

# Flammable Liquids Fire Leading to a Backdraft Explosion

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Firexplo

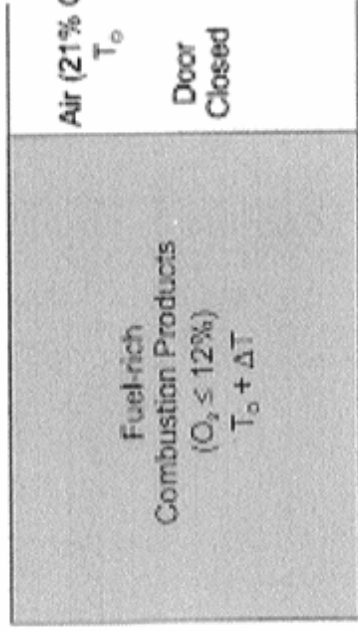


# **Flammable Liquids Fire Event**

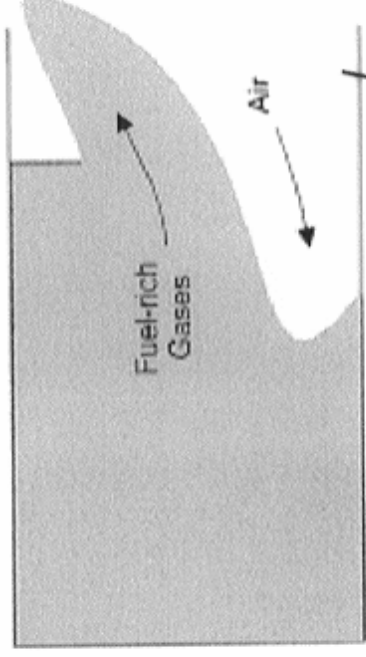
- 1. Flammable liquids in small containers ignited in unsprinklered basement of hardware store.**
- 2. Fire Department access restricted by locked doors and boarded up windows.**
- 3. Large explosion occurs 32 minutes after ignition; result is 3 firefighter fatalities, numerous injuries, and building is destroyed.**

# Was it a Backdraft Explosion?

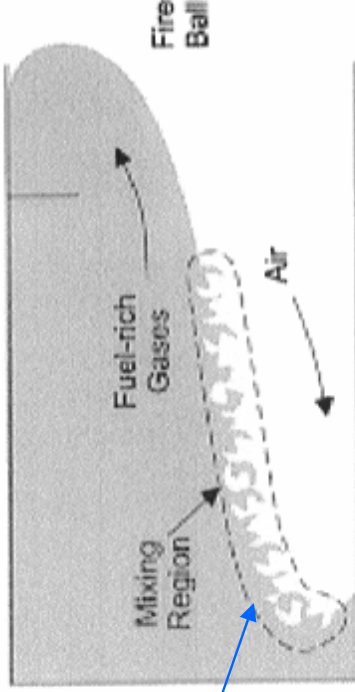
Before window opens



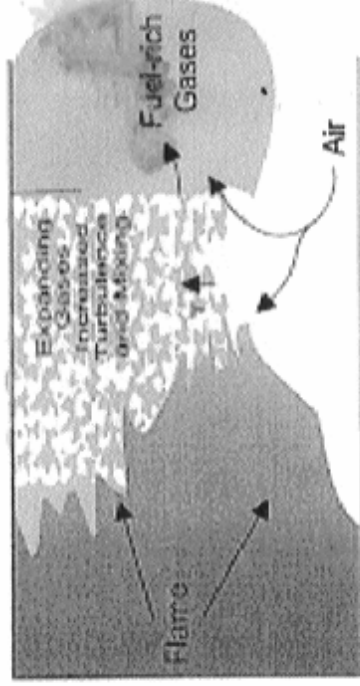
Result of Window Opening



Need mixing prior to ignition for deflagration



Result of deflagration



Expanding gases induce air velocity

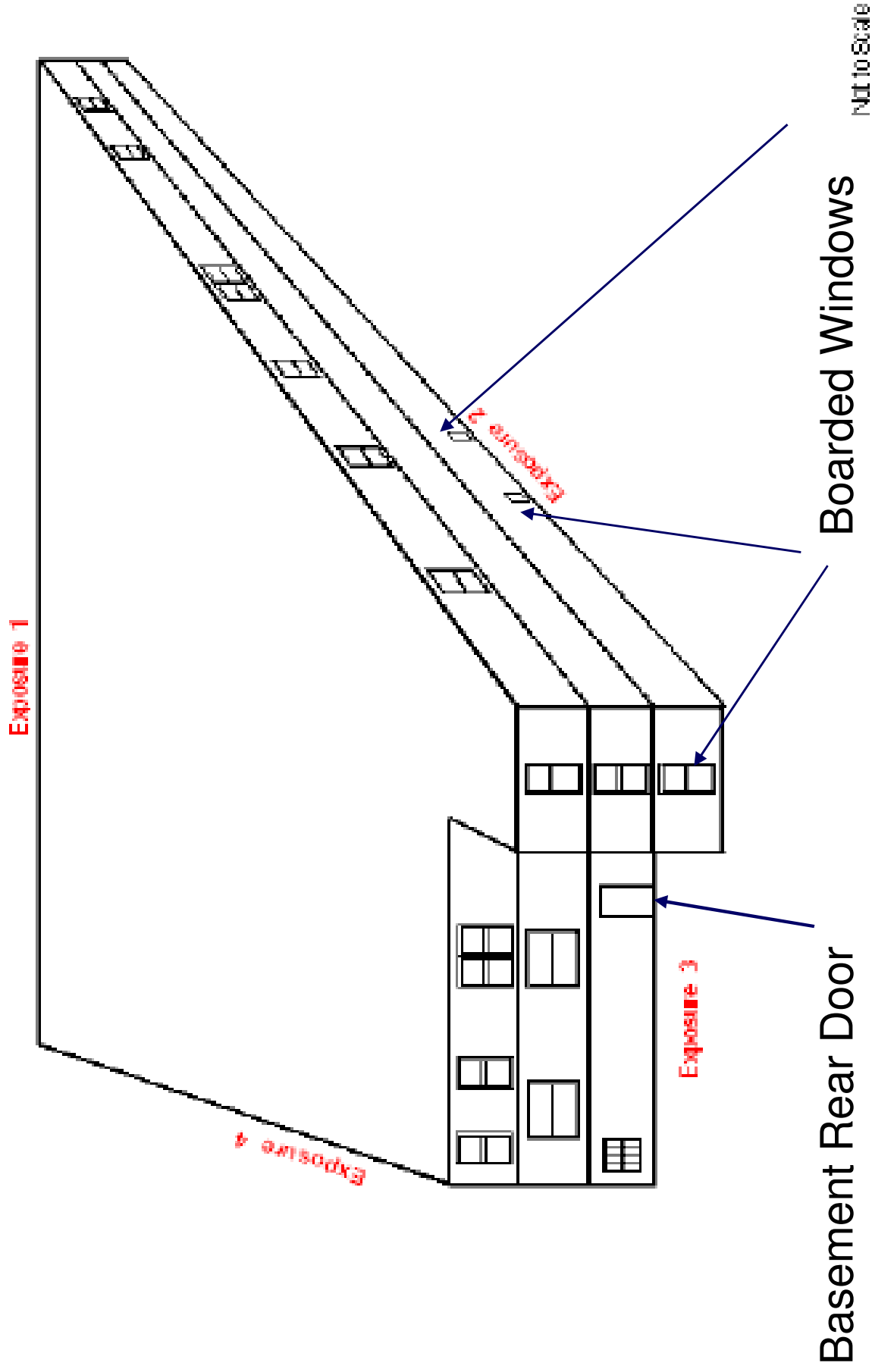


## Backdraft Criteria

- Oxygen concentration < 12 mass percent in basement at time window is opened.
- Fuel vapor concentration > 10 – 15 mass percent\* at time window is opened.
- Need either residual flame or hot spot on wall at temperature > spontaneous ignition temperature (869 °F for acetone, 685 °F for ethanol, 725 °F for MEK)

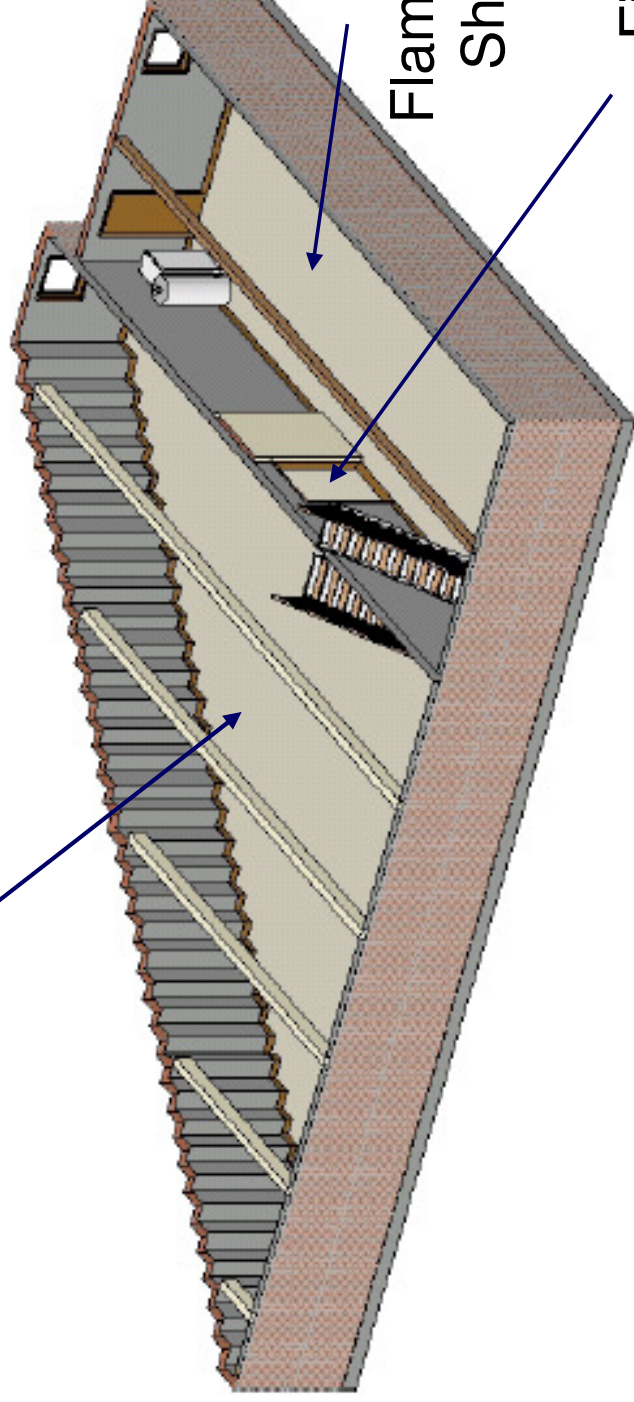
\* Different minimum fuel vapor concentrations measured by Fleischman et al. (1994) and Gottuk et al. (1999) in backdraft experiments.

# Building Isometric



# Basement Layout

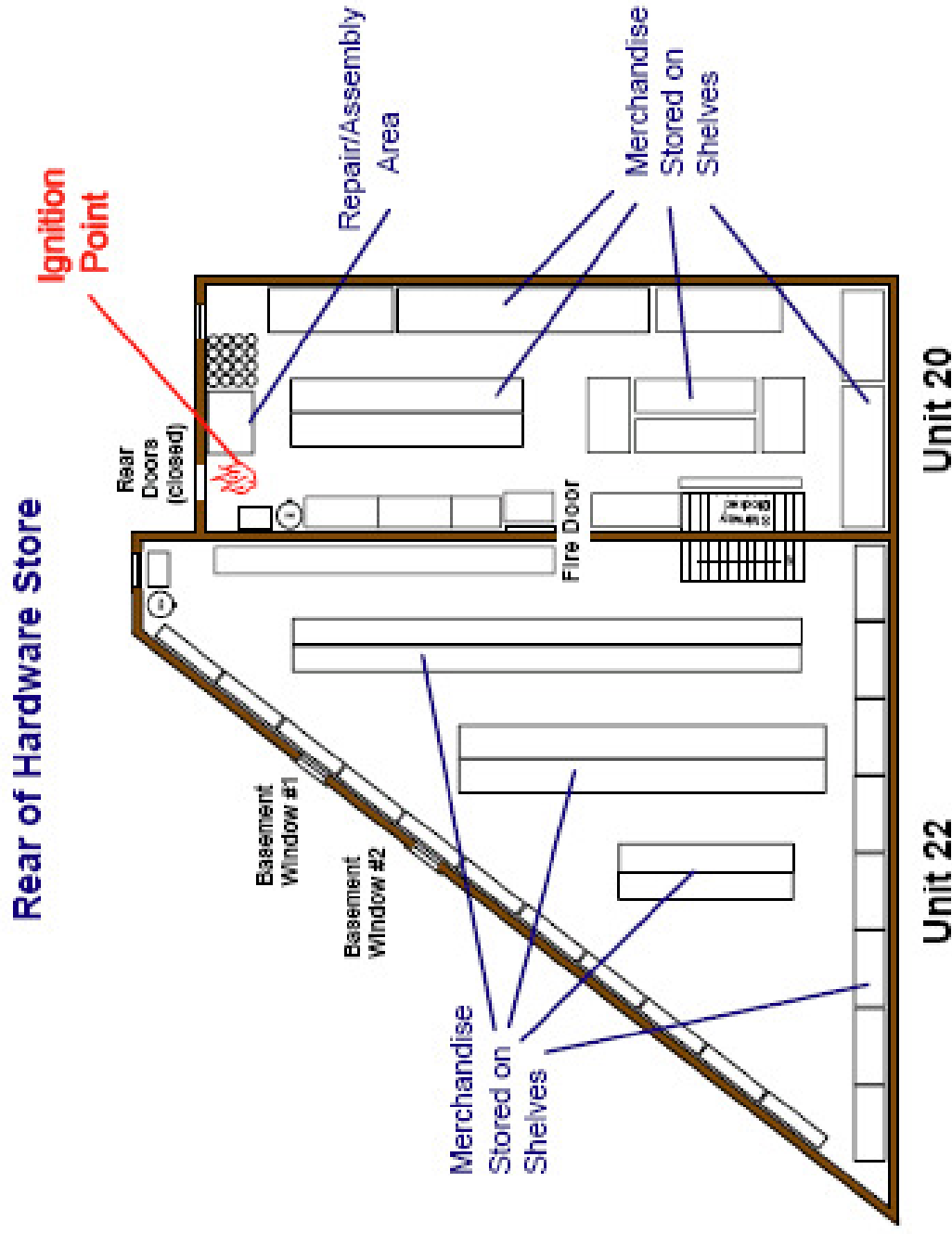
Multiple Solid Shelf  
Storage of Flammable  
Liquids



Flammable Liquid  
Shelf Storage

Fire Door  
Blocked Open

# Basement Layout and Ignition Site



Rear of Hardware Store

# Flammable Liquid Inventory

Flammable Liquid or Gas	Amount	Basement Locations
Acetone	6 – 12 Gallons	Rear of west side
Denatured Ethanol	24 Gallons	Rear of west side
Kerosene	4 Gallons	Rear of west side of basement
Lacquer Thinner	12 – 24 Gallons	Rear of west side
Methanol-Ethanol Blend	12 Gallons	Rear of west side
Methyl Ethyl Ketone	24 Gallons	Rear of west side
MAPP Gas	27 Cylinders	East side
Mineral Spirits	24 Gallons	Rear of west side
Naptha	24 Gallons	Rear of west side
Paint (mostly oil based) in 1-gal Cans	Unknown	East Side on shelves
Paint Thinner	24 Gallons	Rear of west side
Propane	142 14-oz cylinders	Most on east side; about 6 more near receiving area on west side.
Spray Paint (Oil based)	200 – 300 Cans	Rear of west side
Toluene	4 Gallons	Rear of west side
Turpentine	24 Gallons	Rear of west side
Xylene	4 Gallons	Rear of west side

# Ignition Scenario

- Hardware store unoccupied on a Sunday afternoon.
- Two boys playing in alley behind store accidentally knock over a 1-gallon container of gasoline.
- Gasoline flows down ramp leading to back door, and flows under door sill.
- Gasoline ignited by pilot flame on either hot water heater or furnace.
- Fire spreads to combustible cartons containing plastic chimes, and then to flammable liquid containers.

# Abbreviated Fire Timeline

Time After Ignition (min)	Event
2 to 4	Boys and uncle try in vain to pry open basement door to extinguish fire.
5 to 6	911 call received by Fire Department; pedestrian stops fire truck on Astoria Blvd.
16	Firefighters with 2 ½ inch hoseline gain entry to front of store on first floor.
16 – 20	Firefighters intermittently open and close stairway door to basement.
26	Basement rear door forced open approximately 18 inches.
31	Two firefighters force open basement window on 14 <sup>th</sup> Street wall
32	<b>EXPLOSION!</b>

## **Collapsed 14<sup>th</sup> St. Side of Bldg (Exposure 2)**



## **Eye Witness Observations Prior to Explosion**

- Thick, brownish smoke, also described as green ugly pea colored soup, venting from the south window on the 14th St. wall one minute prior to the explosion
- Smoke smelled “different” just before explosion.
- **There was a rush of wind pulling police officer toward building, and then everything was blowing out at him.**
- **A civilian across the street heard a loud sucking noise right before the explosion.**
- **Light smoke started to be sucked back into north basement window.**

## **Flammable Liquid Needed to Produce a Vapor Mass Fraction of 0.15\* in Each Room**

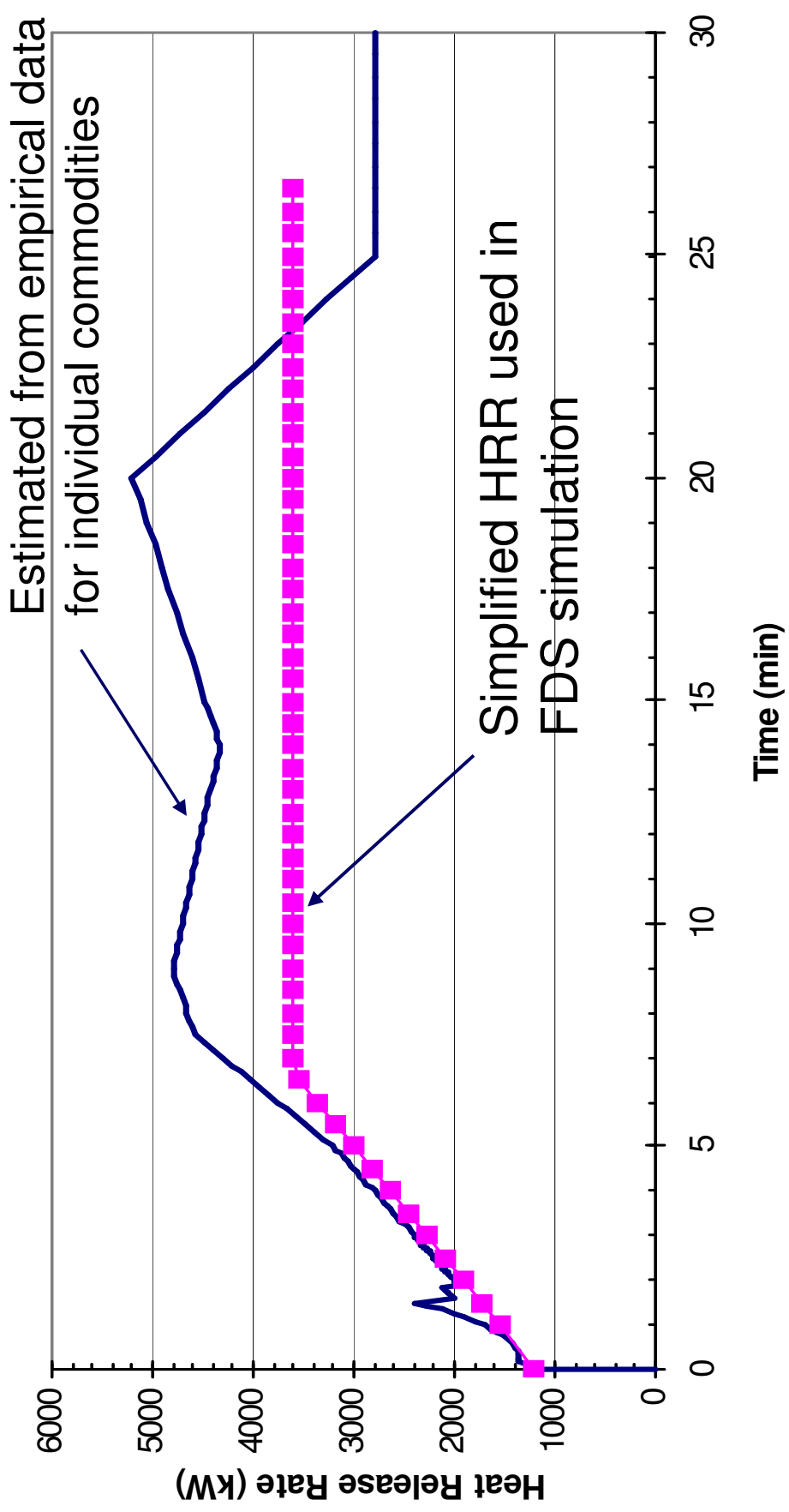
- 18 Gallons on 12-20 (West) Side of Basement: Actual amount > 190 gallons
- 36 Gallons (243 lbm) on 12-22 (East) Side of Basement: Actual amount > 200 lbm pre-fire, plus vapor released on West side and transported to east side through open fire door.

\* Based on MEK liquid density

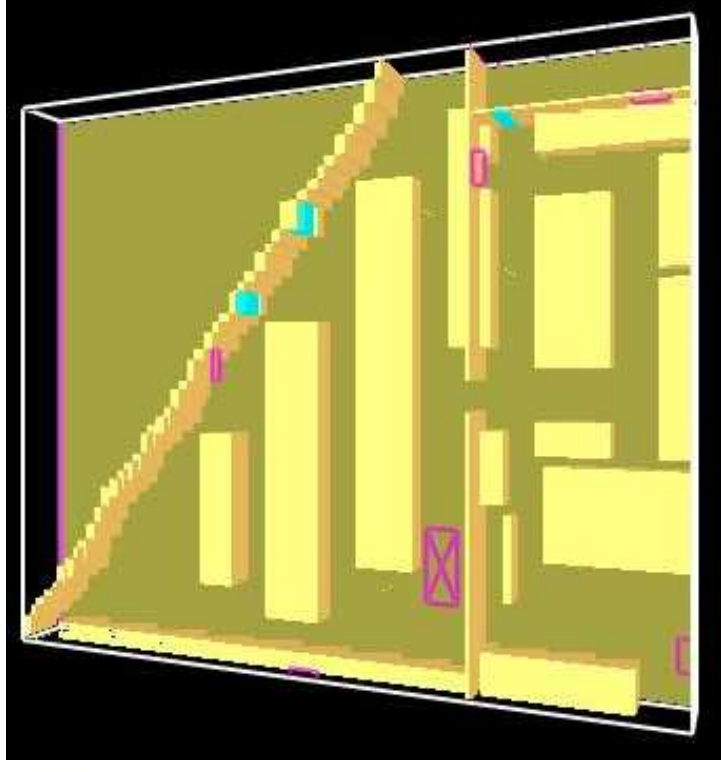
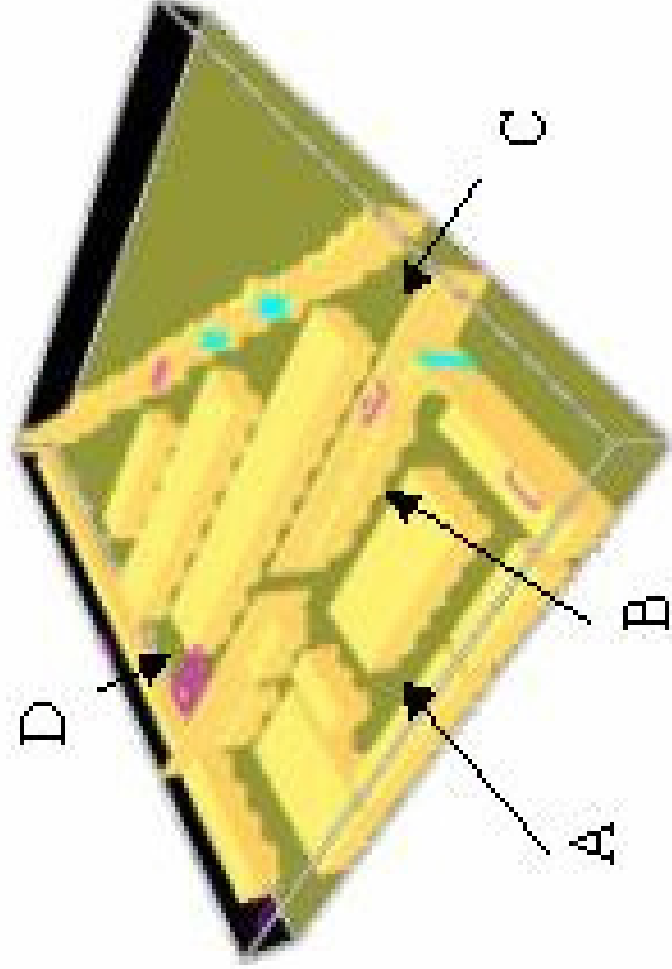
## **FDS Simulation to Determine Conditions in Basement at 32 Minutes after Ignition**

- Grid cell size: 10 cm x 10 cm x 10 cm
- Heat Release Rate from empirical data for representative commodities, including flammable liquids in small containers.
- Vertical profiles of temperature and oxygen output at four designated locations: A, B, C, D.
- Vent openings as described on later slide.

# Astoria Hardware Store Fire Heat Release Rate



# FDS Representation of Basement

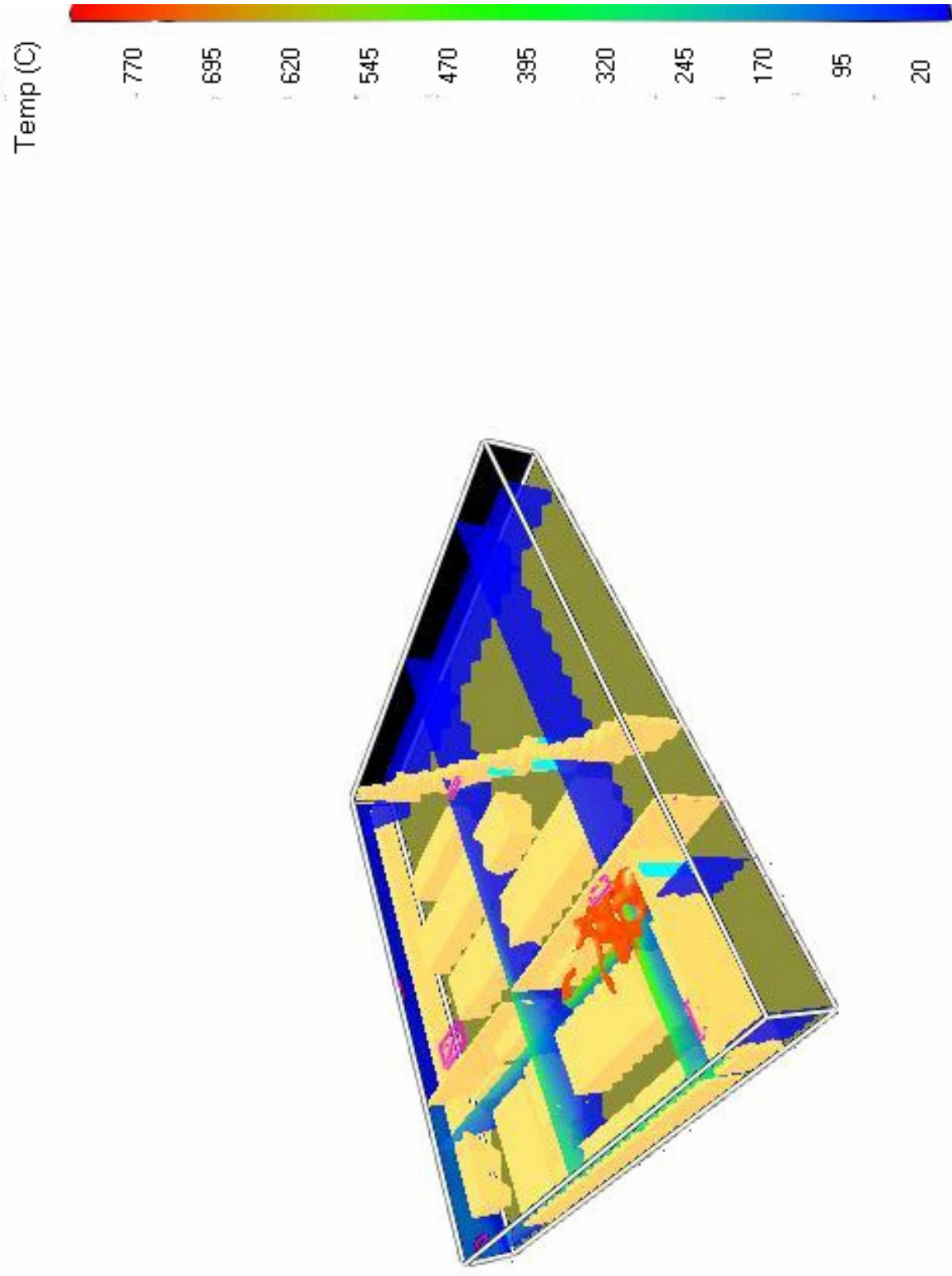


Grid Size: 0.1m x 0.1m x 0.1m

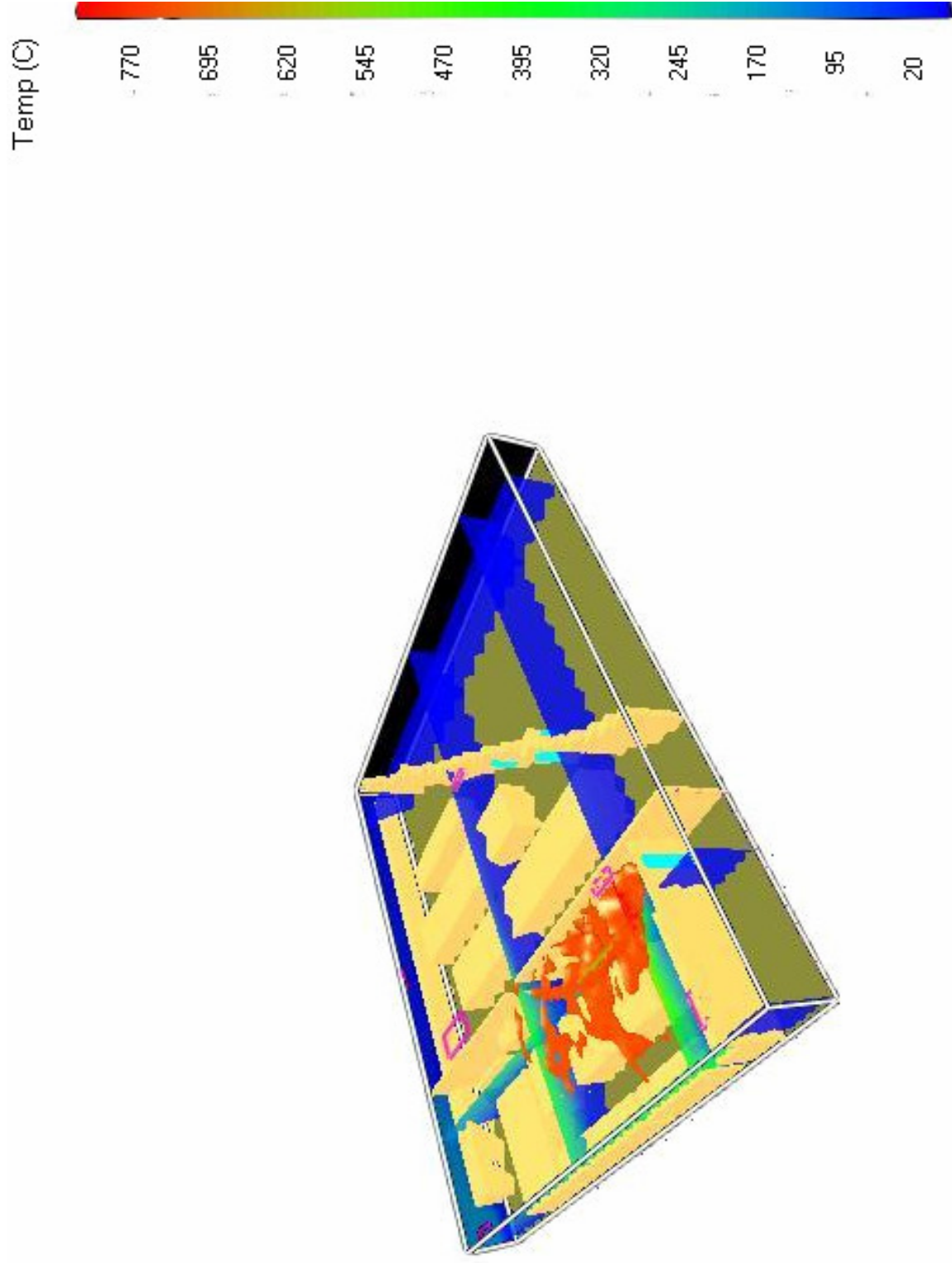
# Vent Openings in FDS Simulation

- Door gap (16-inch long by 1.0-inch high) under the rear door leading to the alley
- Small opening in ceiling above hot water heater in 12-20 basement
- Small openings (one cell wide) in South wall-ceiling intersection and West wall-ceiling intersection in 12-20 basement
- Small openings (one cell wide) in North (Astoria Blvd) wall-ceiling intersection and East (14th St.) wall of 12-22 basement
- A 3-ft by 8-ft covering in the ceiling of the 12-22 basement at the top of the stairs was specified to open 15 minutes after fire initiation to represent the opening of the stairway door by responding firefighters.

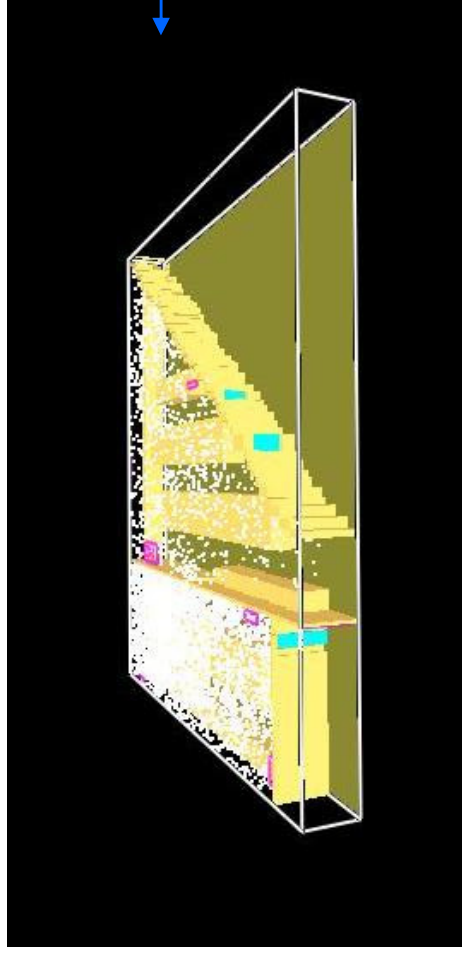
# FDS Isotherms 6 minutes after Ignition



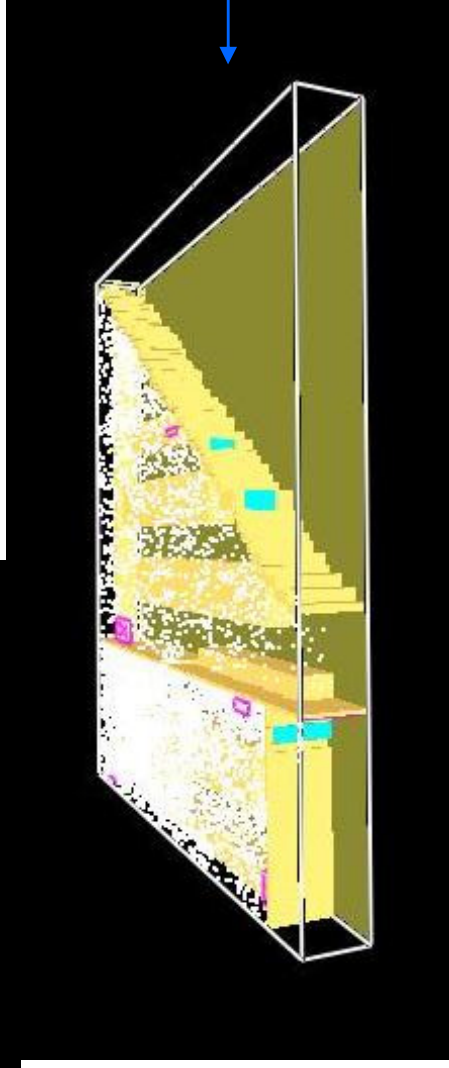
# FDS Isotherms 16 minutes after Ignition



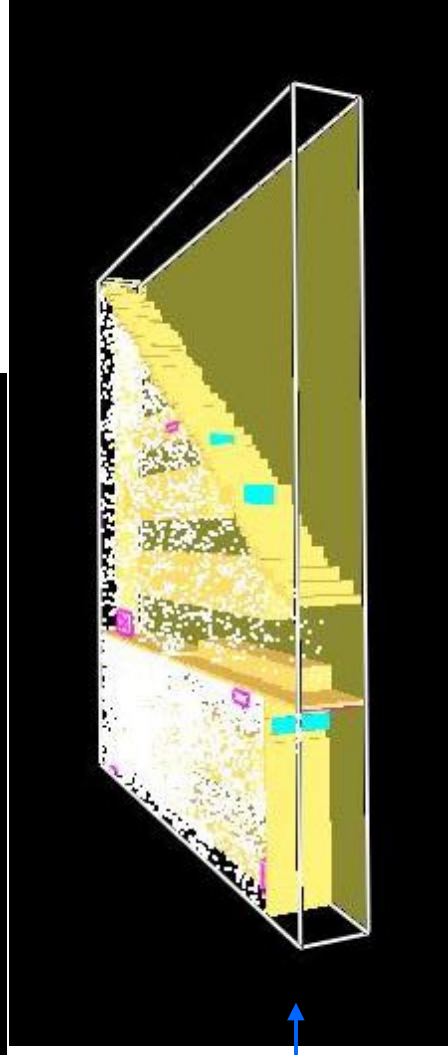
# FDS Calculated Smoke Transport



1 1/2 minutes

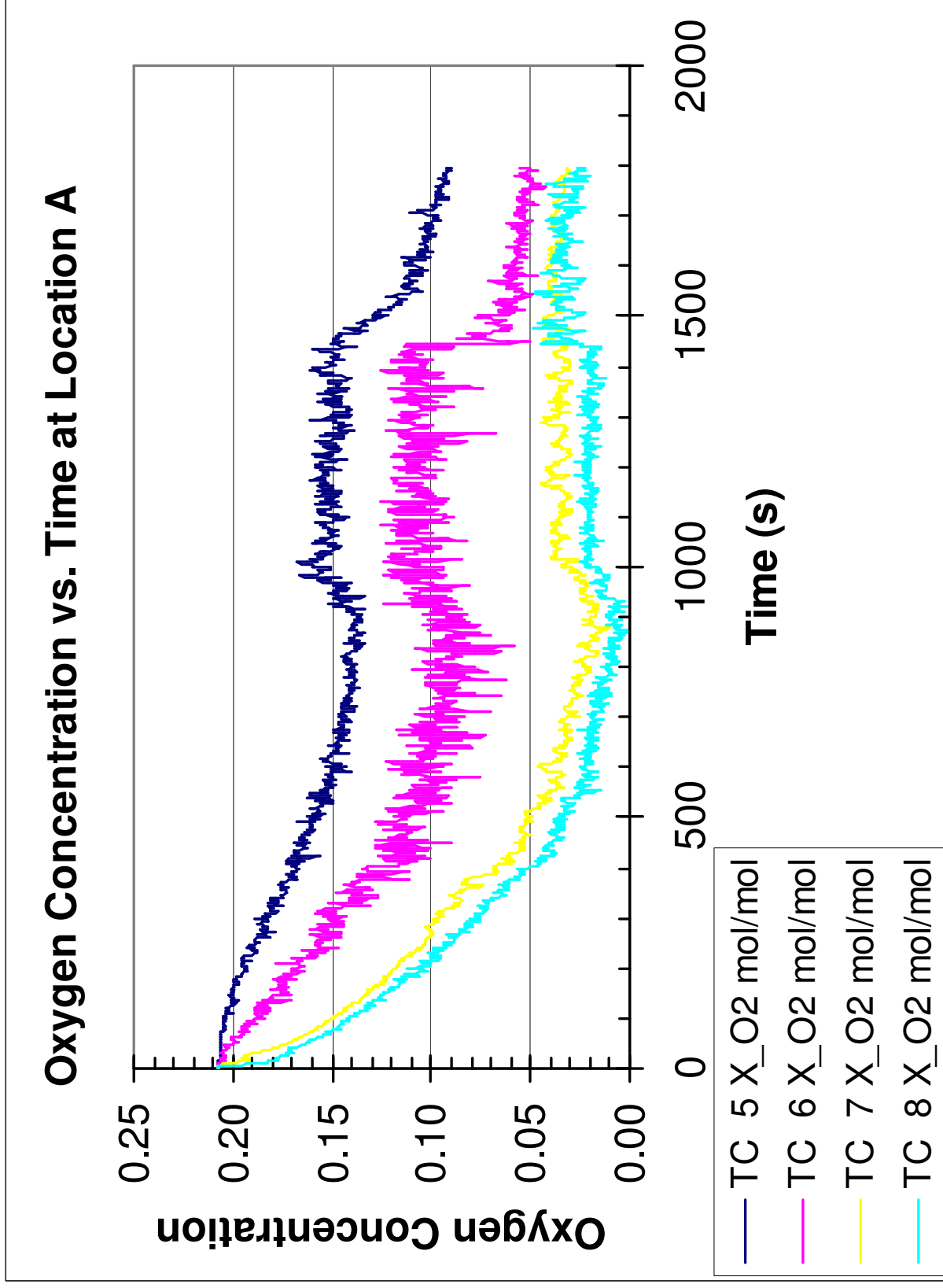


2 1/2 minutes



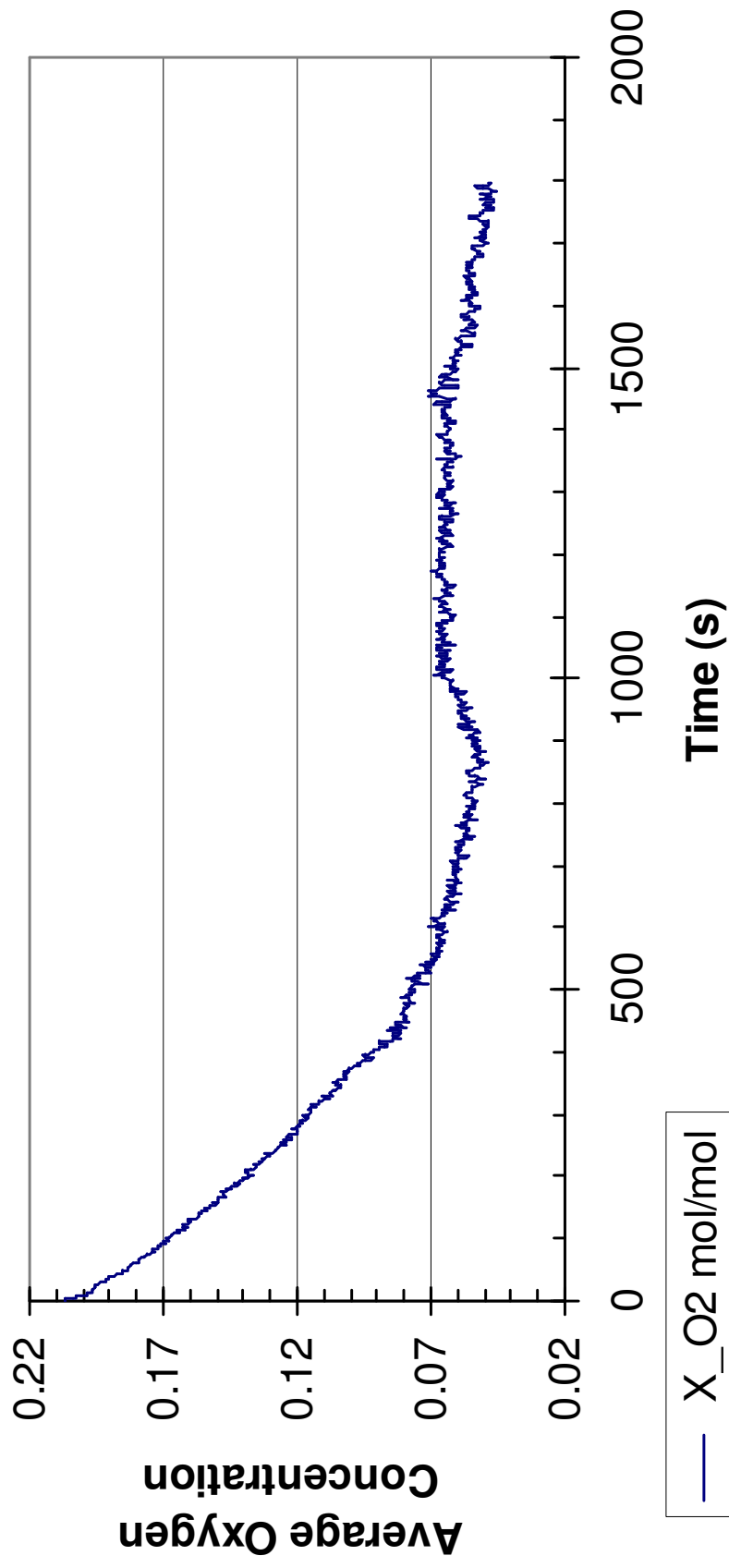
20 1/2 minutes

# Oxygen Concentrations at Location A

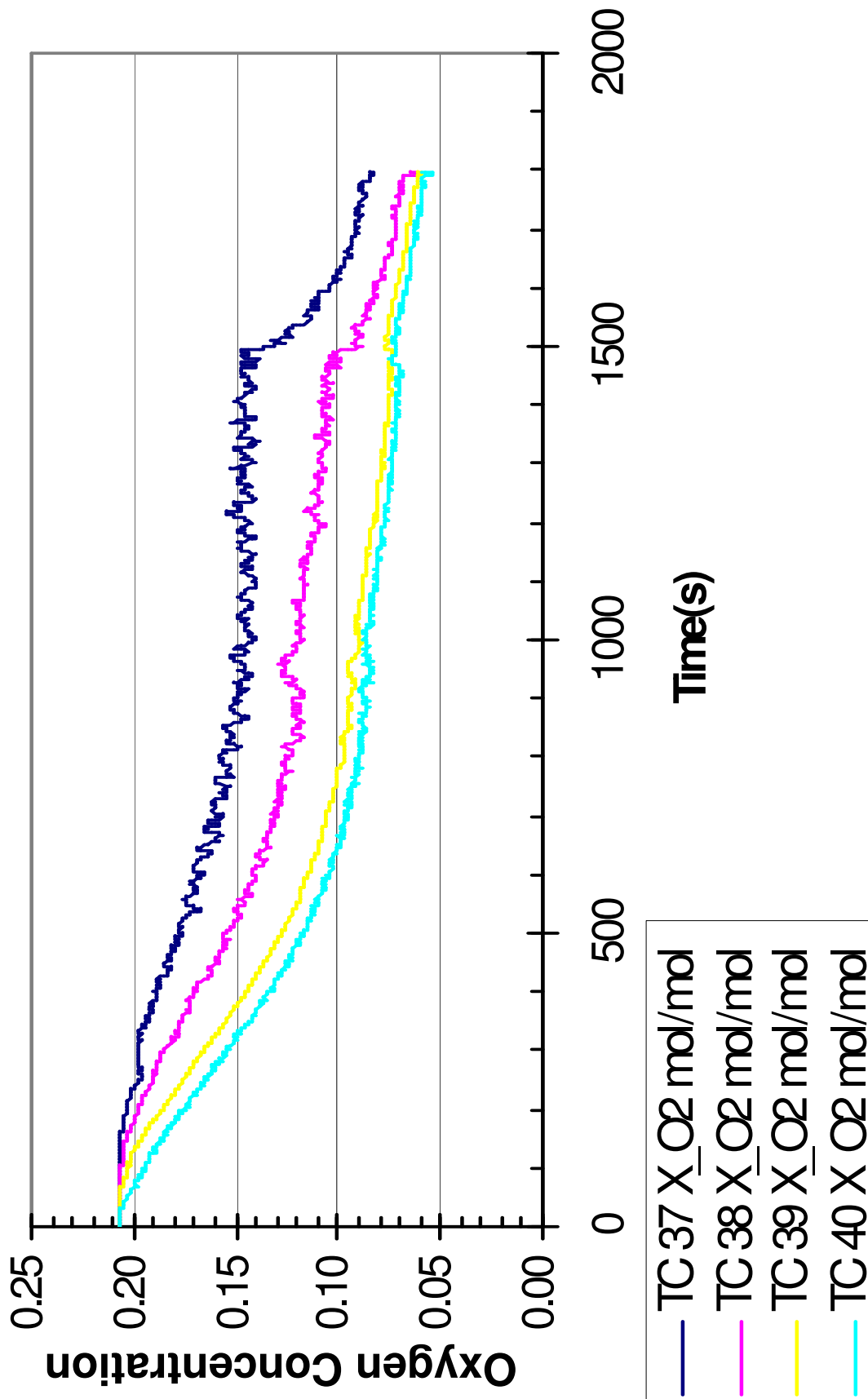


# FDS Calculated Oxygen Concentration

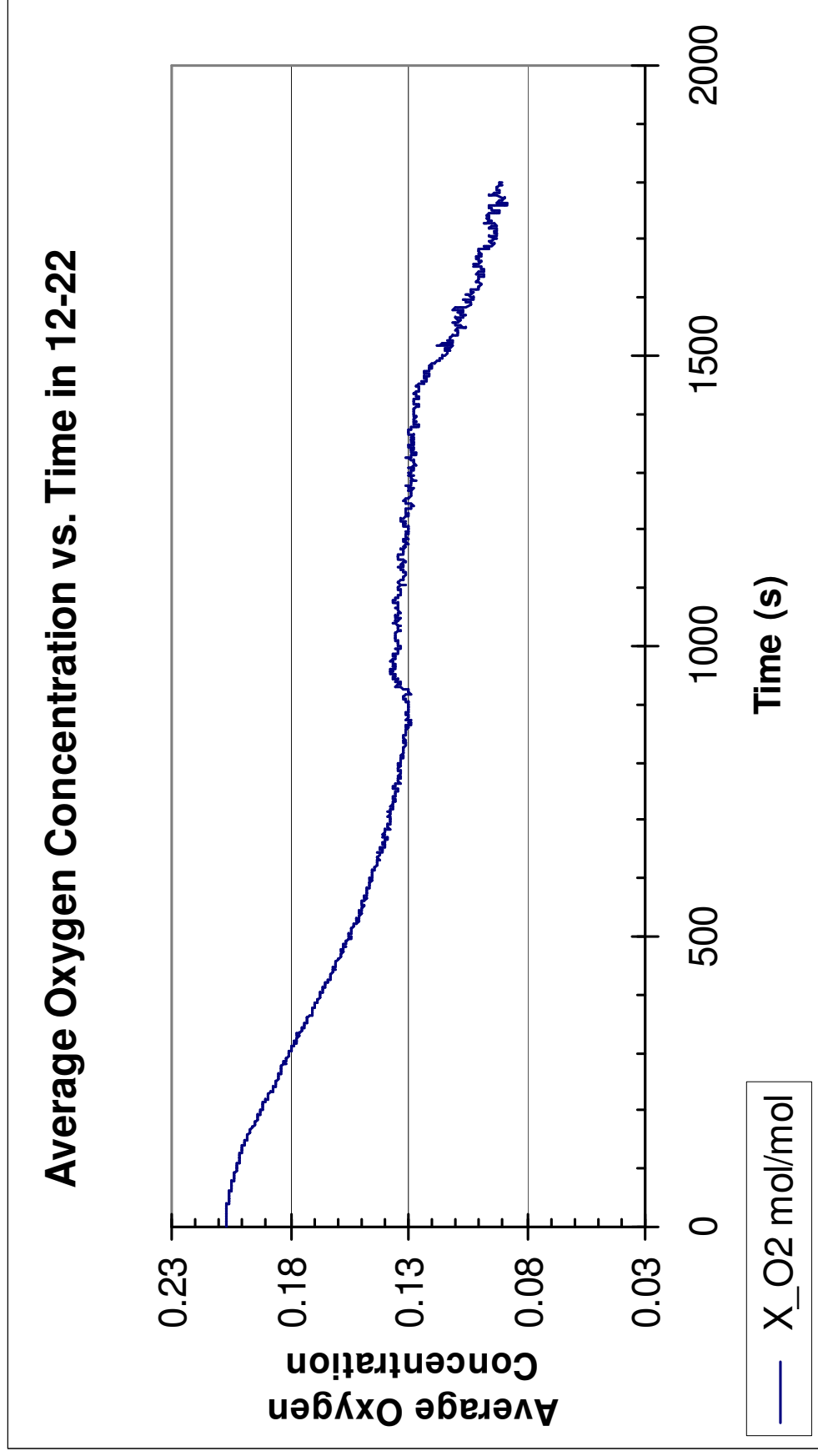
Average Oxygen Concentration vs. Time in 12-20



# Oxygen Concentration vs. Time at Location C

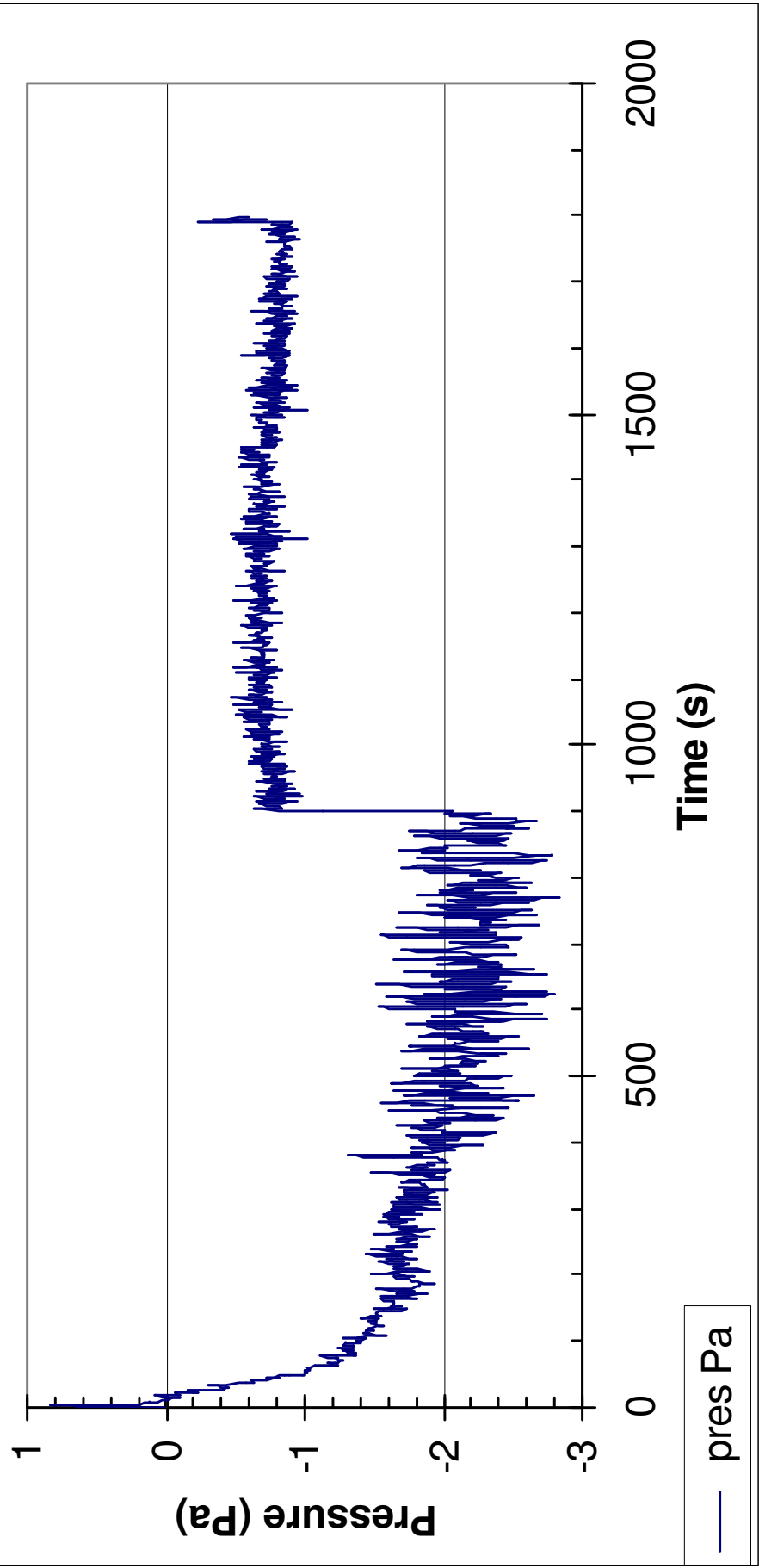


# FDS Calculated Oxygen Concentration in 12-22



# Pressure in East Side of Basement < Ambient Pressure

## Average Pressure vs. Time in 12-22



## Backdraft Criteria Satisfied

- Average Oxygen Concentration < 10% 32 minutes after ignition.
- Pressure < ambient, allowing air to be drawn into basement.
- Fuel vaporizing for many minutes, implies large fuel vapor concentration > 15%.
- Ceiling Temperature > Autoignition Temperature at wall opposite window , allowing mixing prior to ignition.

## **Backdraft Deflagration Effects in this Fire**

- Deflagration Pressure = 2 to 4 kPa, sufficient to blow out 14 St. wall and crush two firefighters; also partially collapsed roof and trapping a third firefighter in the burning building.
- Air flow ahead of expanding fireball knocked over many firefighters in area around building.
- About 40 other firefighters and five police officers injured from flying bricks, nails, cans, and other debris.
- Firefighters at partially open rear door of basement were burned by vented fireball.

## **CONCLUDING REMARKS**

- **Flammable liquids vaporizing and burning in basement for 31 minutes produced fuel vapor and oxygen concentrations for backdraft.**
- **Opening of boarded window allowed air to rush into basement and mix with accumulated vapor.**
- **Backdraft deflagration produced by ignition of vapor-air mixture produced pressure sufficient to lift basement ceiling and blow out side wall.**
- **Additional research and development needed to provide tools/methodology to prevent future large backdraft explosions. Limits on flammable liquid storage in basement would also be helpful.**

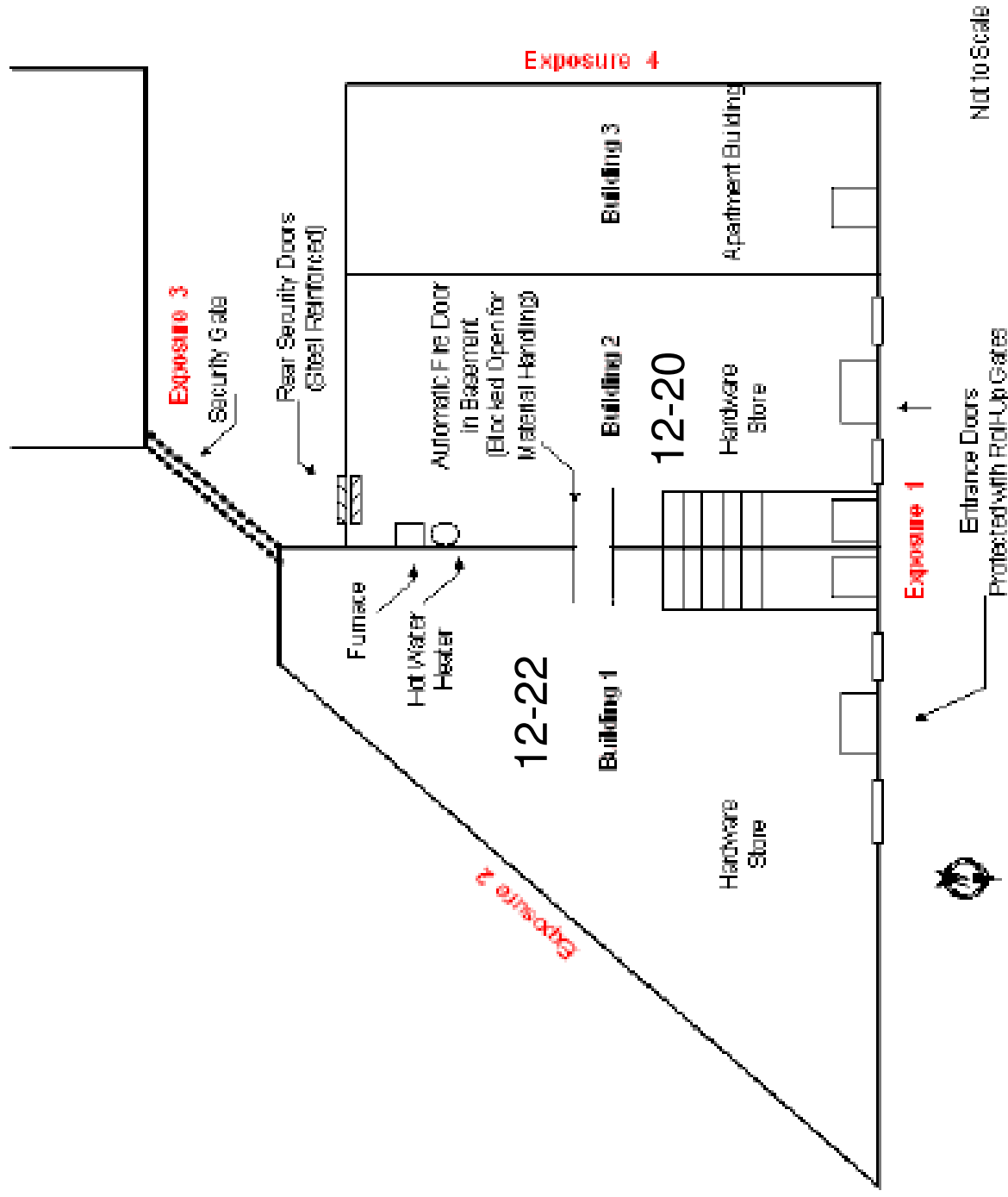
# Potential Backdraft Prevention Measures

- Water Spray discharge either by
  - ≡ Automatic sprinklers (preferable), or possibly by
  - ≡ Water spray injection prior to venting and firefighter entry (needs research/development of delivery method)
- Experiments reported by Gottuk et al. indicate only a small quantity of water needed.
- Flammable vapor and oxygen concentration readings prior to venting and firefighter entry (needs research/development on sensor deployment method)
- Limit amount of flammable liquids in un-sprinklered basements.

## References

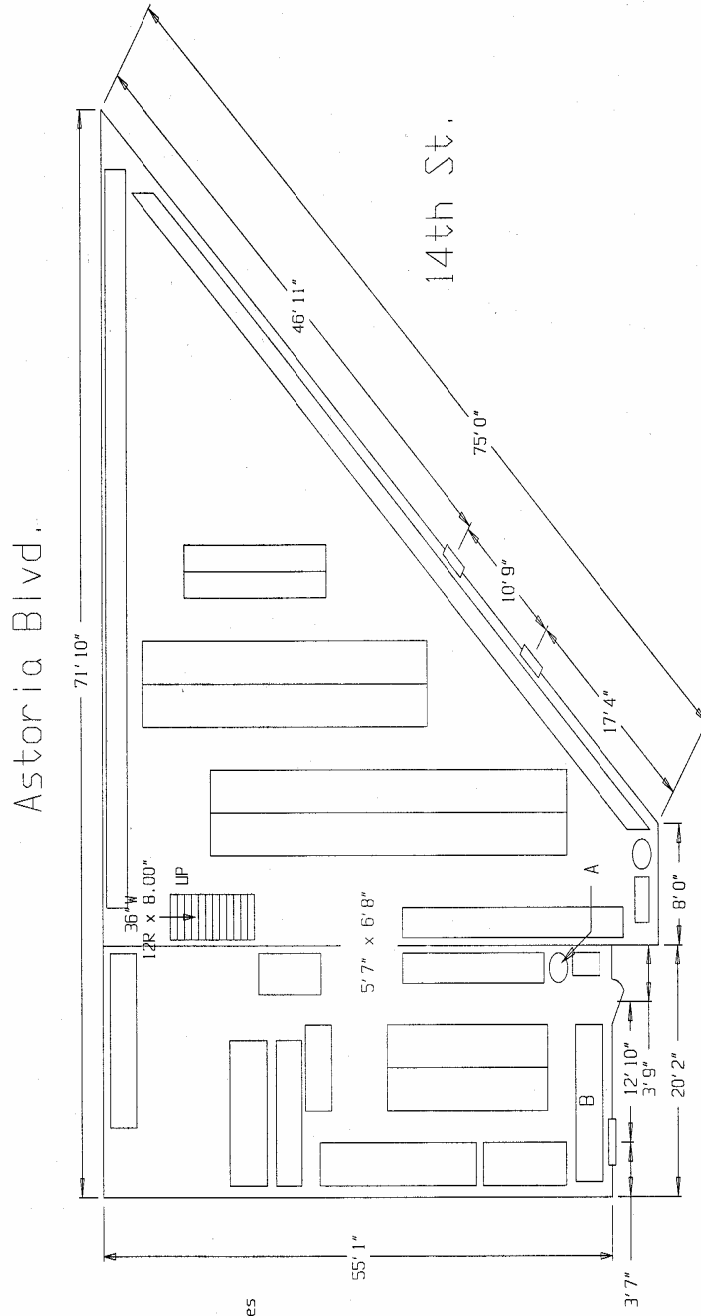
- Bryner, N. and Kerber, S., "Simulation of the Dynamics of a Fire in the Basement of a Hardware Store – New York, June 17, 2001," NISTIR 7137, May 2004.
- "Hardware Store Explosion Claims the Lives of Three Career Fire Fighters - New York," <http://www.cdc.gov/niosh/fire/reports/face200123.html>
- Fleischman, C.M., Pagni, P.J., and Williamson, R.B., "Quantitative Backdraft Experiments," Proceedings of the Fourth International Symposium on Fire Safety Science, pp. 337-348, 1994.
- Gottuk, D.T., Peatross, M.J., Farley, J.P., and Williams, F.W., "The Development and Mitigation of Backdraft: a Real-Scale Shipboard Study," Fire Safety Journal, v 33, pp. 261-282, 1999.
- Zalosh, R. and Ho, S-P., "Analysis of a Flammable Liquids Fire Leading to a Backdraft Explosion," 5<sup>th</sup> International Symposium on Fire and Explosion Hazards, Edinburgh, April 2007.

# Building Plan View



# Basement Dimensions

Monday, February 18, 2002 12:13:39



- A Water Heater
- B Shipping / Receiving Table
- Other rectangles are storage shelves

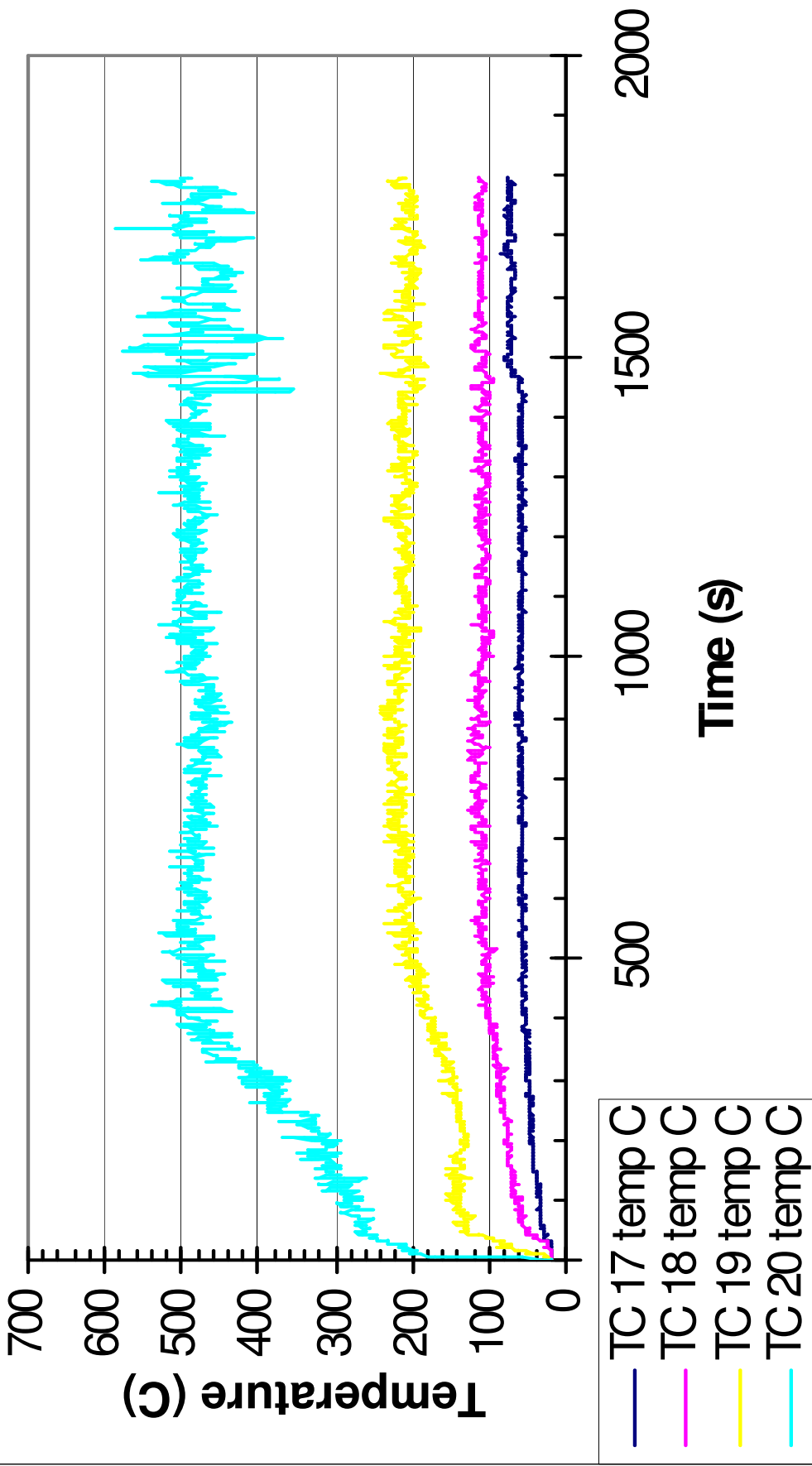
# Firefighting and Rescue Operations After Explosion



# Flammable Liquid and Aerosol Cans After Fire



# Temperature vs. Time at Location B



500 °C = 932 °F > Autoignition Temperature

