTECHNIC DEVICE TESTS

At the beginning of the band performance, four pyrotechnic devices, or gerbs, were discharged in front of the alcove. The video of the nightclub interior showed that glowing particles or "sparks" ignited the foam on both sides of the alcove in approximately 10 seconds. The throw, or distance the hot particles traveled, the period of "spark" discharge, and the white appearance of hot particles, were consistent with a pyrotechnic device called a Silver 15 x 15 Stage Gerb.

Experiments were also conducted to examine the thermal characteristics of a discharging pyrotechnic device onto a wall covered with gypsum board, wood paneling, or polyurethane foam. The walls were instrumented with thermocouples and heat flux gauges. Each discharge was recorded using video and infrared cameras. The visible images show that each gerb discharged a spray of white sparks for at least 14.5 s, but no more than 16 s. While most of the sparks were thrown less than 2.74 m, a limited number of sparks traveled in excess of 4.6 m from the tip of the gerb. As shown in Figure 2, a pyrotechnic device discharging against a non-fire retardant foam covered wall ignited the foam. Although not clear from the image, the foam did ignite at approximately 10 s and the fire is clearly visible at 15 s, just as the gerb discharge ends. The pyrotechnic device was not able to ignite a wall lined with gypsum board, wood paneling, or fire retardant foam within the 15 s discharge period. The hot sparks did cause "pitting" in the fire retardant foam. The pits were areas where the sparks melted or burned away small amounts of foam, but the process did not propagate. The hot sparks did create small black marks and craters in the finish of the wood paneling, but did not cause ignition. For the gerbs that were positioned at 45 degrees, infrared images show a central core of hot gases, which do not travel as far as the hot metallic particles. The buoyant hot gases developed a vertical trajectory within 1.2 m of the gerb tip. The measured heat fluxes from the gerbs impinging on the wall were less than 2.5 W/m^2.

Figure 2. Pyrotechnic Device Discharging Against Non-Fire Retardant Foam Wall Section, Prior to Ignition of Gerb, 10 s after ignition, 15 s after ignition, and 30 s after ignition (l to r).



SUMMARY

Small-scale data was collected to characterize the material properties of polyurethane foam, ceiling tile, wood paneling, and carpeting. Data from these test series provided insight into the material properties, fire spread, heat flux, and fire growth of the different materials and led to an improved set of input data for the combustion model used in predicting the behavior of the fire and allowed a better understanding of the parameters that affected the performance of the computer simulation of the entire nightclub.

The polyurethane foam was a low density material and was quick to ignite, but the mass of the foam was consumed in a relatively short period of time. The foam would have contributed to a quick initial fire growth, but typically would not have had sufficient mass to carry the fire past the initial stages. Wood and the carpet flooring had greater mass and were a larger source of energy than the foam, although the wood and carpet required longer times to ignite. Once ignited, both the wood and carpet would release a substantial amount of the energy during the fire. The ceiling tiles would have released relatively little energy compared to the other fuel components.

The contribution of a specific fuel is dependent on the relative amounts of the fuel and how quickly the fuel becomes involved in the fire. Wood is often found in flooring, wall paneling, and structural members such as studs, joists and rafters. Carpeting is typically used only as a floor covering. In a wood frame structure, the wood component of the fuel load may provide the bulk of the energy released. The location of the fuel can also impact when and how rapidly a specific fuel becomes a contributor to the heat release rate. For instance, wood paneling near the ceiling ordinarily would become involved more quickly than wood flooring.

The experiments that involved discharging pyrotechnic devices against a foam-covered wall demonstrated that the shower of sparks could ignite non-fire retardant polyurethane foam, but that the sparks were not able to ignite fire retardant polyurethane foam, wood paneling or gypsum board within the 15 s discharge period. The ignition of the non-fire retardant polyurethane foam was similar to the ignition sequence observed in the video of the incident.

RECOMMENDATIONS

Based on the reconstruction of the fire using FDS and the findings of the technical investigation, NIST made a number of recommendations that are aimed at improving life safety in nightclubs. Calling for changes to the national model building codes, the key recommendations include:

- Require the installation of NFPA 13 compliant automatic fire sprinklers in all new nightclubs regardless of size and in all nightclubs with an occupancy limit greater than 100 people.
- Materials that ignite easily and propagate flames rapidly, such as non-fire retardant polyurethane foam, should be clearly identifiable and be specifically forbidden as an interior finish material in all nightclubs
- NFPA 1126 standard on the use of pyrotechnics before an audience should be strengthened by addressing the need for automatic sprinkler systems; minimum occupancy/building size levels; the posting of pyrotechnic use plans and emergency procedures; and setting new minimum clearances between pyrotechnics and the items they potentially could ignite.

There is also a critical need for research to serve as the basis for further improvements in codes, standards and practices. NIST urges studies be conducted to:

- better understand human behavior in emergency situations and to predict the impact of building design on safe egress in emergencies;
- better understand fire spread and suppression.

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