SMOKE DETECTOR PERFORMANCE FOR LEVEL CEILINGS WITH DEEP BEAMS AND DEEP BEAM POCKET CONFIGURATIONS

10th Fire Suppression & Detection Research Application Symposium

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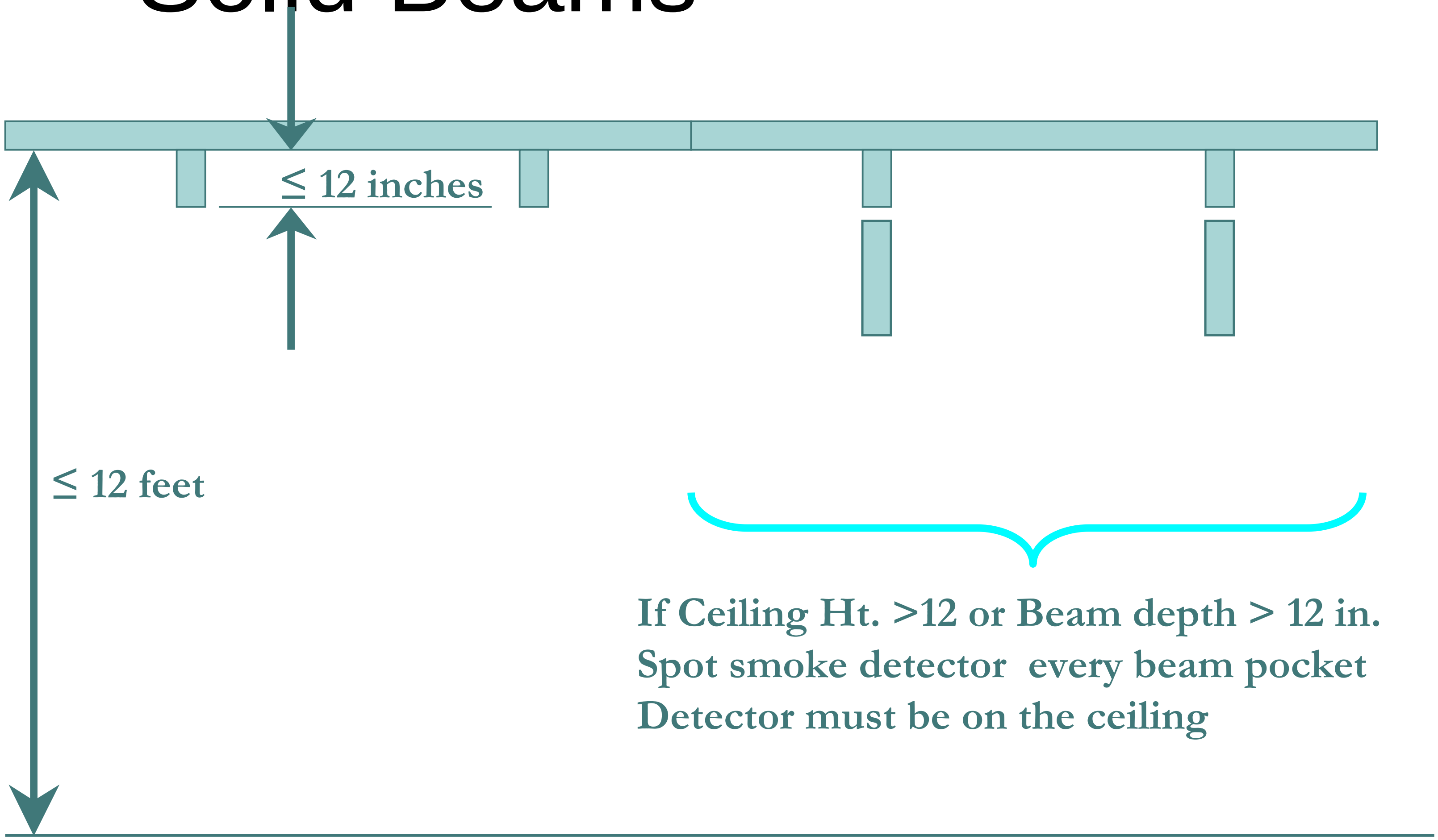
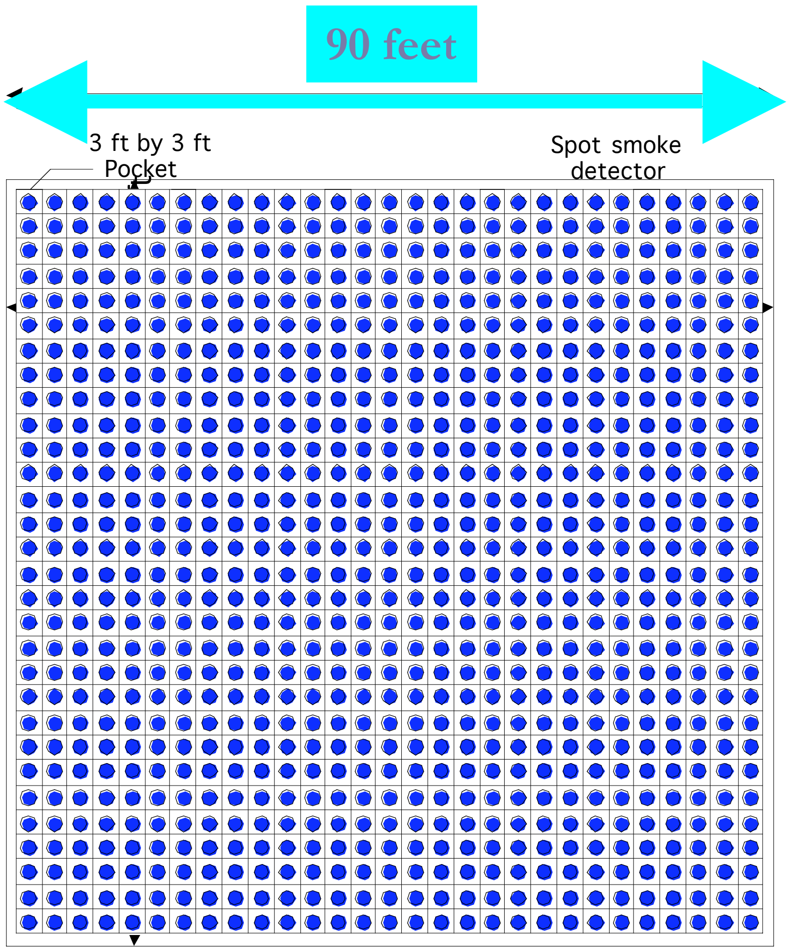
- Fire Detection and Alarm Research Council
- FPRF Appointed Project Technical Panel
- NFPA 72 Initiating Devices Committee

Current NFPA 72 Spot Smoke Detector Rules for Solid Beams

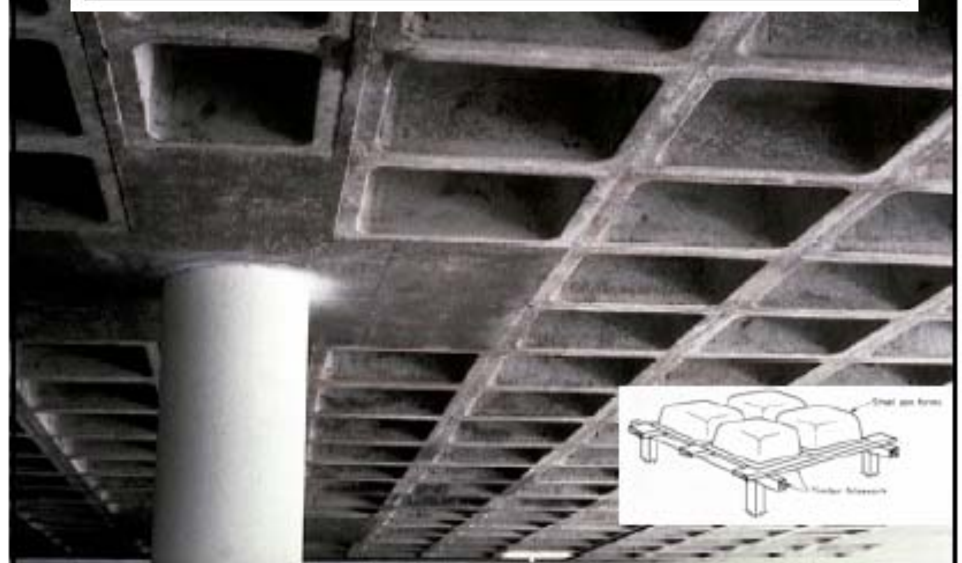


Parallel direction -30 ft. guideline
Perpendicular -15 ft spacing

Why Most Questioned Requirement




flat slab floor

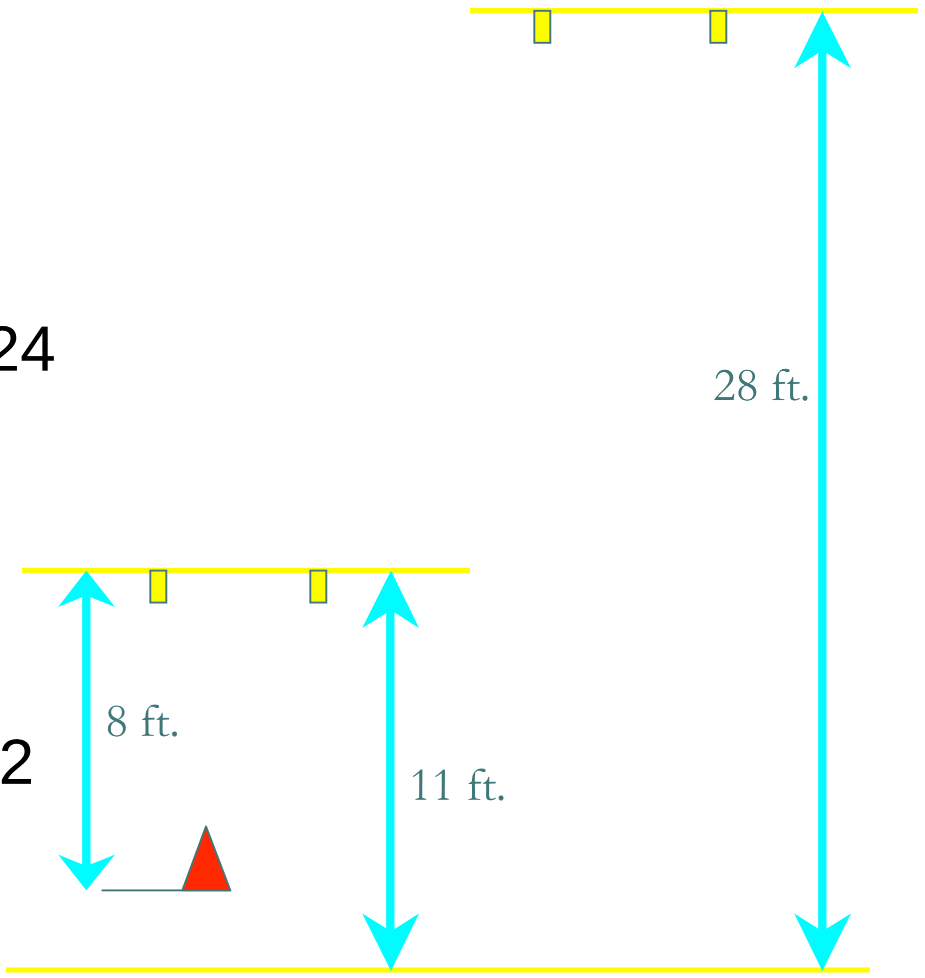

waffle slab floor

Review of Previous Work

- NFPRF Sponsored NIST's CFD work in 1993-94
- *International Fire Detection Research Project, Field Modeling: Effects of Flat Beamed Ceilings on Detector and Sprinkler Response; Technical Report Year 1, October 1993*
- Significant in identifying flow effects resulting from parallel channels due to beams
- Scope was limited, CFD modeling was computational intensive in early 1990's

Scenarios of 1993 Work

- Majority of Scenarios
  - 11 ft. ceiling
  - Fire to ceiling distance, constant at 8 ft.
  - Beam depths 0, 4, 8, 12, 24 inches
  - Beam spacing varied
- Few high ceiling scenarios
  - 28 ft. ceiling
  - Beam depth constant at 12 inches



Extract from 1993 Technical Report Year 1

- Activation – 13˚ C rise only
- Criteria for detector activation narrowly defined using a threshold fire size
  - Medium growth 100 kW fire
  - Medium growth 1 MW fire
- No comparison to the expectation of smoke detectors spaced per 30 foot guideline
- No understanding of how field conditions would change if examined 5, 10, 30 or 60 seconds later
- No review of gas velocities at smoke detector
- Most scenarios with parallel channels, no consideration for constraining effects of corridor walls or beam pockets

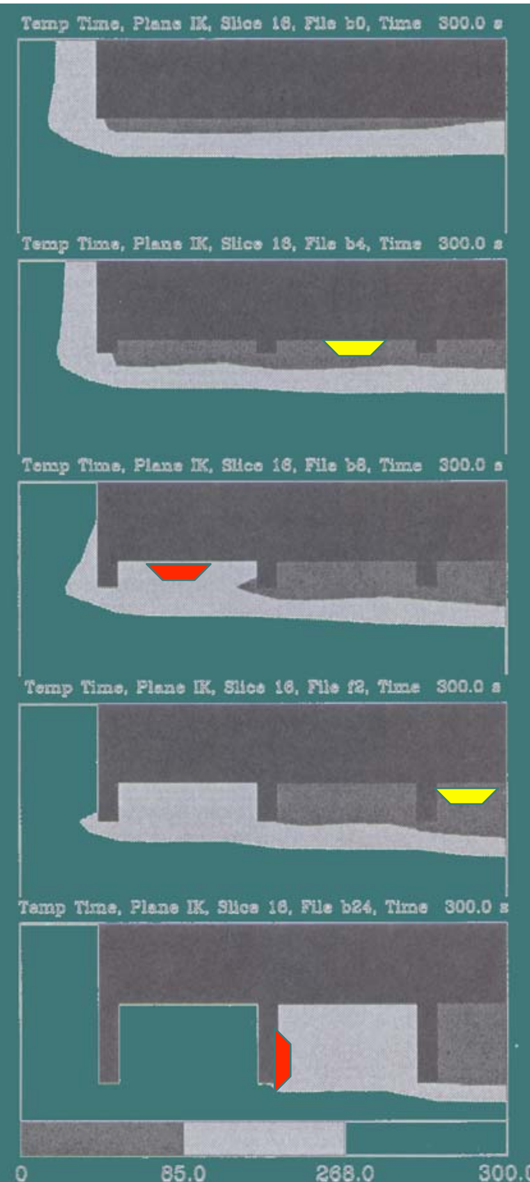


Figure 19: Shaded contour plot of smoke detector response volumes for various beam depths: 0.0 m (0 in), 0.10 m (4 in), 0.20 m (8 in), 0.30 m (12 in), 0.61 m (24 in)with 3.35 m (11 ft) ceiling height, 1.22 m (4 ft) beam spacingand medium fire. Dark and light grey denotes where a sensor activates before the fire reaches 100 kW and 1.0 MW respectively. White denotes where the sensor would not activate. Activation criteria: when the gas temperature rises 13°*C* above ambient.

Objectives - Methodology

- Identify appropriate spot smoke detector activation thresholds
  - Optical density
  - Temperature rise
  - Flow velocity
  - Best Source for data on thresholds - Recent work by Geiman (Masters thesis) and Geiman & Gottuk (paper in Fire Safety Science)
- Identify baseline detector performance
  - 30 ft x 30 ft spacing on unconfined flat ceiling
  - Vary performance with increasing height
- Perform modeling & examine field conditions
  - At postulated smoke detector locations
  - Determine likelihood that field conditions would result in activation
- Compare postulated detectors with
  - Baseline detector performance
  - Spot detector activation thresholds
- Reduce the data to usable format – results, trends, conclusions

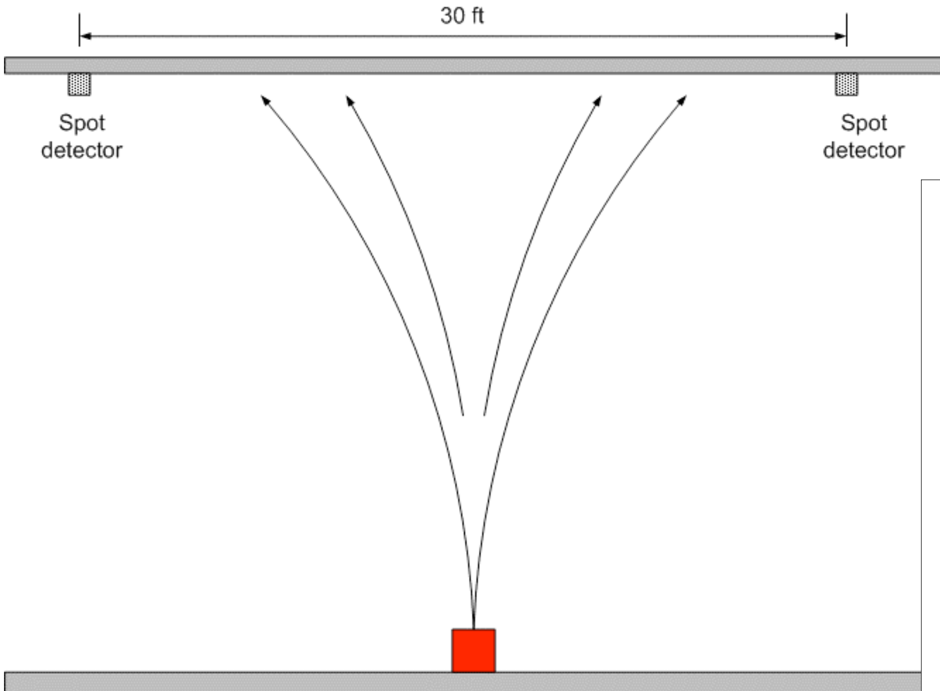
Review of Work by Geiman and Geiman & Gottuk – Flaming Fires Only

	Predicted Alarms	*Over & under Predictions*	*Alarms within ± 60 seconds*	*Evaluation for Beam Study*
Nominal Sensitivity per UL 217/268 ~ 1- 3% Obs/ft ~.014 - .043 OD/m	High % predicted	3:2 ratio over : under	30-40 %	Not sufficiently conservative
Max. Black Smoke OD 10% Obs/ft 0.14 OD/m (closer to 0.15)	30%	Almost all over-predictions +1000 % -2000% error	<10%	Too conservative, unrealistic view of detector performance for flaming fires
20th percentile Average OD Alarm Threshold 0.007 ± OD/m (ion) 0.031 ± OD/m (photo)	High % predicted	Majority under-predicted	63% ion 49% photo	Under- prediction not suitable for code requirement study
80th percentile Average OD Alarm Threshold 0.072 ± OD/m (ion) 0.106 ± OD/m (photo)	Fewer predictions than 20th percentile Average OD Alarm Threshold	More over-predictions than 20th percentile Average OD Alarm Threshold		Tendency for over prediction suitable for code requirement study, but not overly conservative as 0.14 OD/m

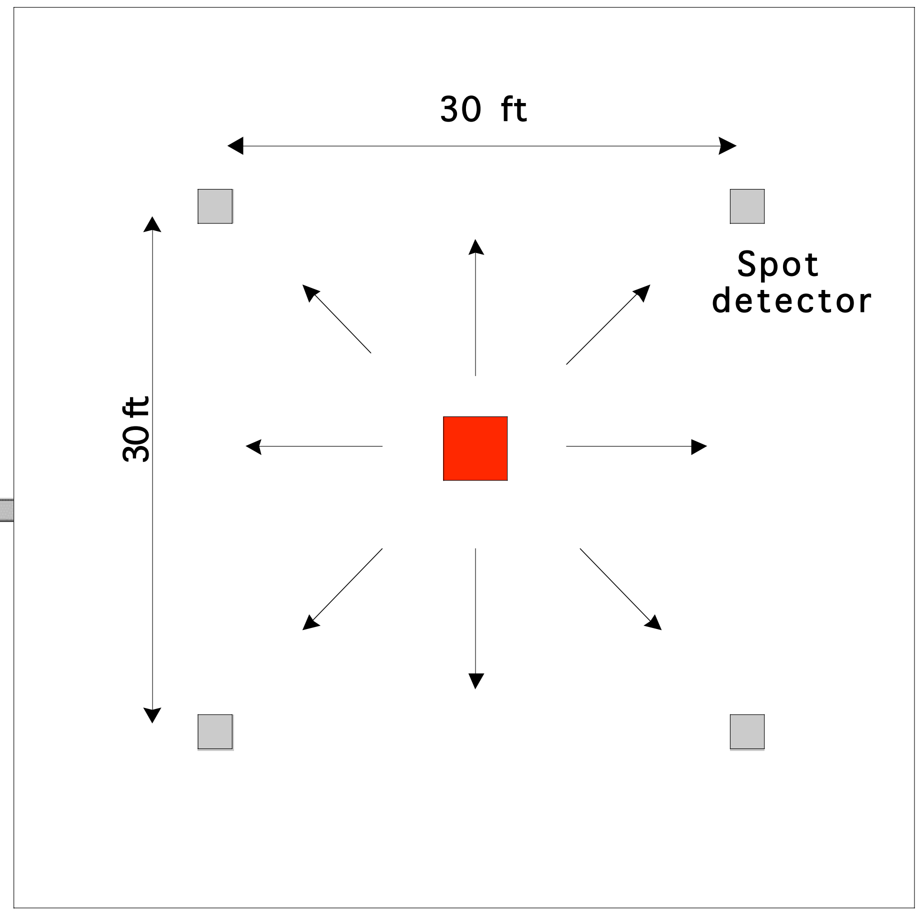
Review of Work by Geiman and Geiman & Gottuk – Flaming Fires Only

	Predicted Alarms	*Over & under Predictions*	*Alarms within ± 60 seconds*	*Evaluation for Beam Study*
4 degrees C Temperature Rise	100 % predicted	4:1 over/under –ion 1: 3 over/under –photo	57% ion 30% photo	representative of a conservative threshold for ionization detection
13 degrees C Temperature Rise	90%	Ion vast majority over-predictions Photo 1:1	Very few	representative of the typical photoelectric detector
Flow Velocity 0.15 m/s Mean 0.13 ± 0.07 m/s (from GG data review)	100% predicted	Slight over-predicted	~ 40 %	Use mean value to review velocity field conditions to be assured of sufficient velocity at for smoke entry into detector
80th percentile Average OD Alarm Threshold 0.072 ± OD/m (ion) 0.106 ± OD/m (photo)	Fewer predictions than 20th percentile Average OD Alarm Threshold	More over-predictions than 20th percentile Average OD Alarm Threshold		Tendency for over prediction suitable for code requirement study, but not overly conservative as 0.14 OD/m

Baseline – 30 ft. Guideline Spacing

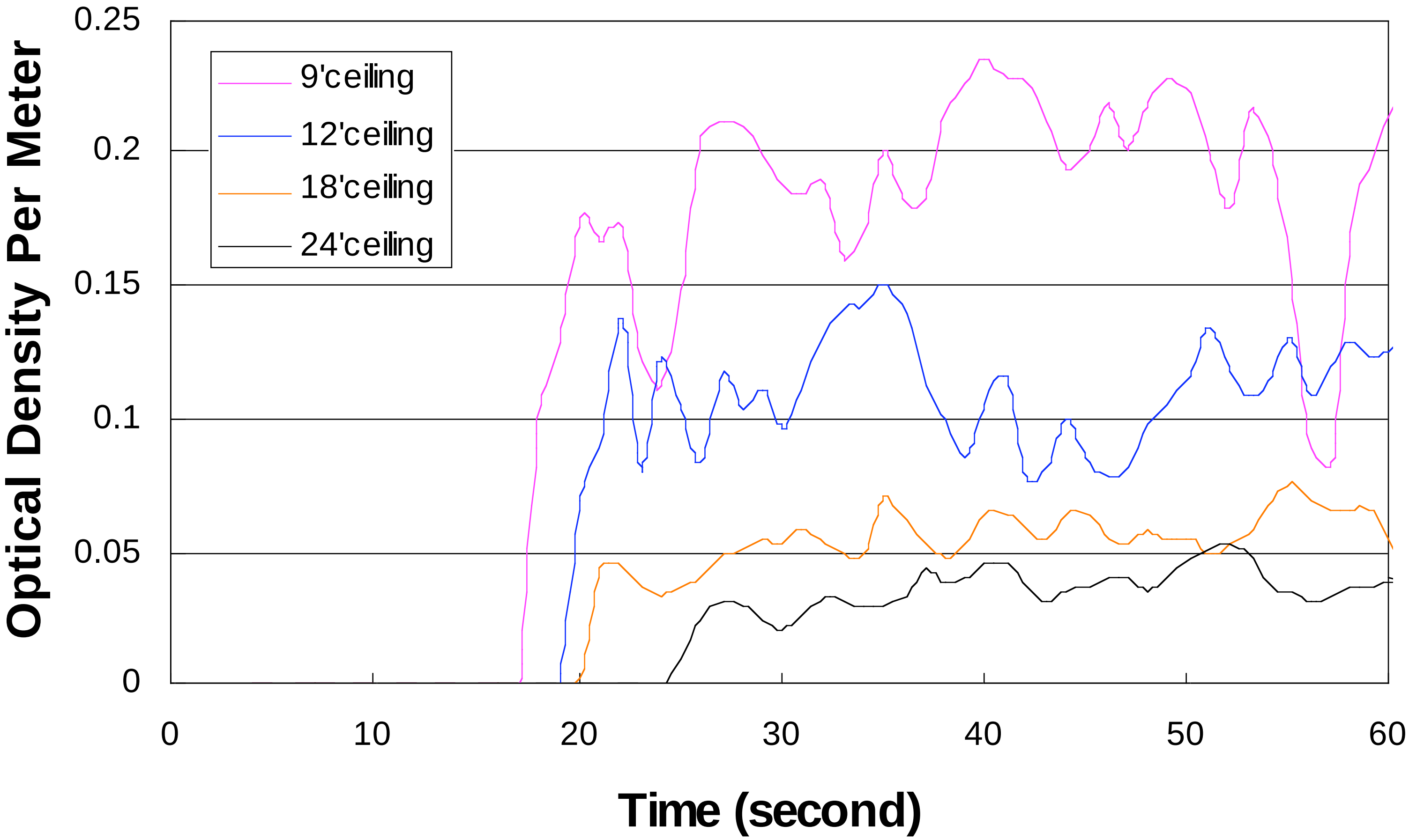


Elevation View



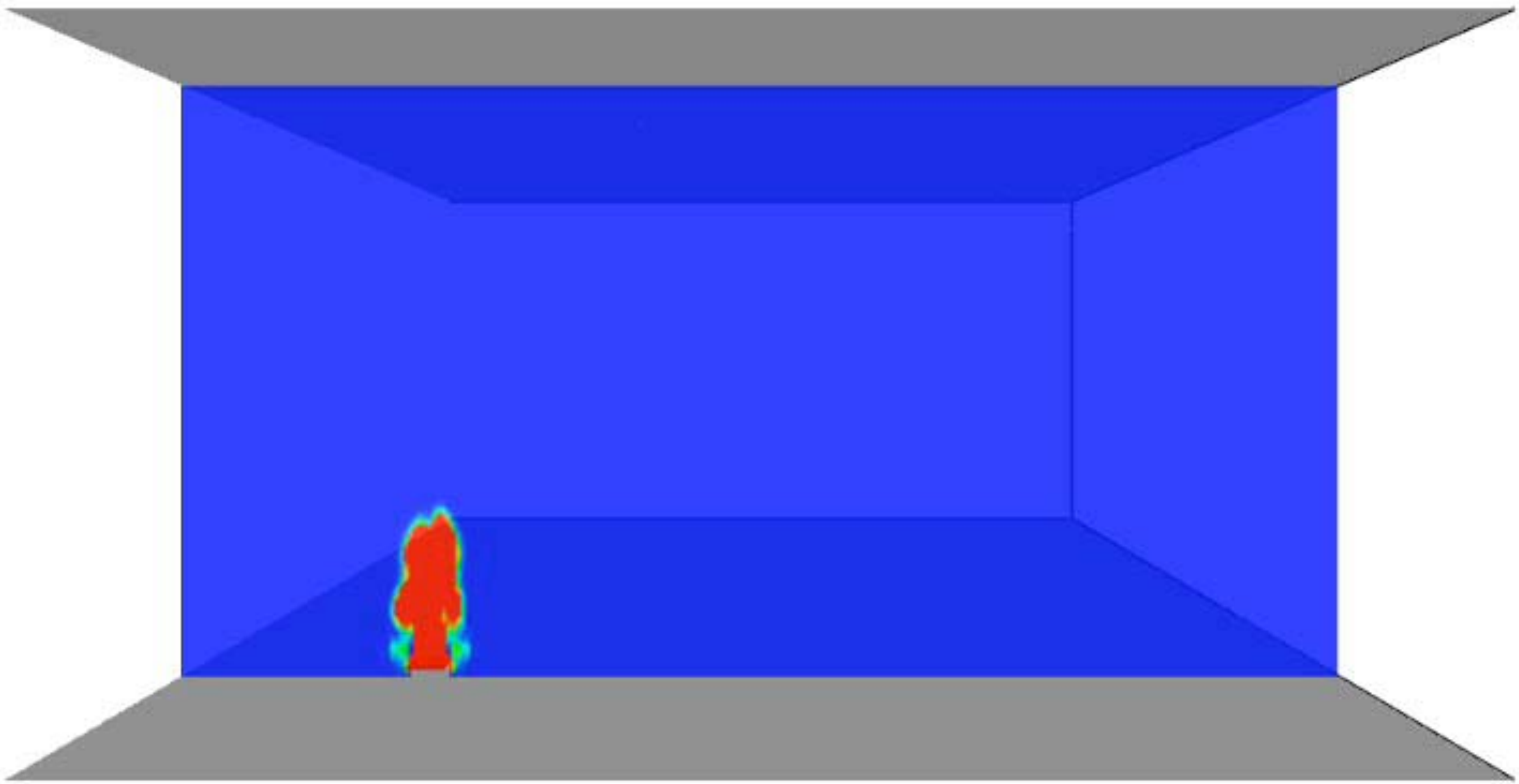
Plan View

Baseline – 30 ft. Guideline Spacing

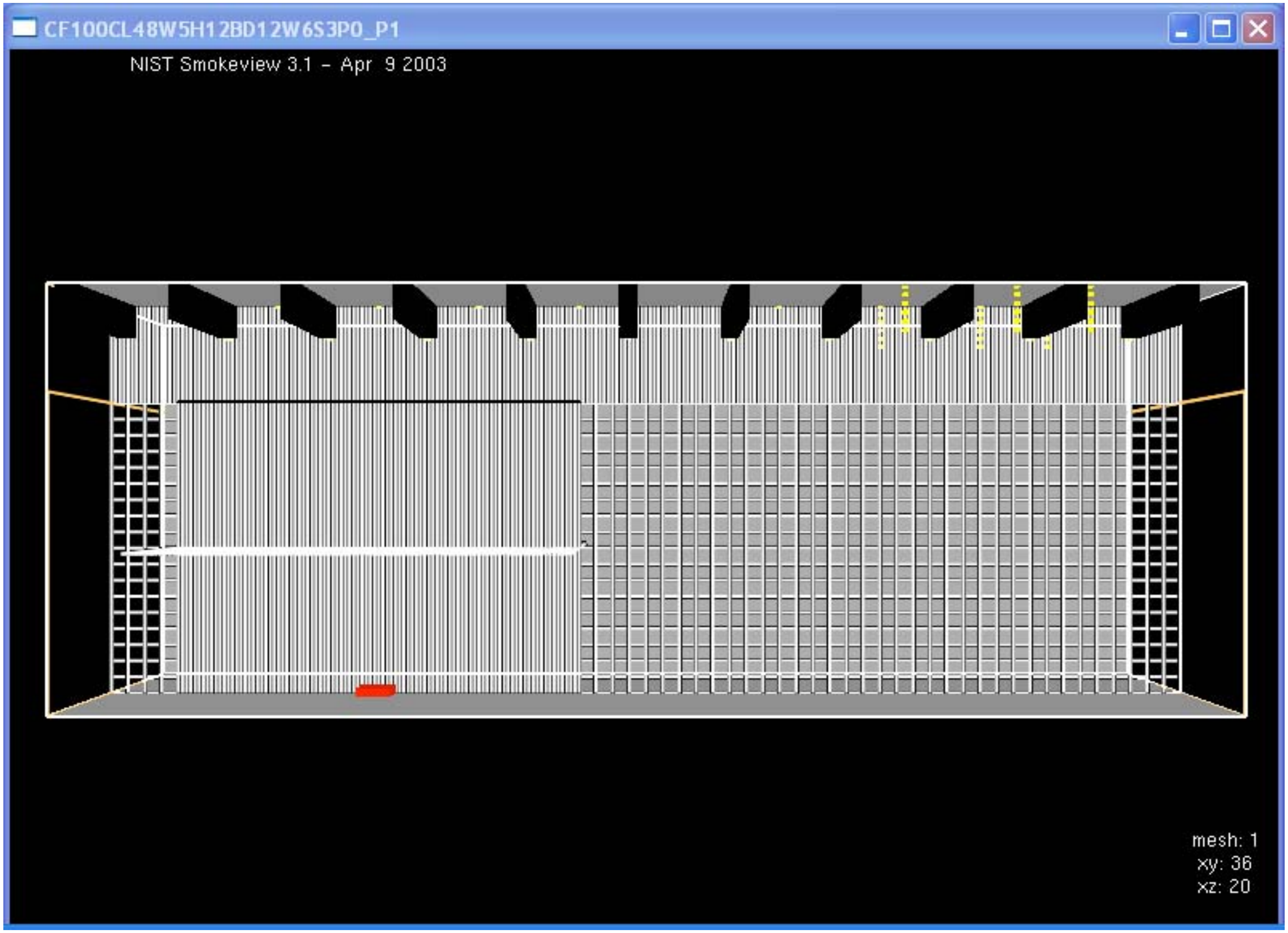


Baseline Ceiling Jet Development

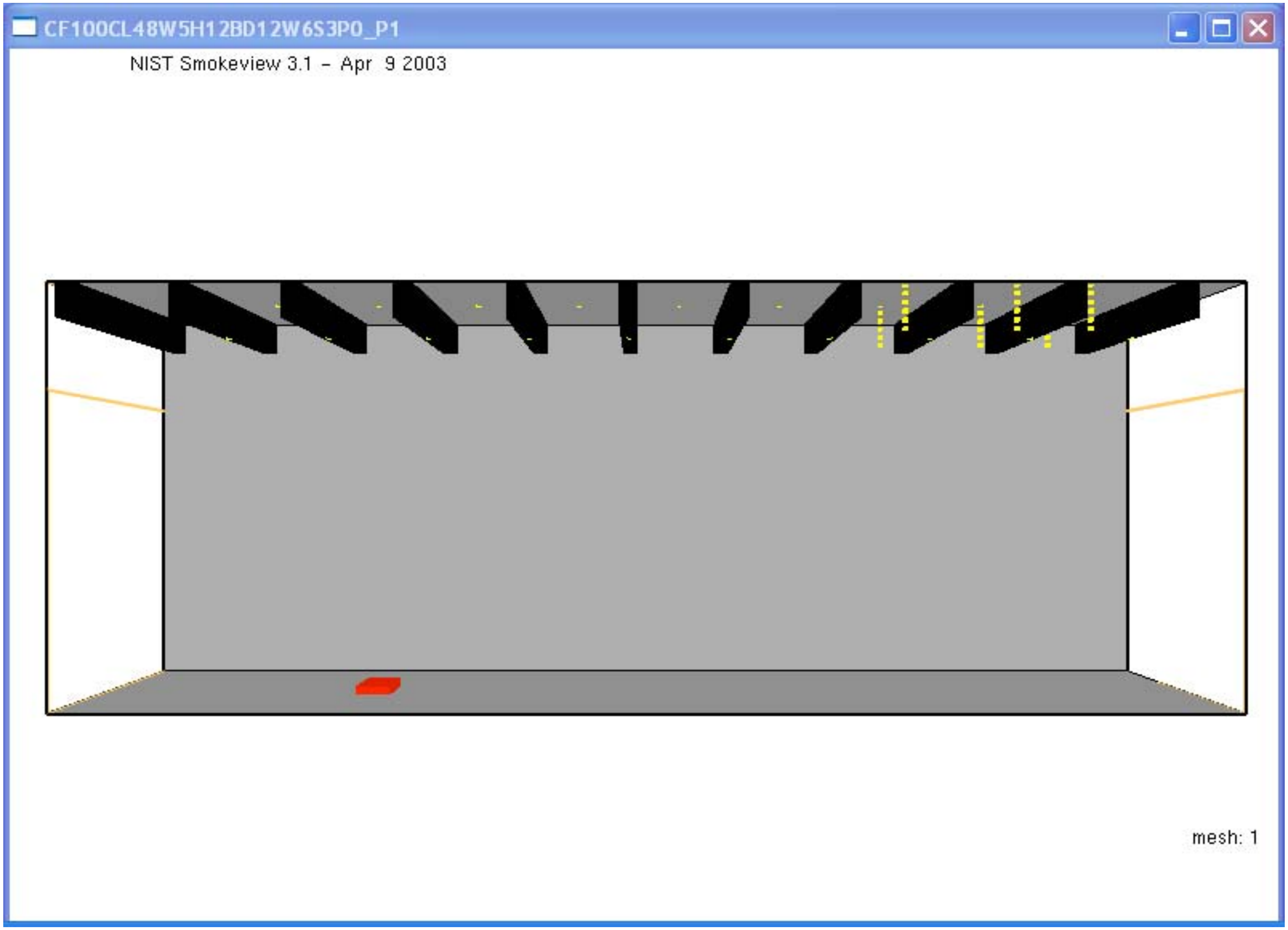
12 ft Ceiling Ht., Red ≥65˚ C , Green ~ 40˚ C



CFD Grid System

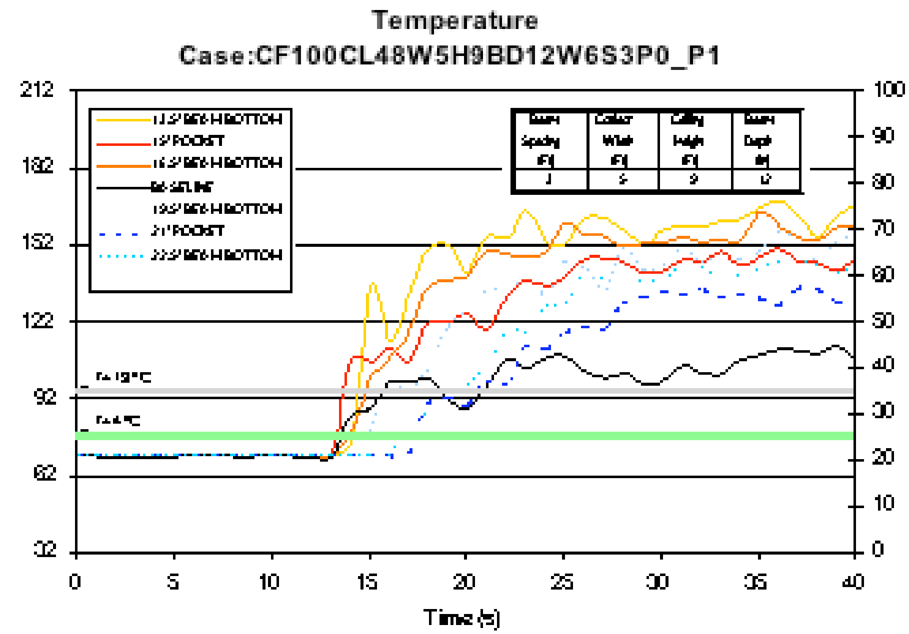


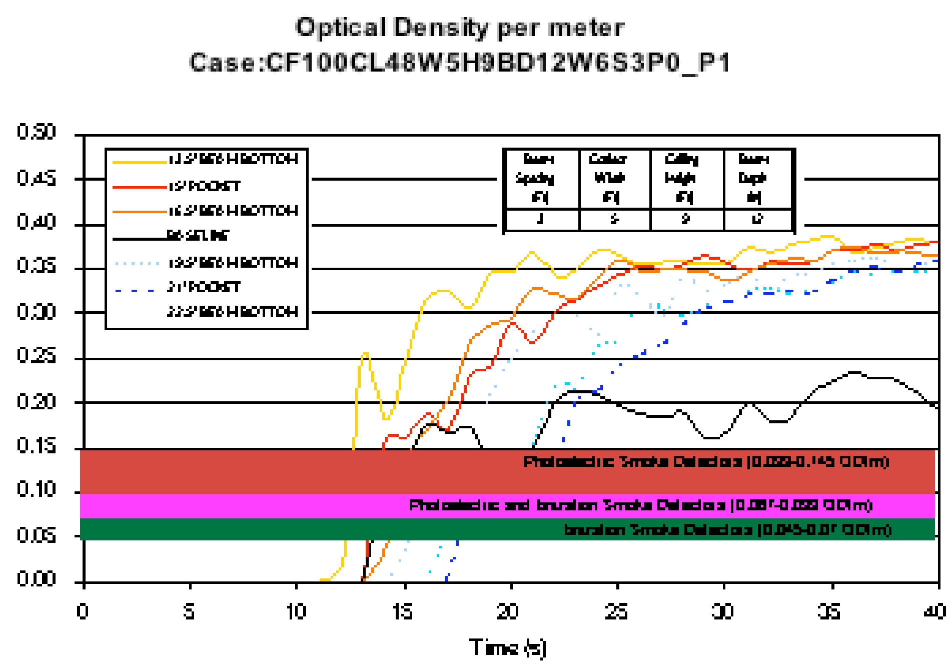
Measurment Points



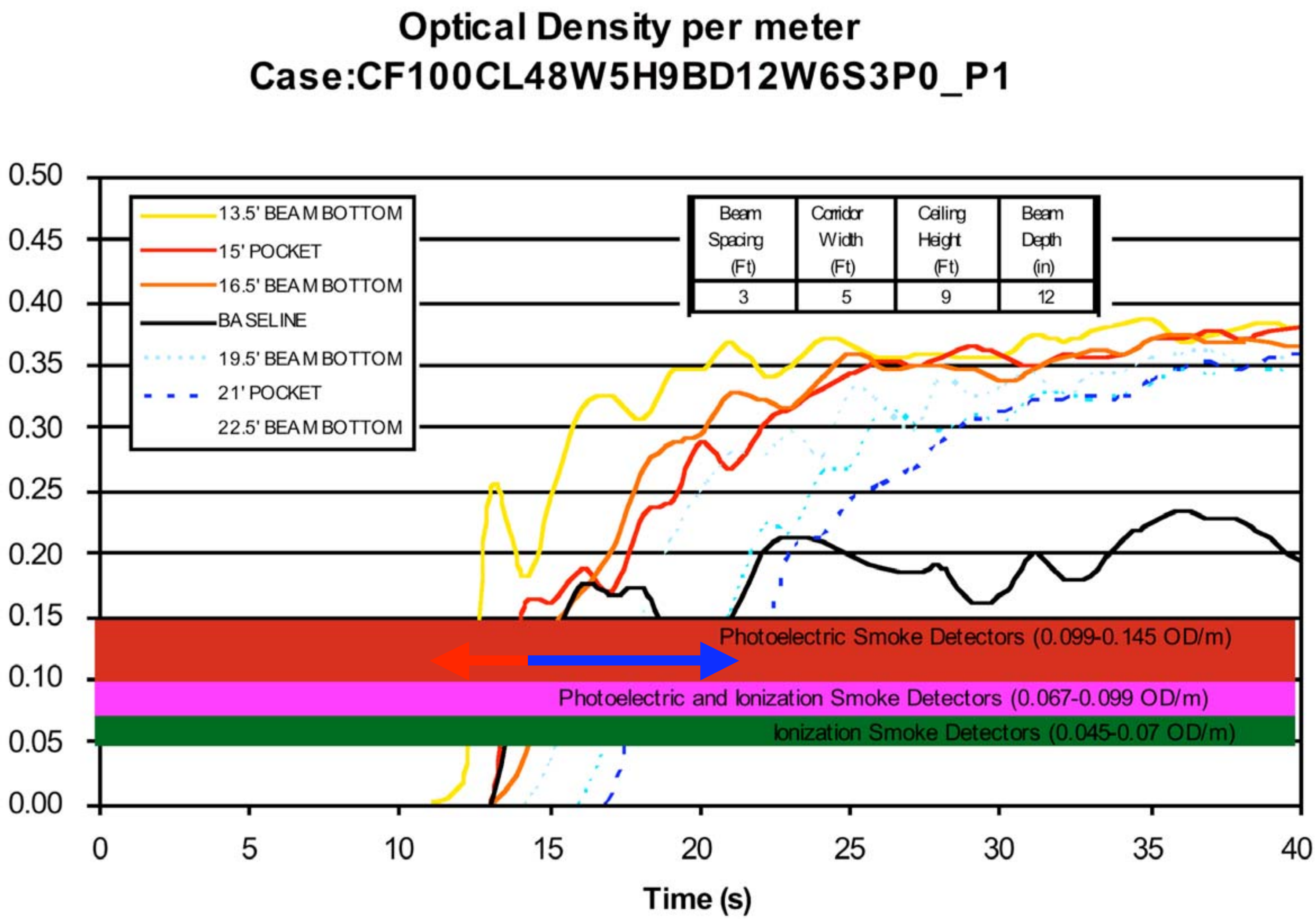
Corridor Scenario 2

- In this scenario 12 inch deep beams interrupt the ceiling surface every 3 feet. Temperature rise exceeds the threshold of 13ºC and 4ºC during an early time frame and all locations exceed that of the baseline detector. Optical density exceeds that of the baseline for all detector locations. Detector locations within pocket or on the bottom of the beam experience comparable optical density valu



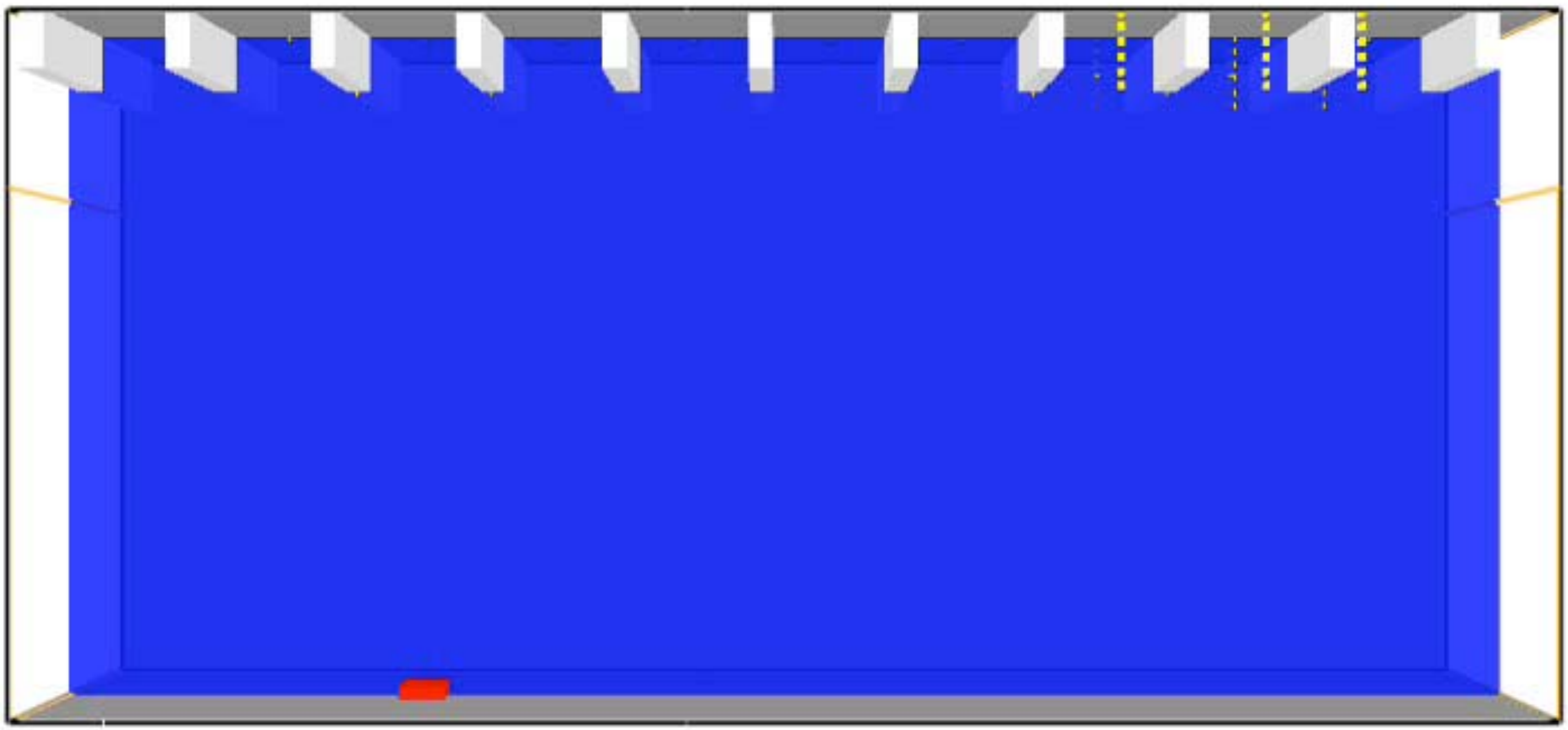


Time Shift – Δt Relative to Baseline



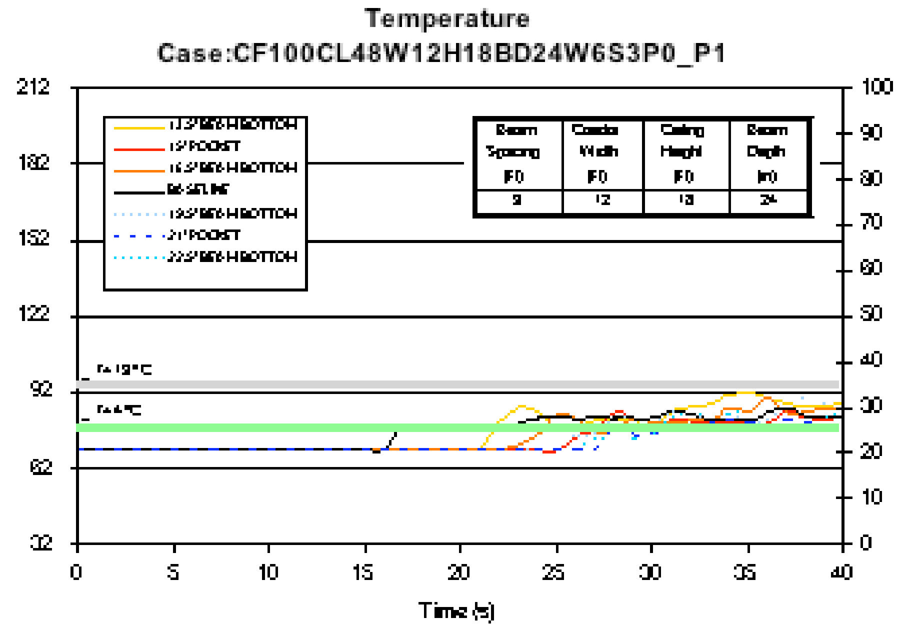
Corridor Ceiling Jet Development

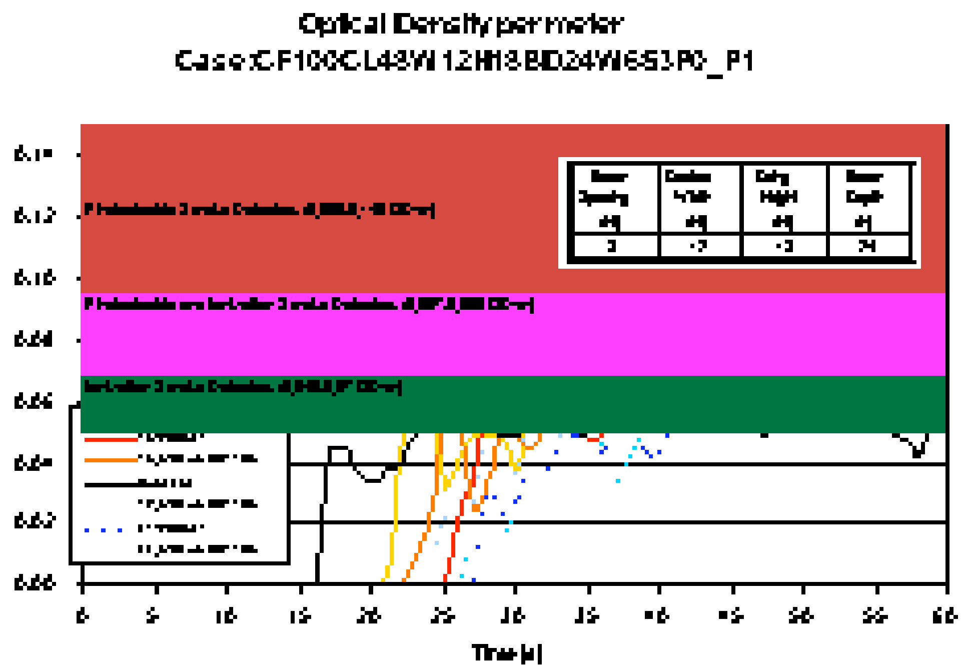
12 ft Ceiling Ht Width 5 ft Beam Depth 12 in - Red >65° C Green ~



Corridor Scenario 1

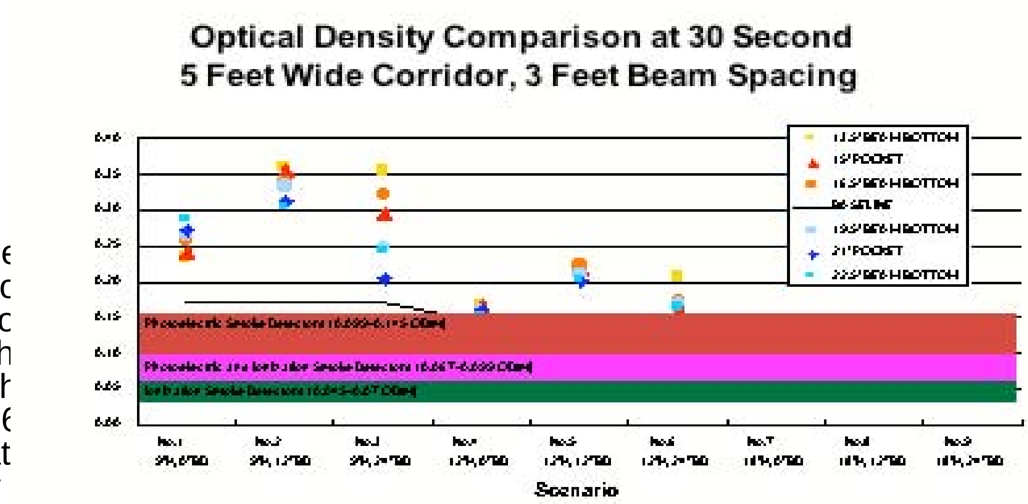
- : In this scenario 24 inch deep beams interrupt the ceiling surface every 3 feet. Introducing a 24” beam at the 18 ft ceiling height shifts the baseline 15 to 20 seconds before the noted detector locations. However, all detector locations relatively quickly exceed the temperature rise and optical density values observed for the baseline

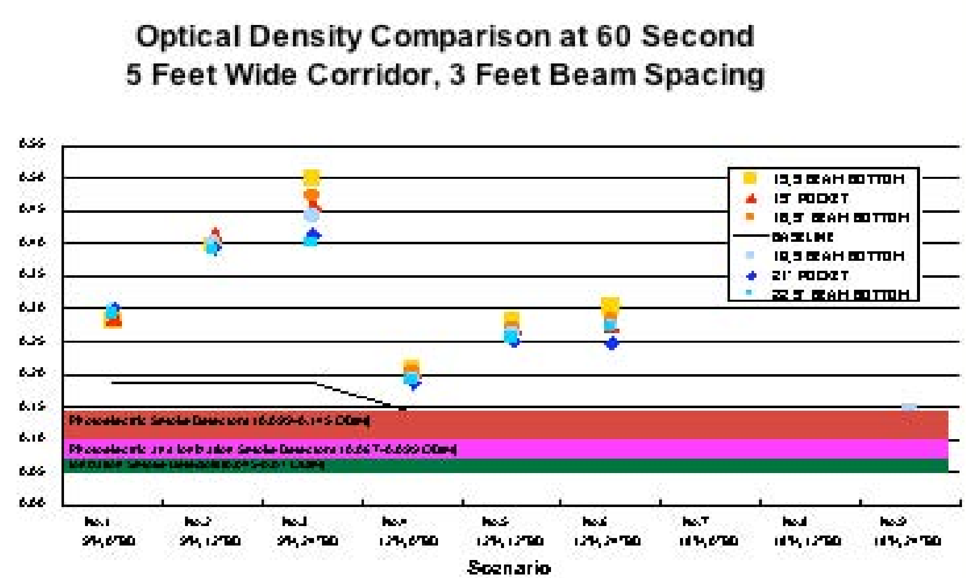




Trends Shown

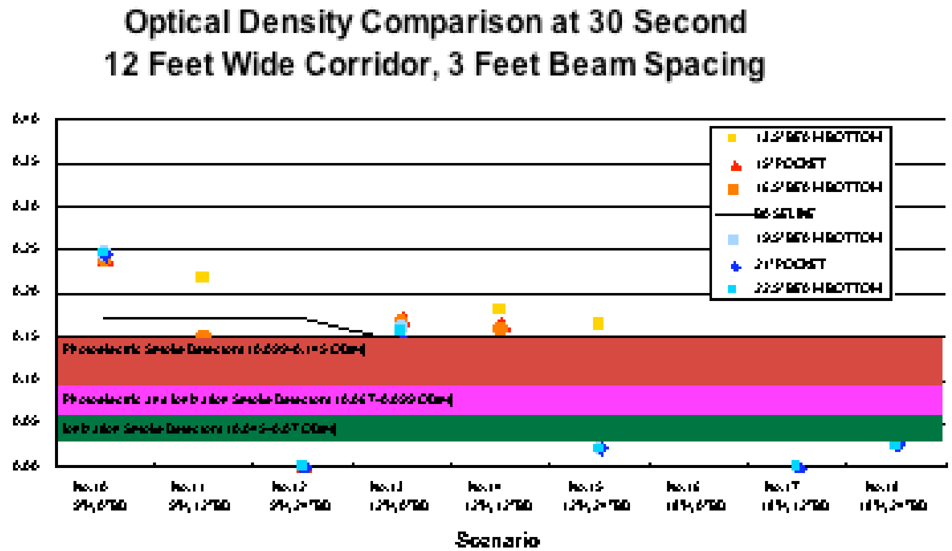
- For a 5 ft wide corridor, the
optical density at all locatic
along corridor reaches intc
blue range and exceeds th
baseline in 30 seconds. Th
comparison graph for the 6
second time frame illustrat
trends resulting as steady
conditions are reached. A
seconds for any given ceili
height grouping the genera
trend is that optical density
values tend to increase as
depth increases. This is
attributable to a reservoir e
that allows soot concentrat
build in the deep beam poc
As ceiling height groupings
data are reviewed left to ri
(from 9 ft to 18 ft) the trenc
that optical density values
reducing in value due to th
additional entrainment into
plume that results with
increasing ceiling height. I
cases shown it is evident t
60 seconds all postulate
detector locations would b
expected to alarm and exceed
value for the baseline case

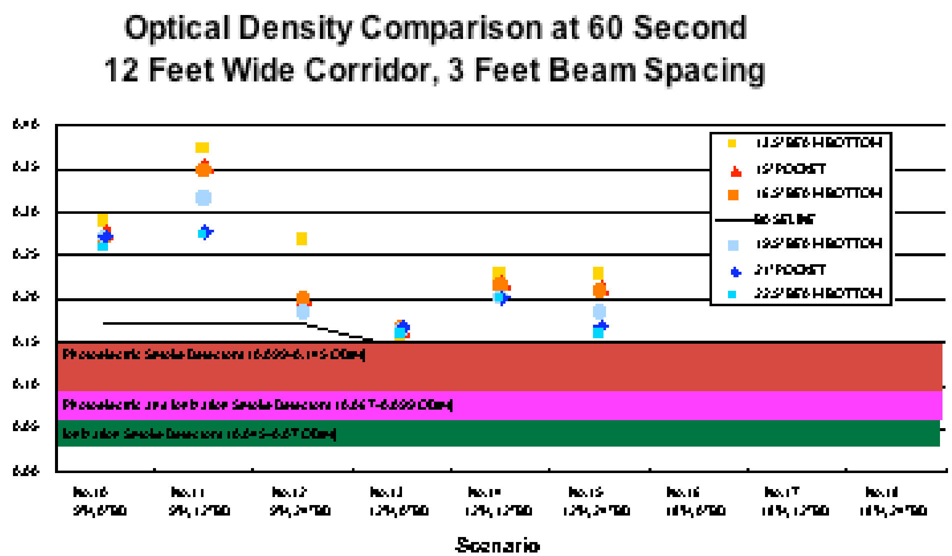




Trends Shown

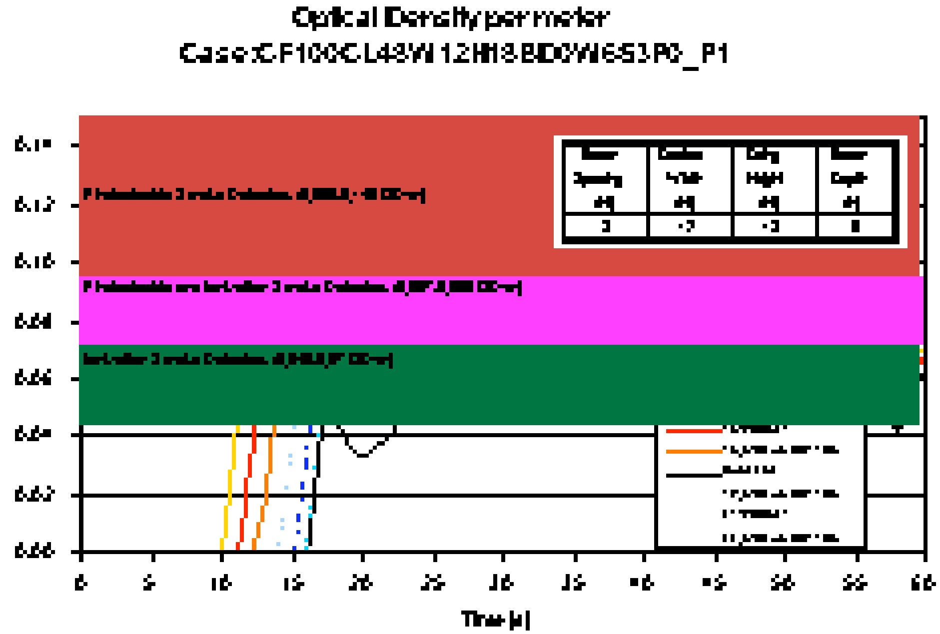
- For a 12 ft wide corridor, the optica density at all locations along corridor reaches in the green range ar exceeds the base line in most cases 60 seconds. Some turbulence impacts are observed at ea time frame (30 seconds). Also Optical density val shows more entrainment and dilution results in tl

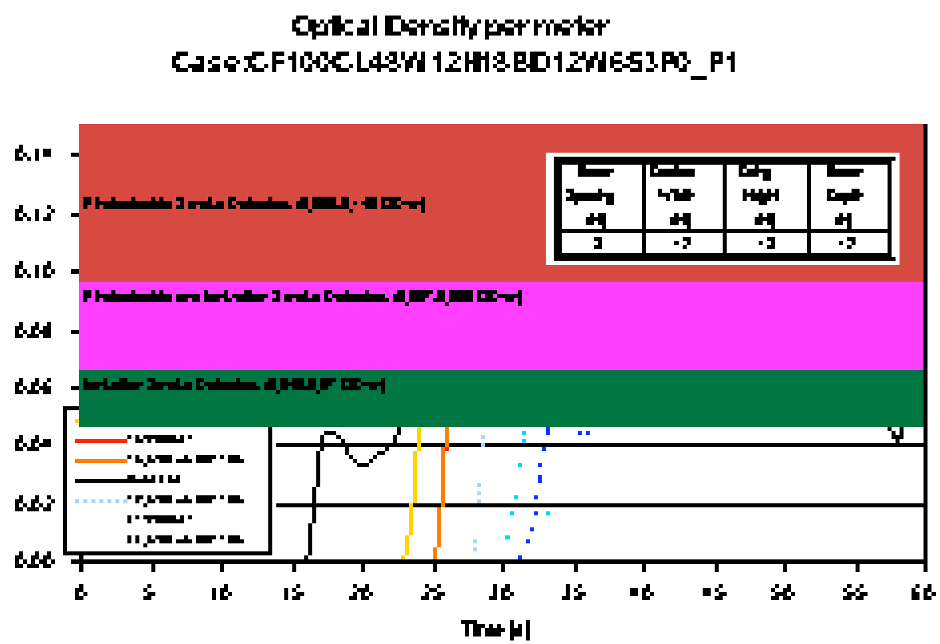




Reservoir Effect – ncreases OD

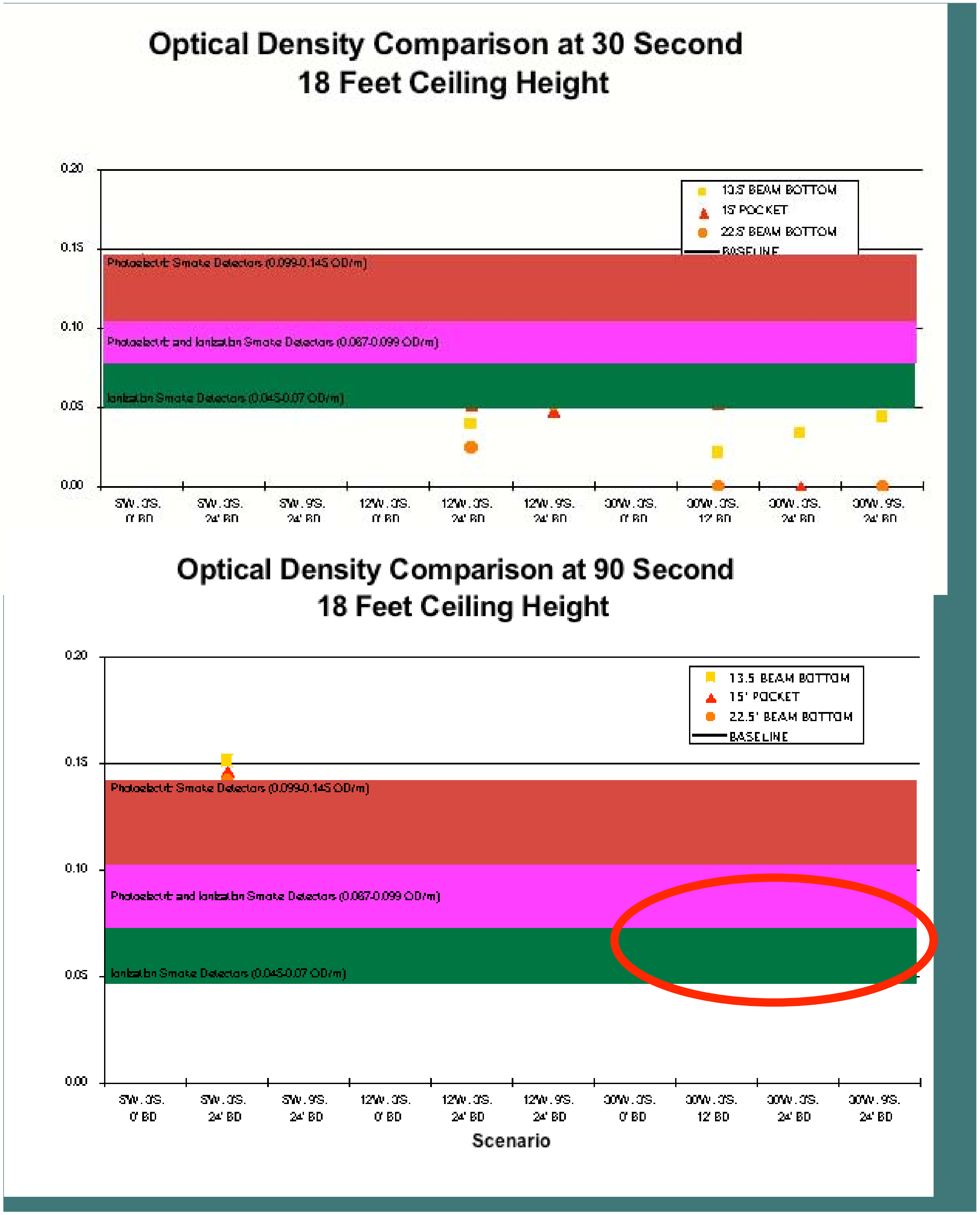
- Top Graph
  - Corridor Smooth Ceiling
  - OD rise earlier than unconfined smooth ceiling baseline
- Bottom Graph
  - 12 in. beams delay transport 10-15 sec.
  - OD rise readily surpasses baseline





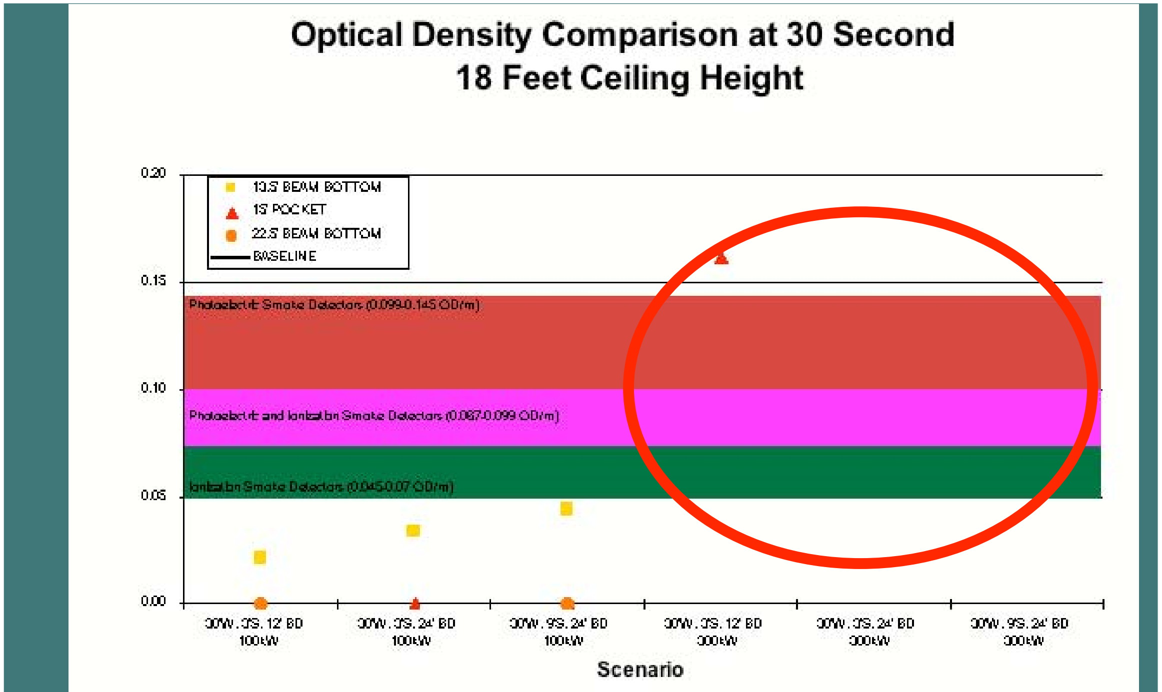
Beam Effect Diminishes at 30 ft. Corridor Width with 18 ft. Height

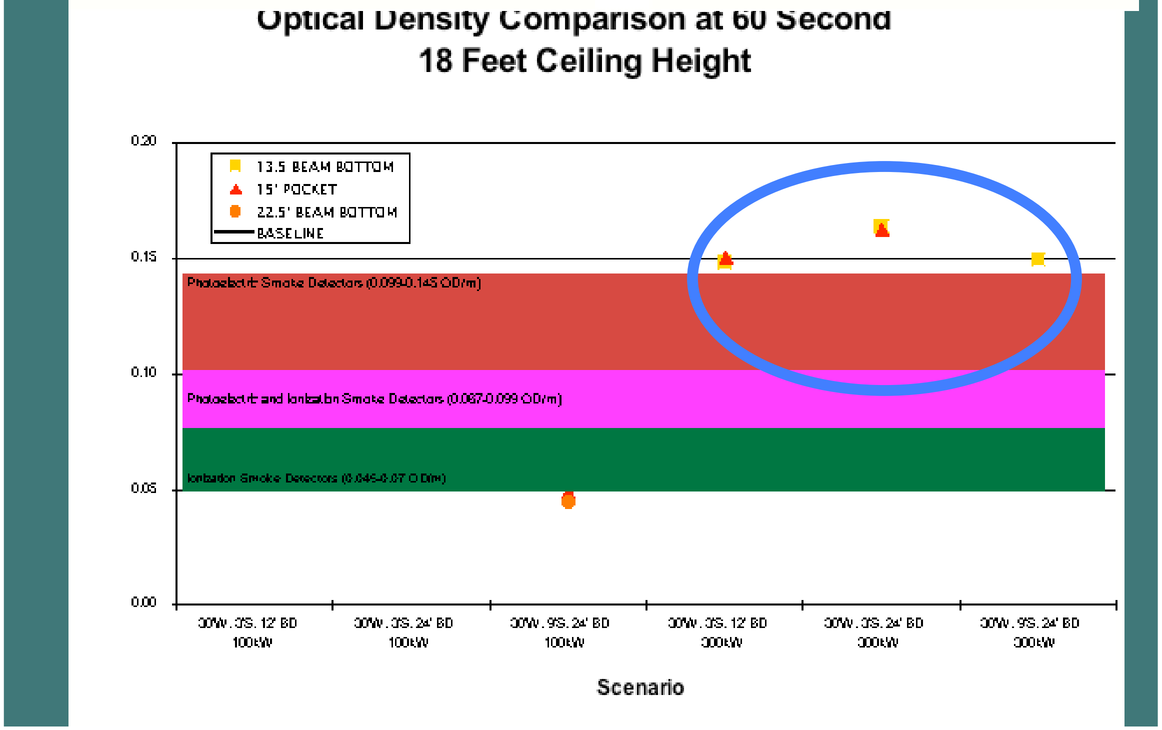
- For 100kW fire result is comparable to baseline
- Expectation for alarm of baseline detector and postulated detectors with 30 ft. corridor width is low



Fire Size Key To Detection for Increasing Ceiling Heights

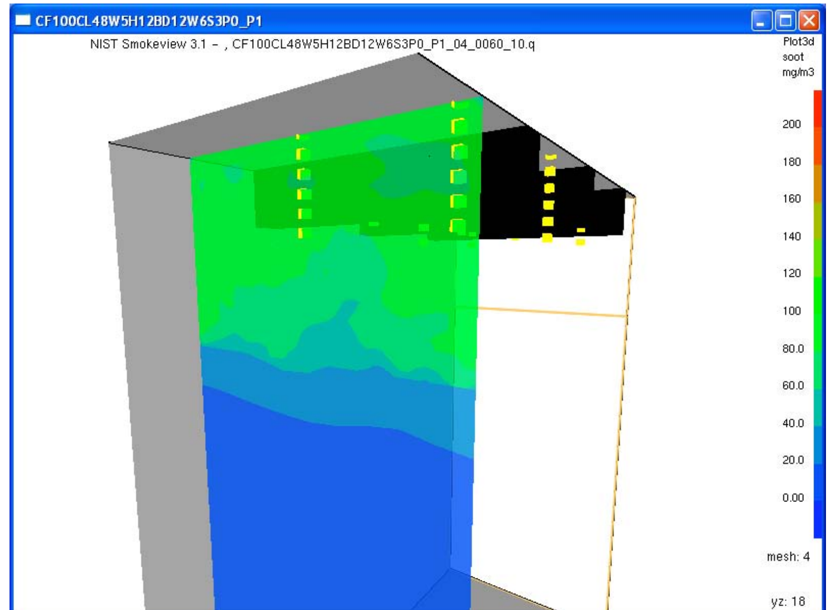
- For 100kW fire result is comparable to baseline
- Circled data is result for 300 kW fire
- An increased fire size results in relatively fast rise in OD to levels of expected alarm

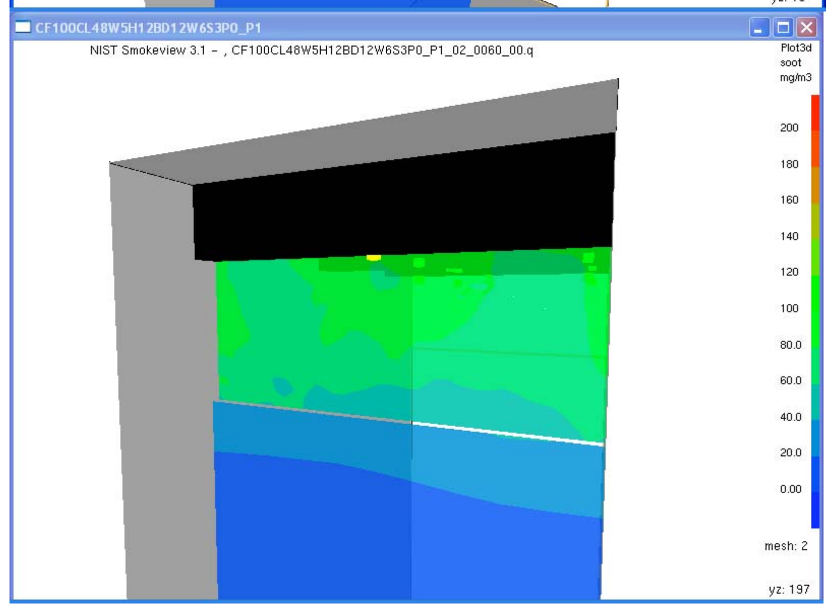




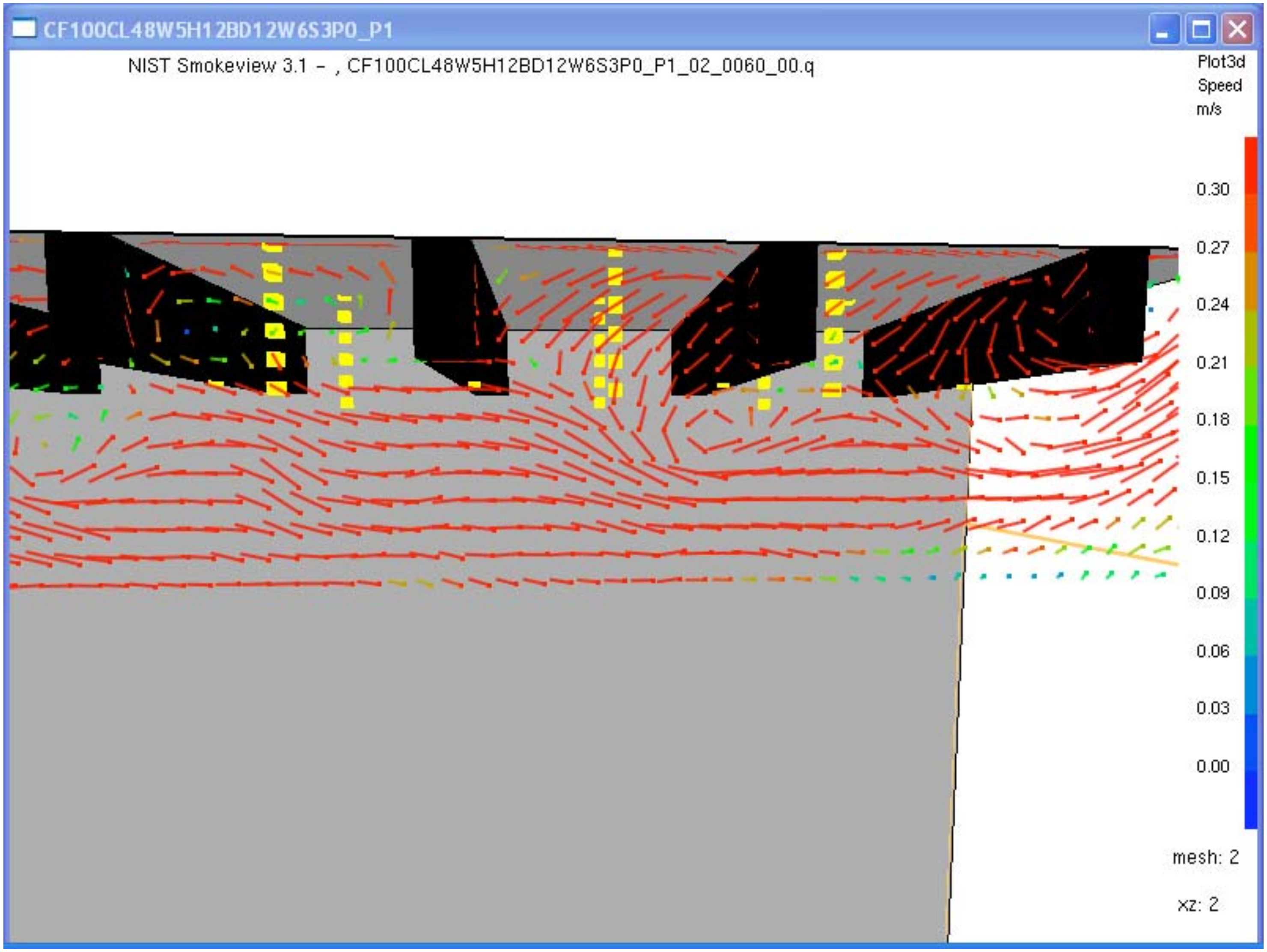
Optical Density – Well Mixed

- These graphics show the traversal soot density distribution at 15’ and 16.5’ from fire, at 60 seconds. The results show that the spaces inside the beam pocket and near the bottom of the beam have comparable soot density gradient. No stagnant zone is observed near the sidewall or at the corners

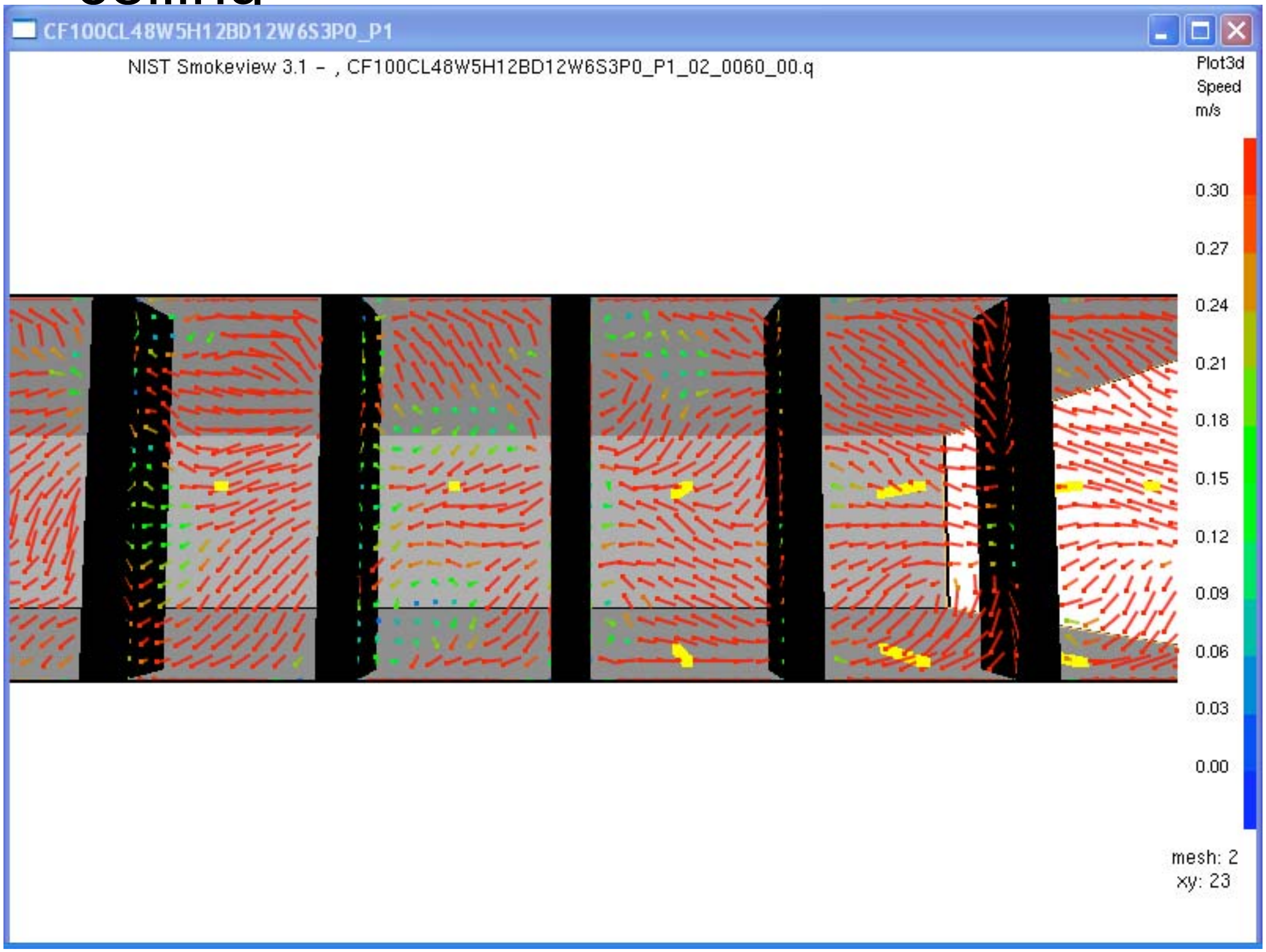




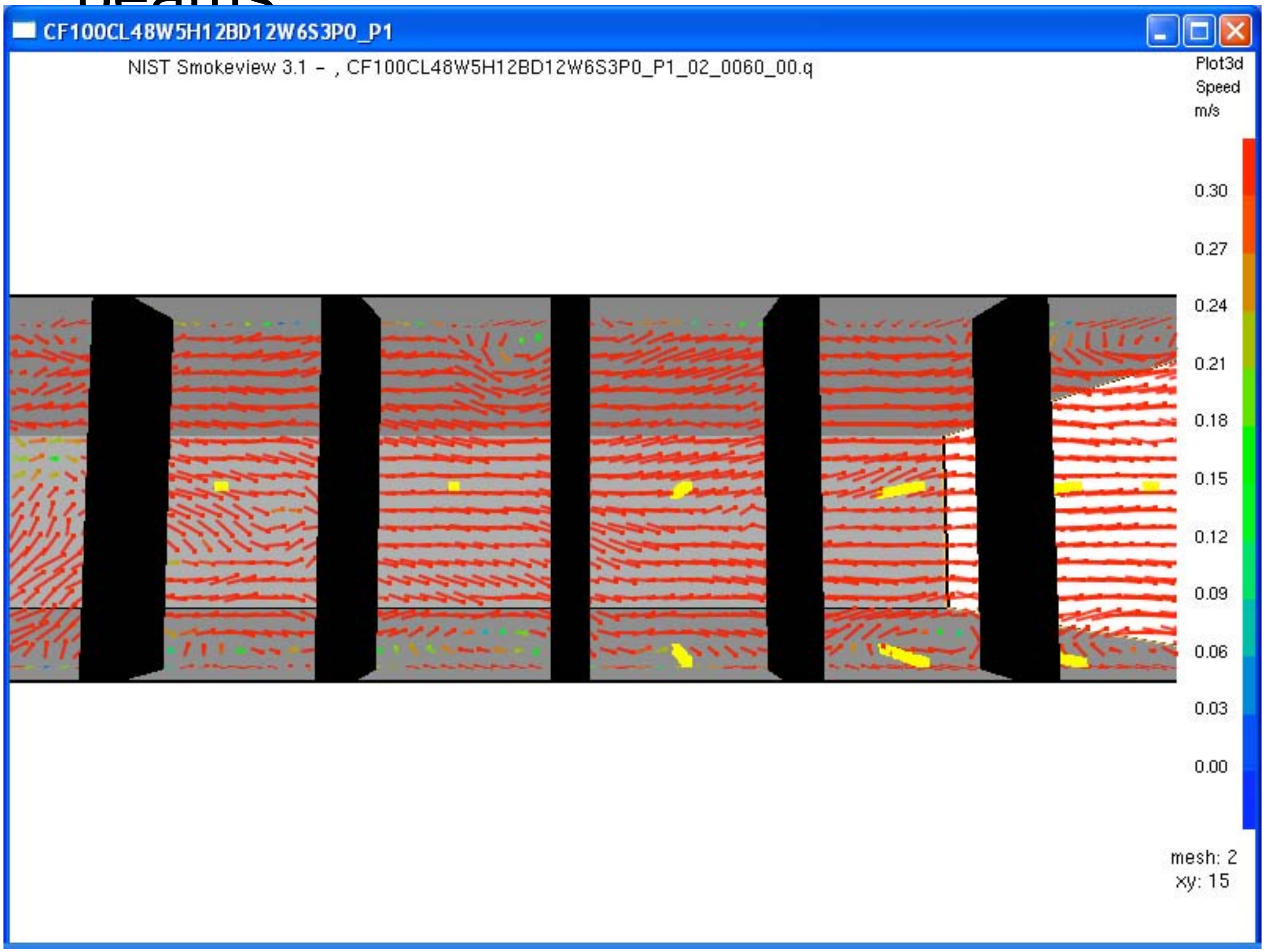
Velocity - (Ceiling Height 12’, Corridor Width 5’, Beam Depth 12”) - 1.5” off wall



Velocity - (Ceiling Height 12', Corridor Width 5', Beam Depth 12") - 1.5" below ceiling



Velocity - (Ceiling Height 12', Corridor Width 5', Beam Depth 12") - 1.5" below beams



Corridor - Basic Findings

- **Linear Spacing of Smoke Detection**
  - The data observed in this analysis indicates that for ceilings up to 18 feet in height, that deep beam configurations do not negatively affect expected performance. Reservoir effect contributes to beneficial rise in OD as compared to smooth ceiling scenarios. This means that for these conditions, detector can be effectively used in corridor with deep beams at spaces of 30 to 41 feet as is permitted for smooth ceilings
- **Increasing Ceiling Heights**
  - As ceiling height increases the fire size threshold needed for activation of the baseline spot smoke detector must increase. With an increased fire size the smoke detectors on a beam ceiling will be comparable to the performance result for the baseline detector at the same ceiling height.
- **Location Under Beams/On Ceiling Between Beams**
  - Where deep beams interrupt the ceiling surface in a corridor, mounting the detector on the ceiling between beams or the bottom of the beam is acceptable, either location providing comparable response to alarm
- **Sidewall Mount or Center of Corridor**
  - Keeping smoke detector locations 12 inches below or away from a ceiling-wall corner appears unsubstantiated. No stagnant zone or locations are observed that would preclude smoke detector alarm. Temperature and smoke optical density are relatively uniform and well-mixed throughout the volume of the beam pocket within seconds after the initial ceiling jet passes

Beam Pocket Scenarios

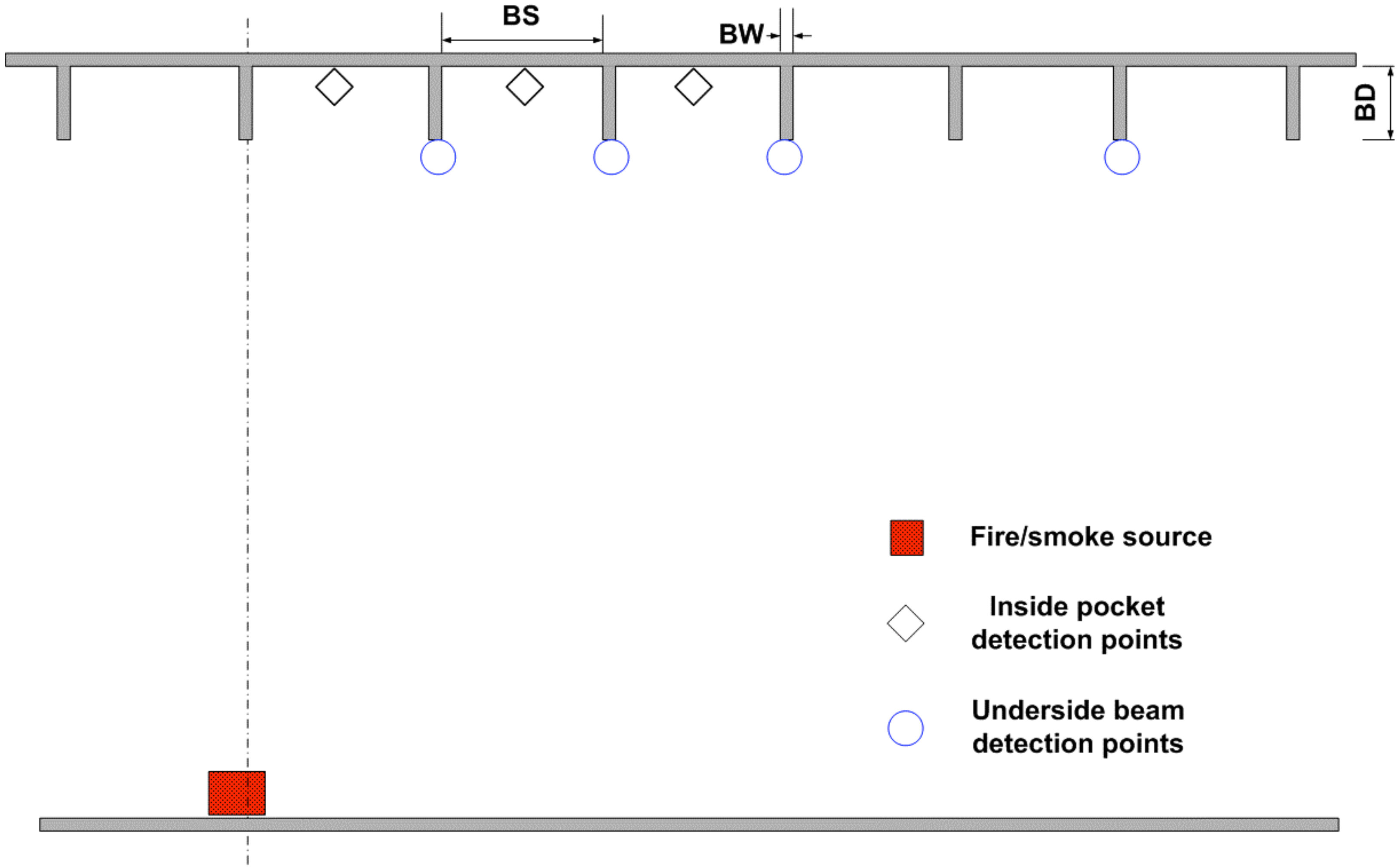
Small rooms:
- Pocket size 3x3, 6x6, 12x12 ft, and
- Beam depth of 0 (as baseline), 12, 24 inches, with
- Ceiling heights of 12, 18, and 24 feet

Large rooms:
- Pocket size 3x3, 6x6, 12x12 ft, and
- Beam depth of 0 (as baseline), 12 inches, with
- Ceiling heights of 36 feet

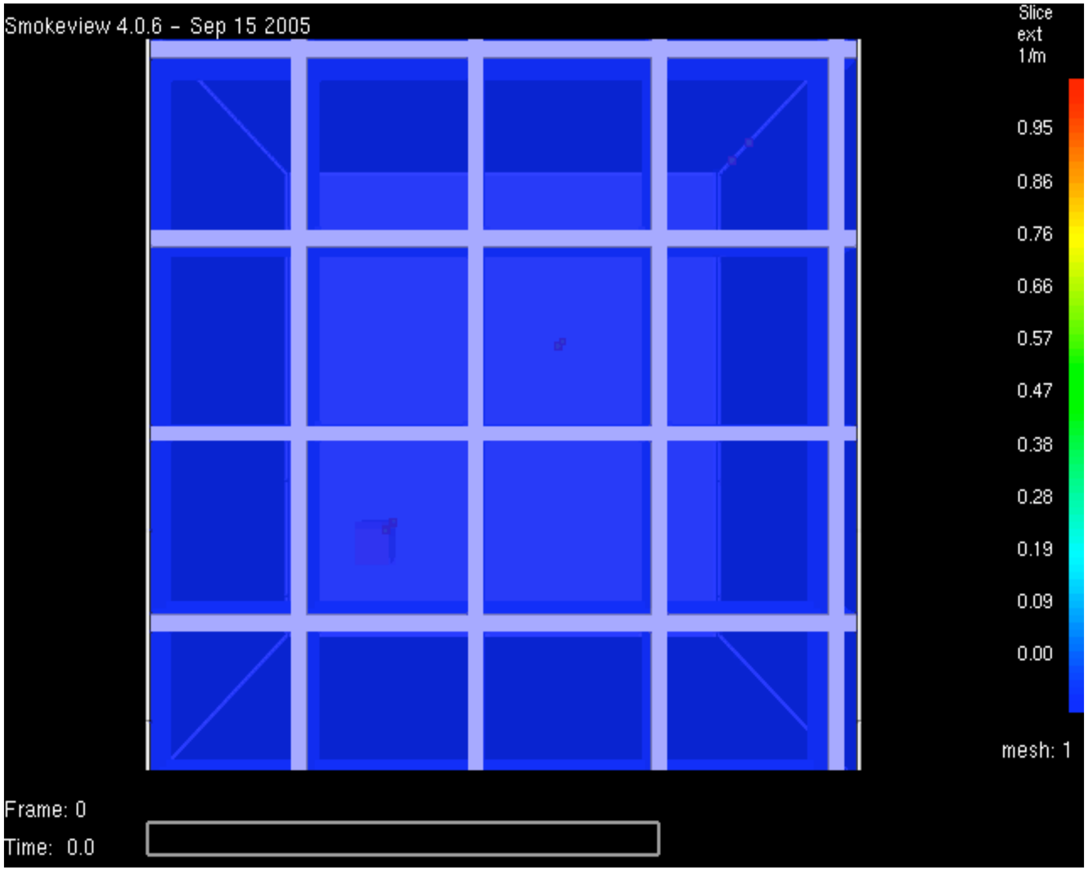
Fire sizes:

Ceiling height (ft)	Constant Flaming Fire (kW)
12	100
18	200
24	300
36 feet	600kW

Beam Pocket Model

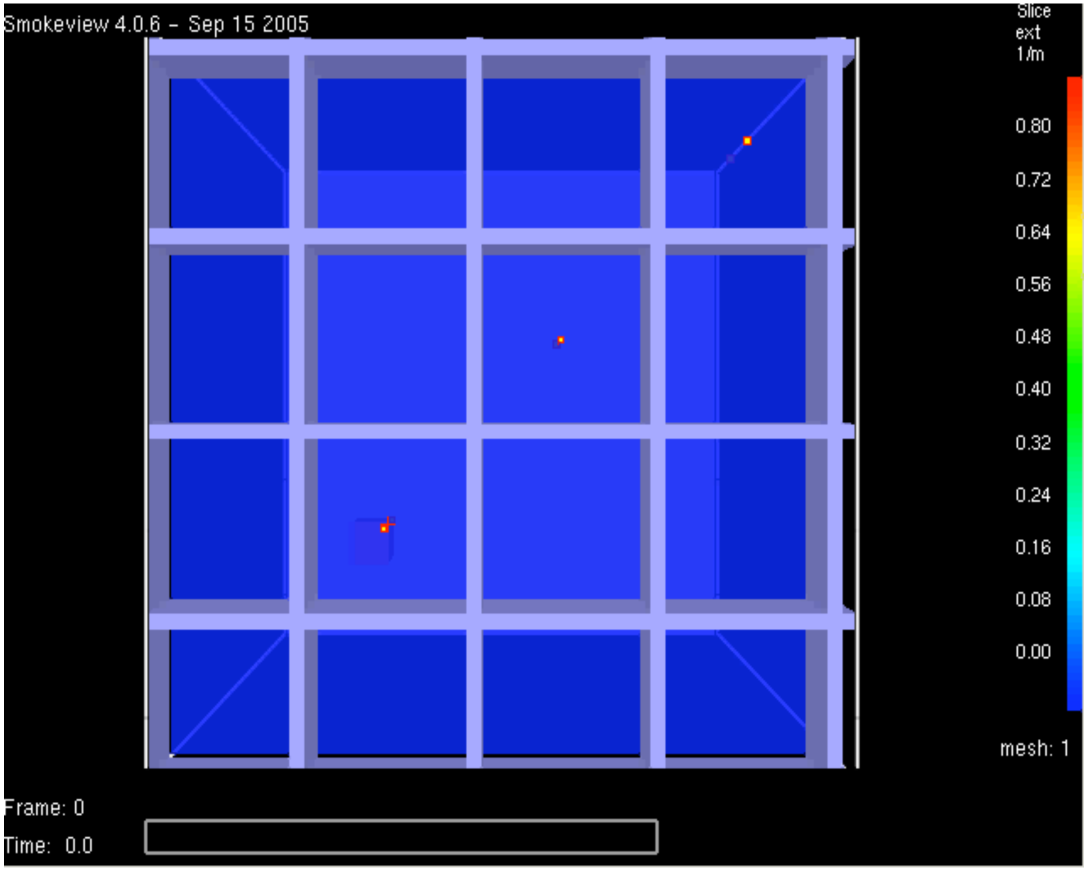


Case – CH 18 ft., BD 24 in., PS 6x6 ft.



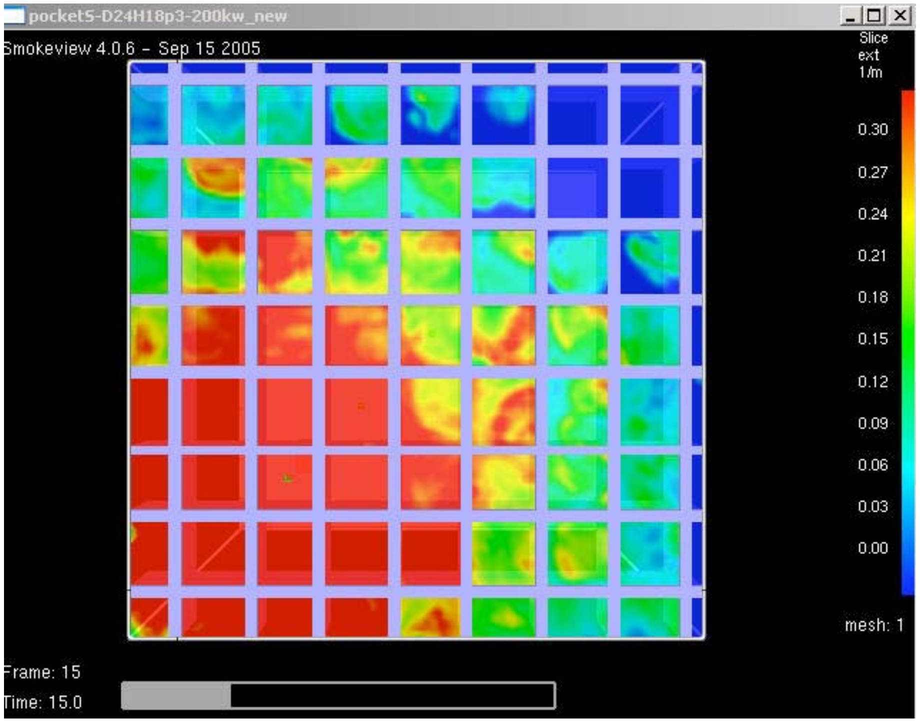
slice in-pocket under ceiling

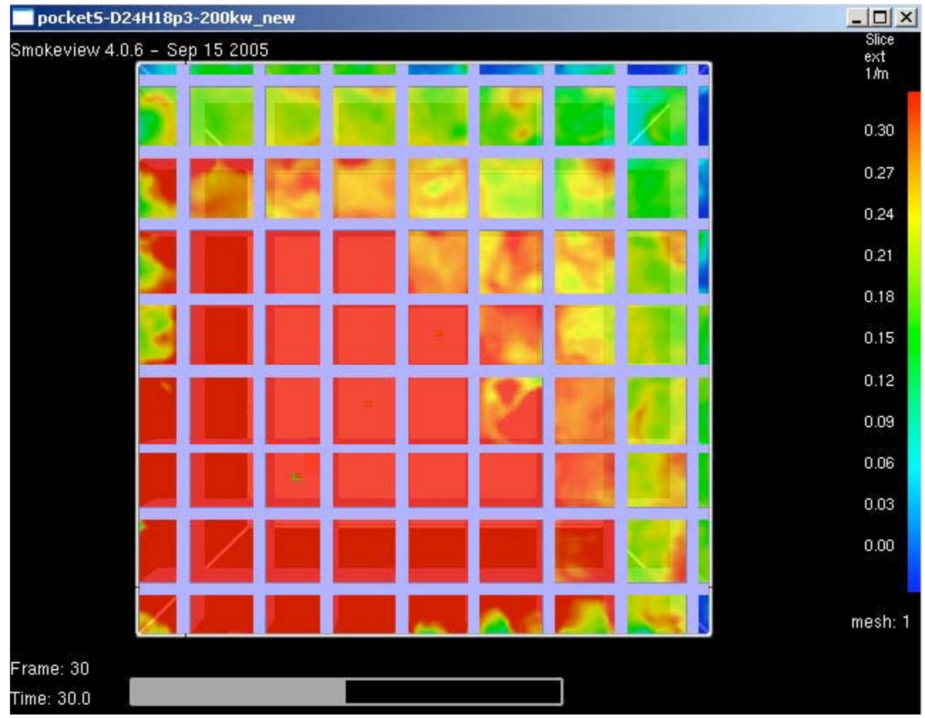
Case – CH 18 ft., BD 24 in., PS 6x6 ft.



slice just under beams

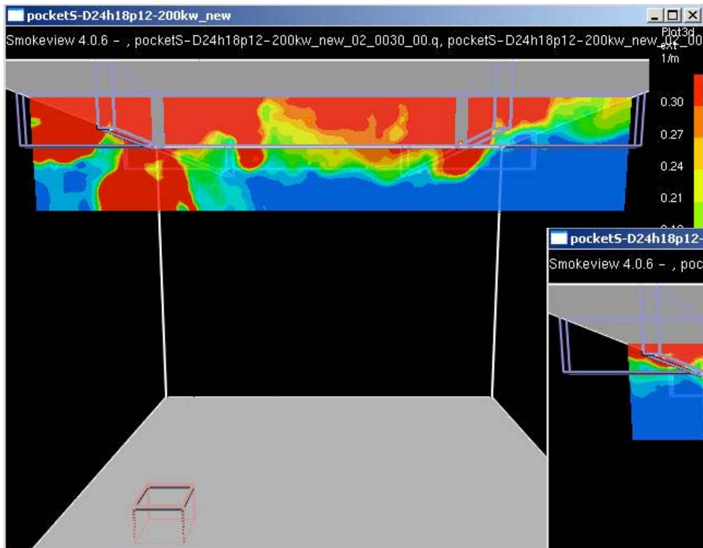
Optical Density Profile for 3 x 3 ft. Pockets



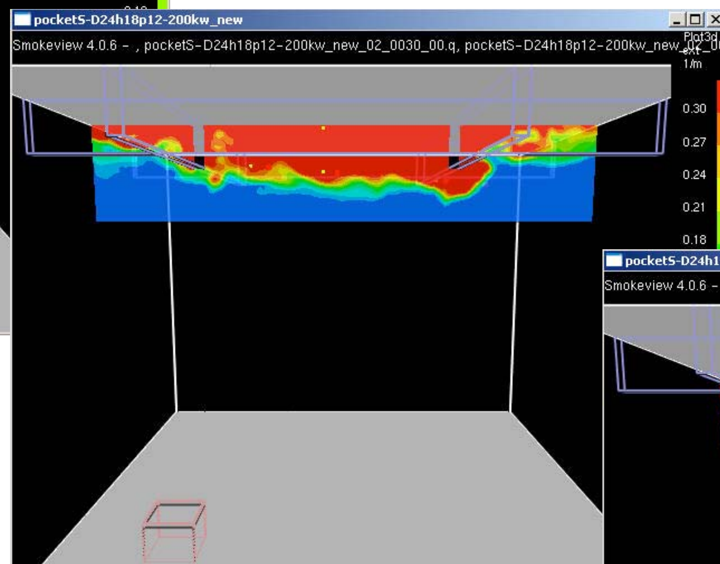


OD, H18D24P3, 15 to 30 seconds, 10cm below the ceiling

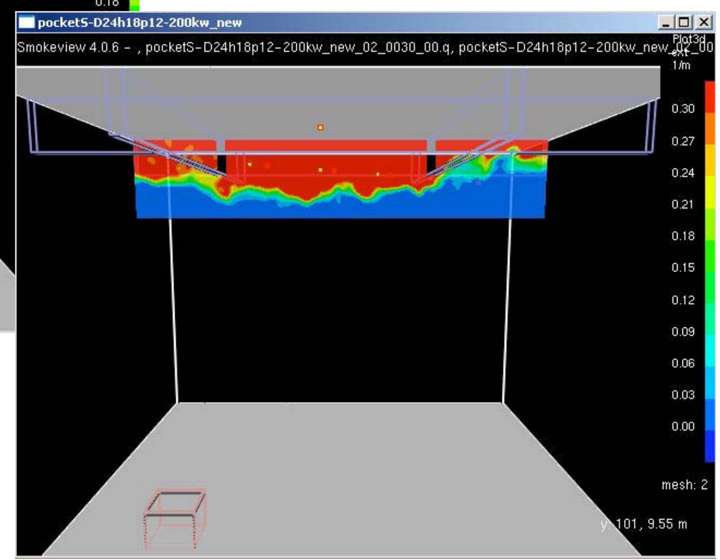
Optical Density Profile for 12 x 12 ft. Pockets



Near Beam



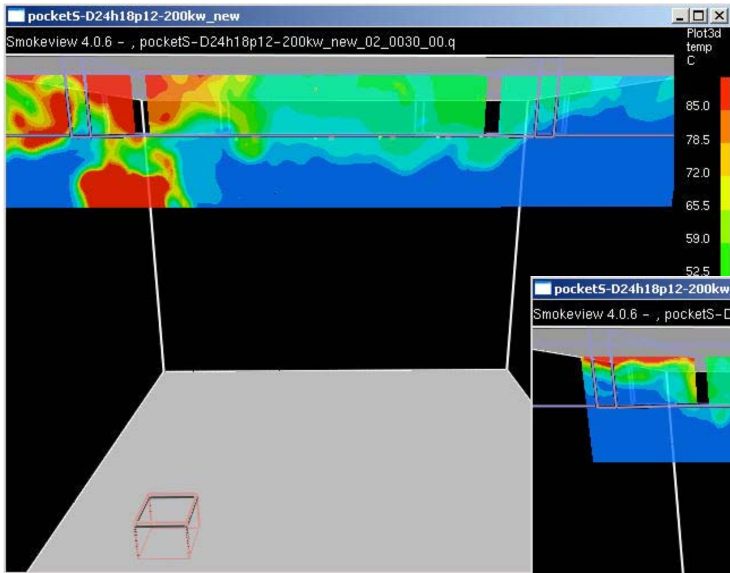
Centerline of pocket



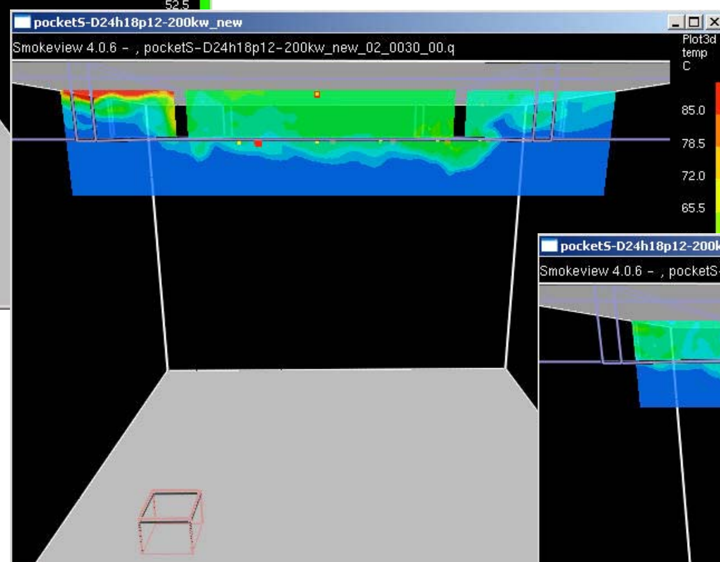
Far Beam

OD, H18D24P12 at 30 seconds

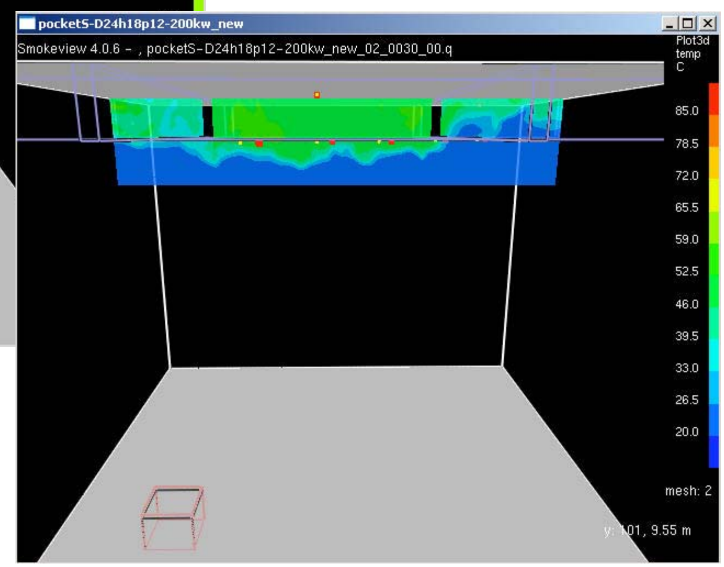
Temperature Profile for 12 x 12 Pockets



Near Beam



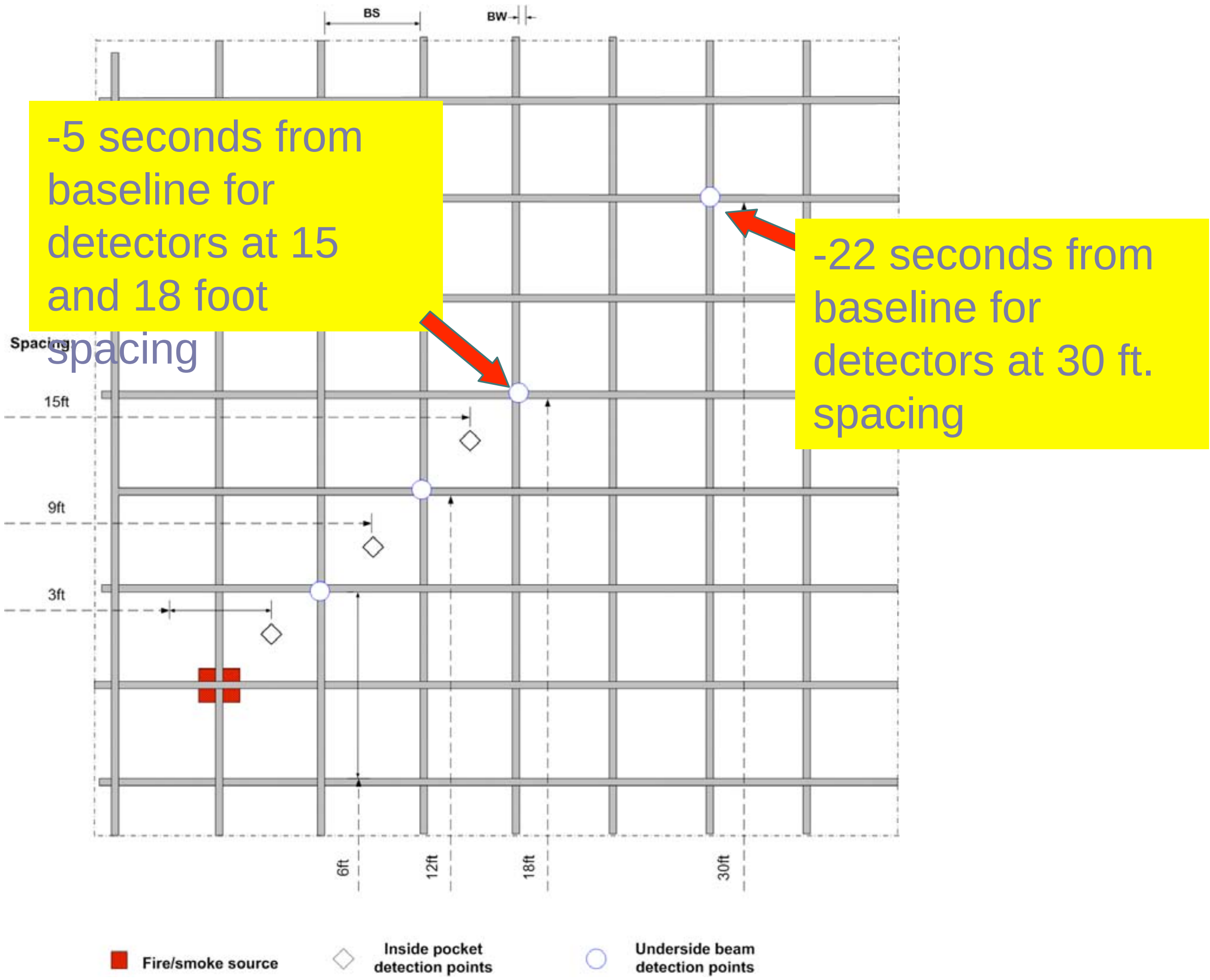
Centerline of pocket



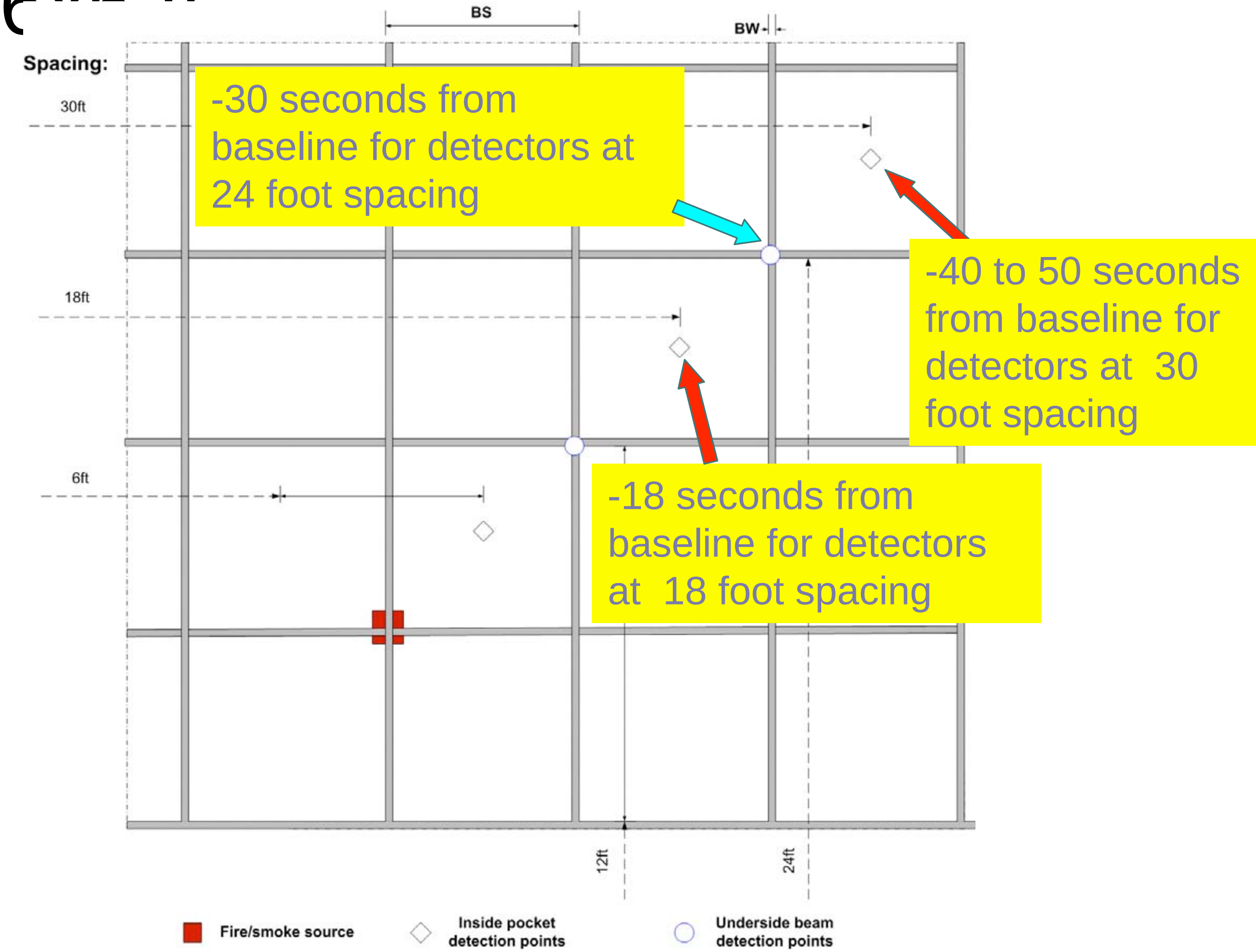
Far Beam

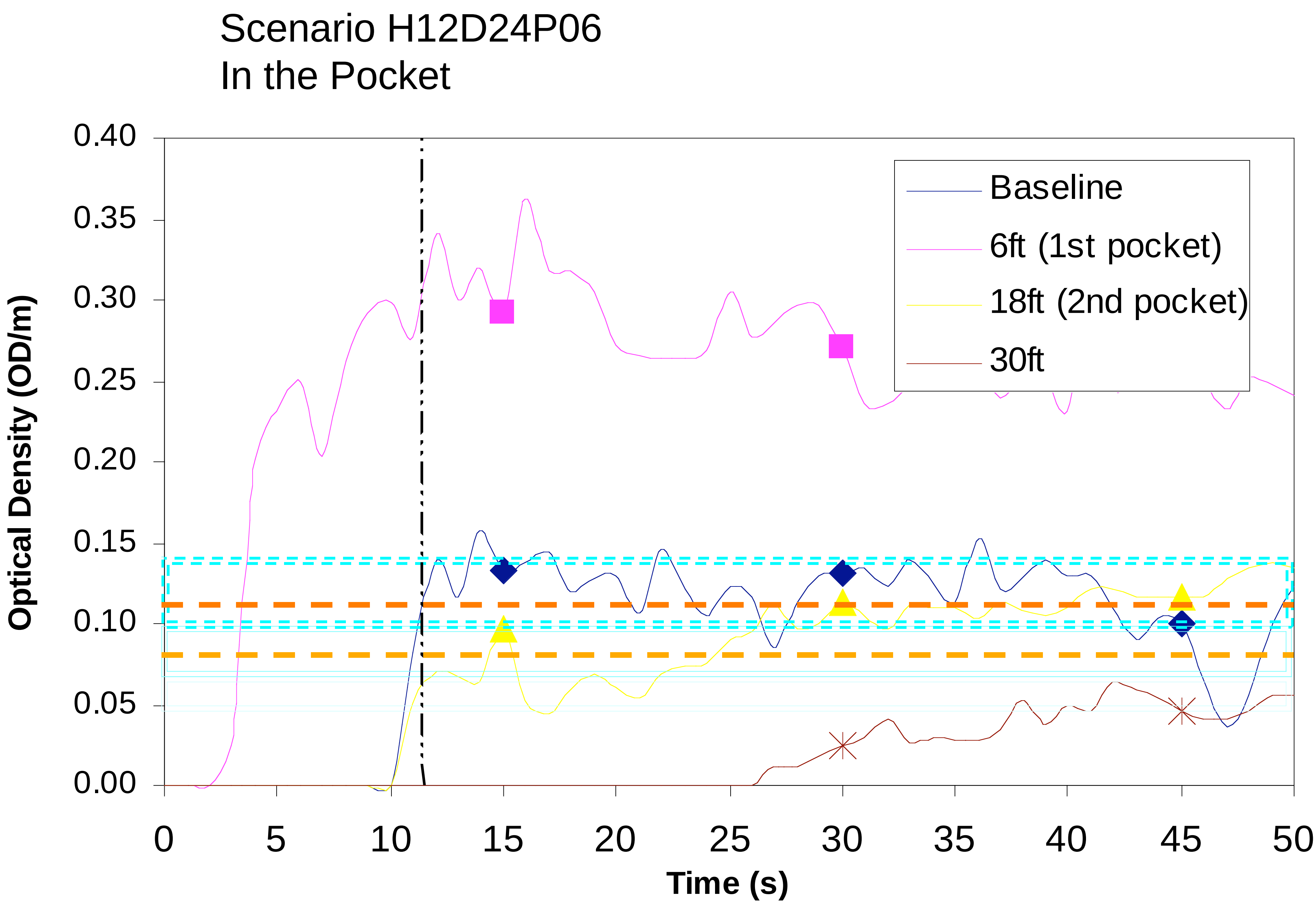
Temperature, H18D24P12 at 30 seconds

Case – CH 18 ft., BD 24 in., PS 3x3 ft.

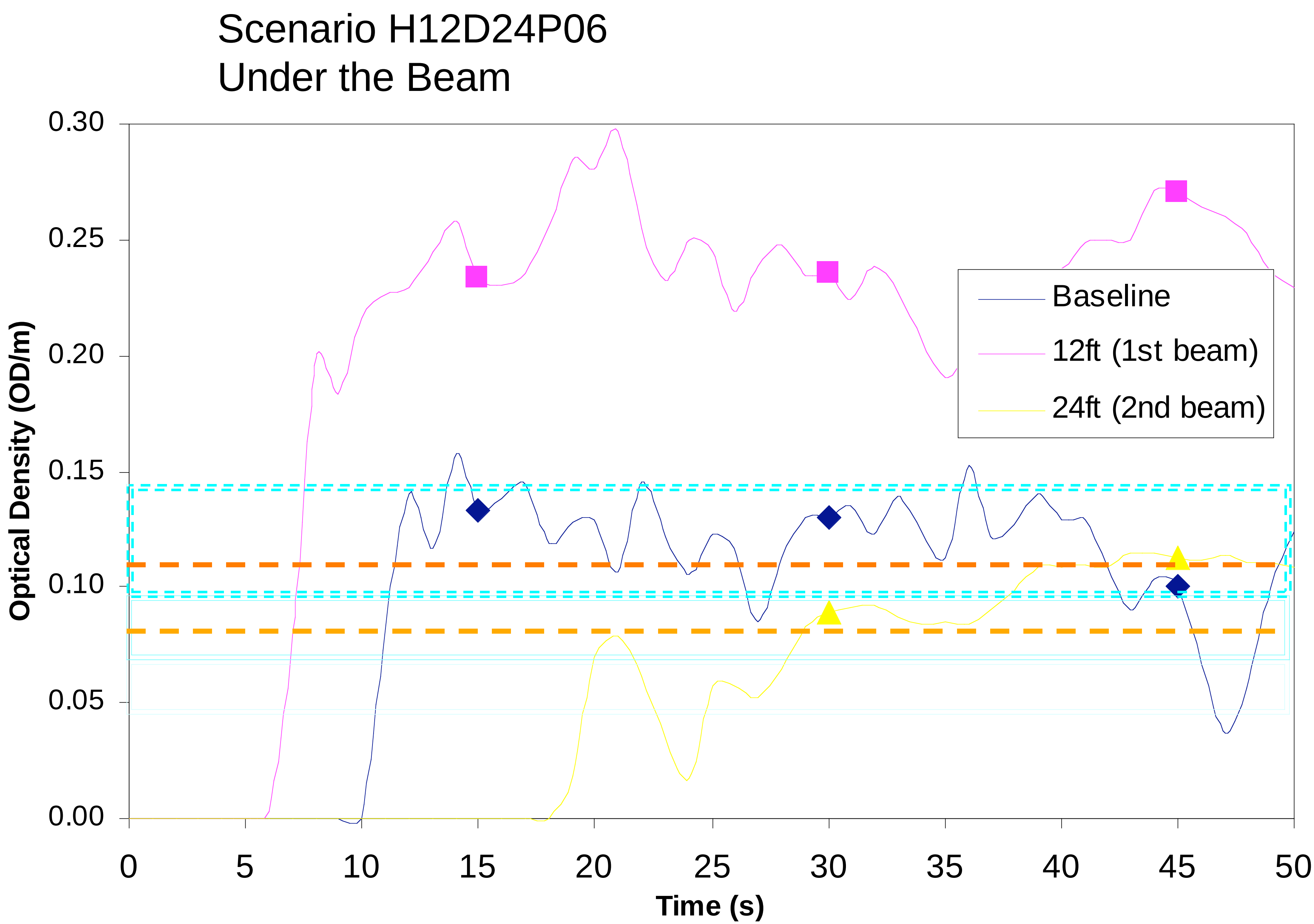


Case – CH 12 ft., BD 24 in., PS 6x6 ft



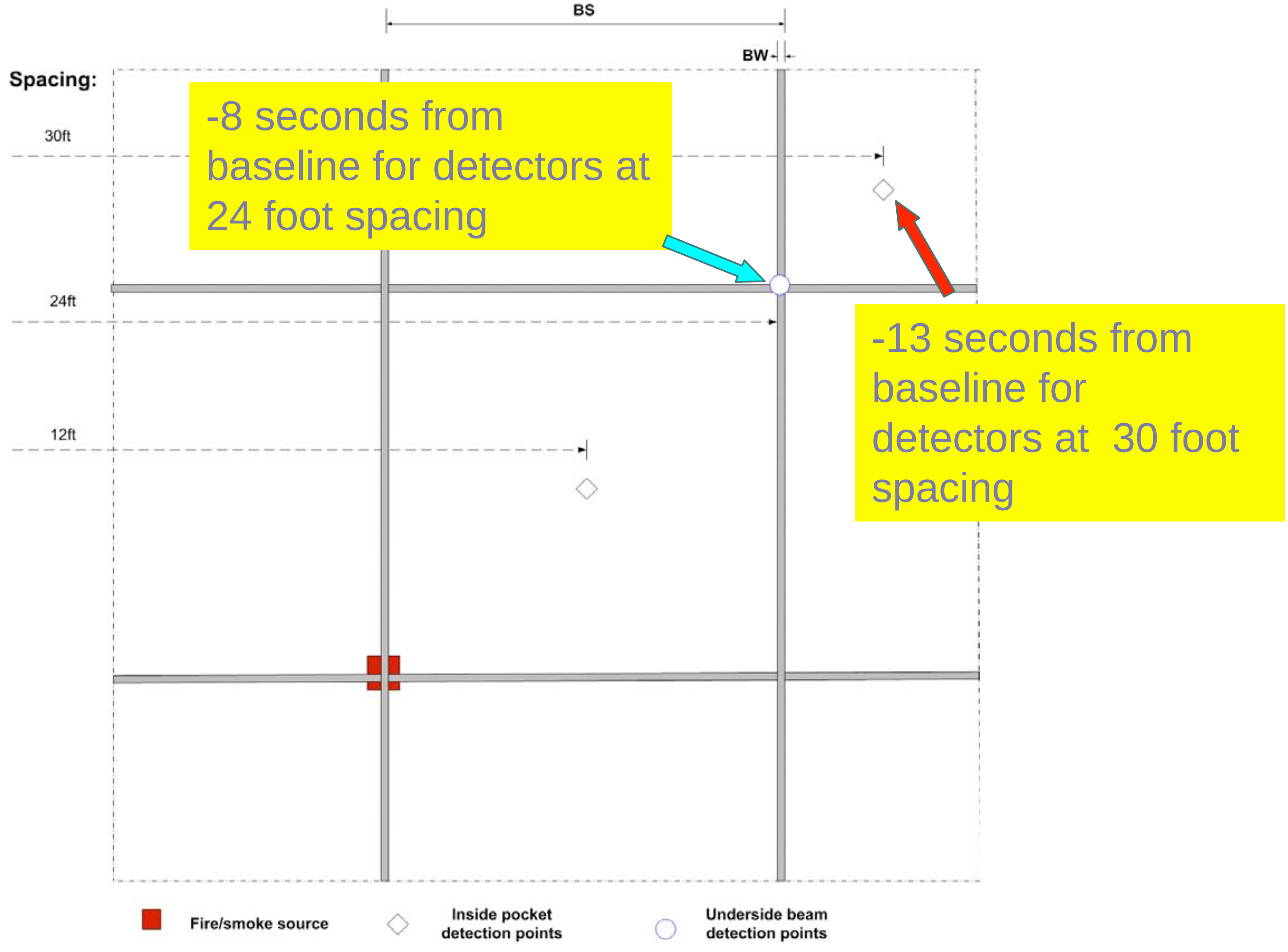


Scenario H12D24P06
In the Pocket
Optical Density (OD/m)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
40
45
50
Time (s)
Baseline
6ft (1st pocket)
18ft (2nd pocket)
30ft

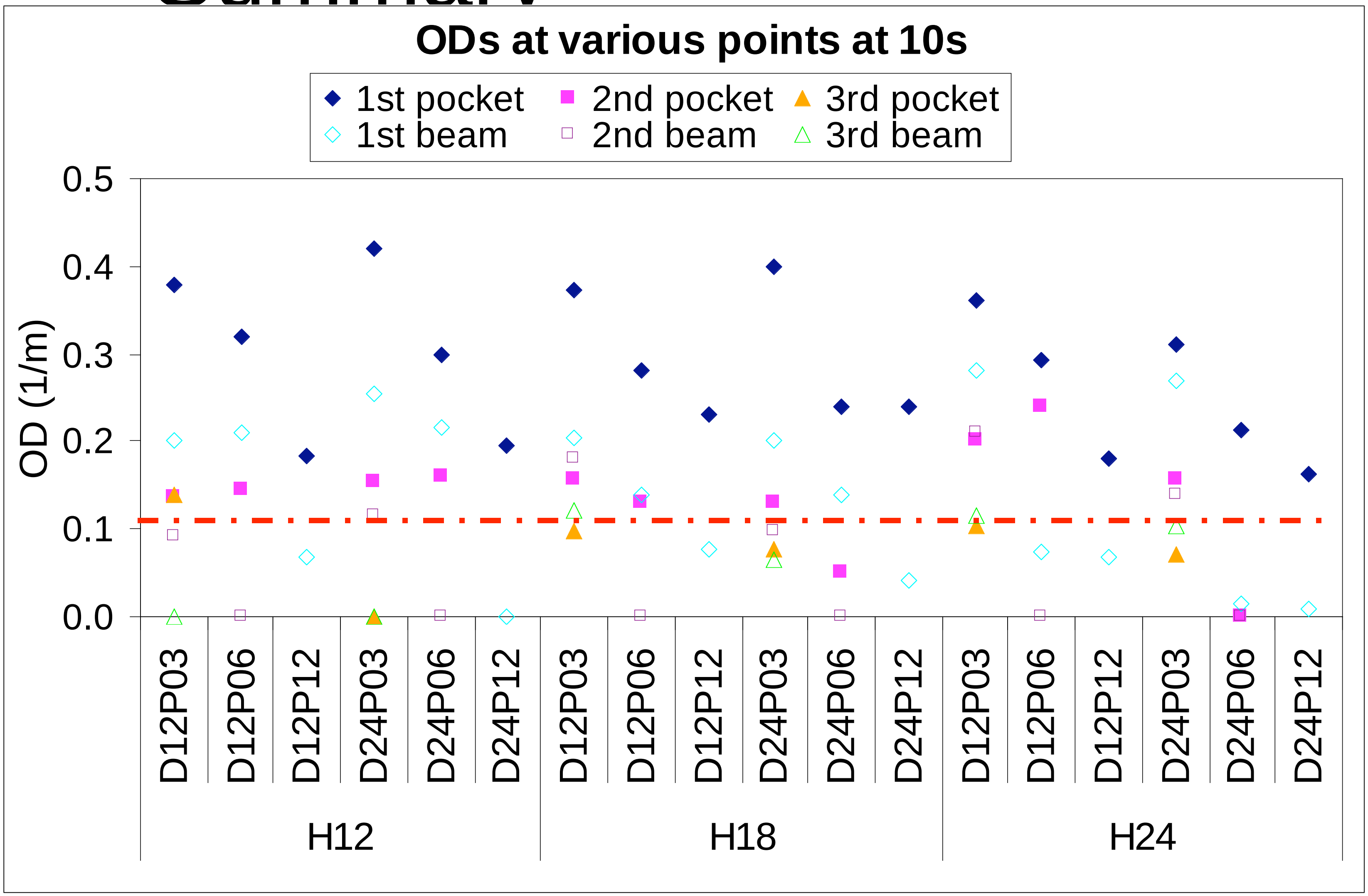


Scenario H12D24P06
Under the Beam
Optical Density (OD/m)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
35
40
45
50
Time (s)
Baseline
12ft (1st beam)
24ft (2nd beam)

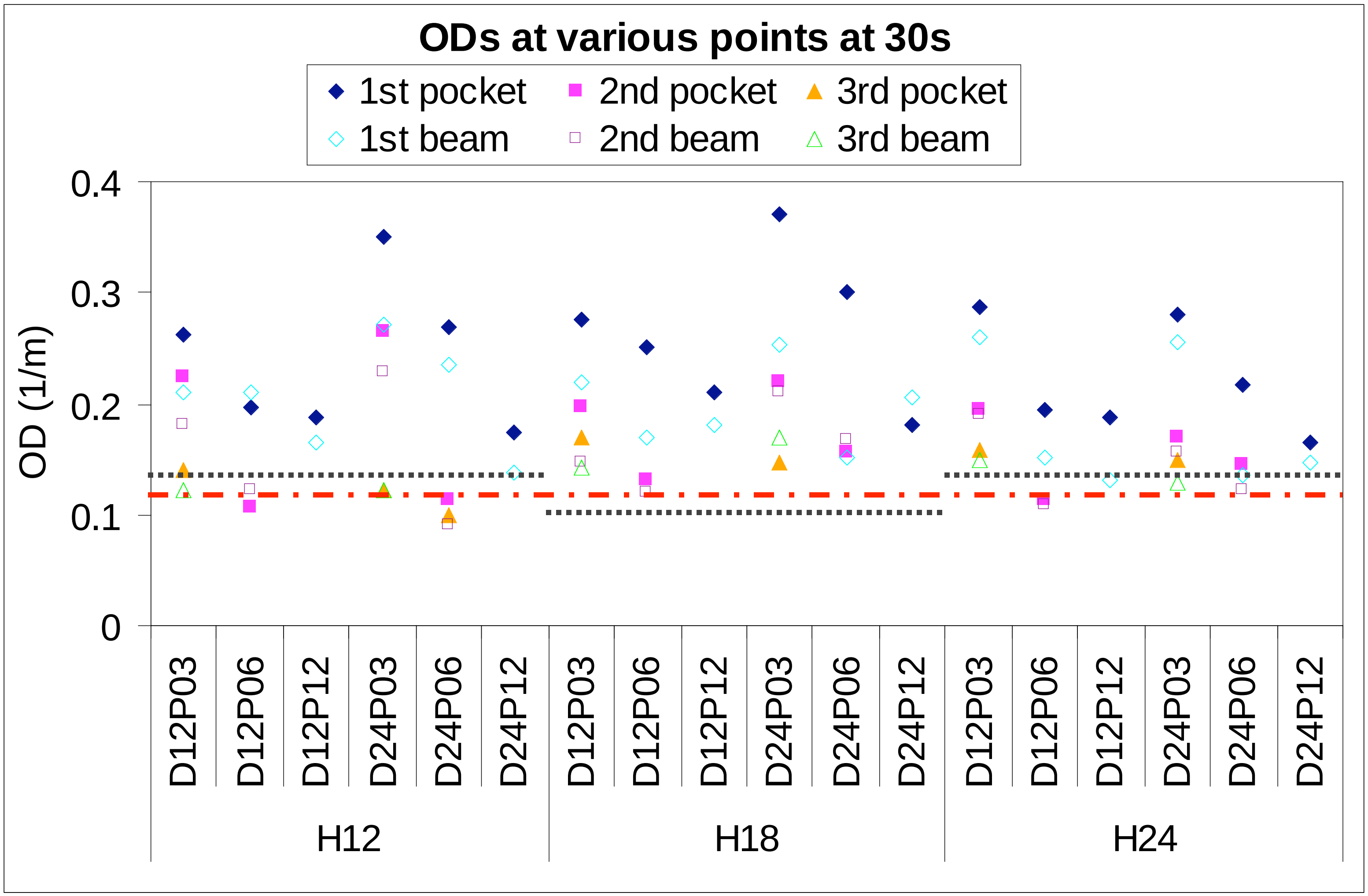
Case – CH 12 ft., BD 24 in., PS 6x6 ft.



Beam Pockets Data Summary



Beam Pockets Data Summary



Waffle or Pan Type Ceilings Basic Findings

- **Linear Spacing of Smoke Detection**
  - The data observed in this analysis indicates that for pan type ceilings with beams or solid joists no greater than 24 in. deep, and beam spacing no greater than 12 ft. center -to-center configurations do not negatively affect expected performance. Reservoir effect contributes to beneficial rise in OD as compared to smooth ceiling scenarios. This means that for these conditions, detector can be effectively used in waffle or pan type at a spacing of 3o ft.
- **Increasing Ceiling Heights**
  - As ceiling height increases the fire size threshold needed for activation of the baseline spot smoke detector must increase. With an increased fire size the smoke detectors on a beam ceiling will be comparable to the performance result for the baseline detector at the same ceiling height.
- **Location Under Beams/On Ceiling Between Beams**
  - Where deep beams interrupt the ceiling surface in a room, mounting the detector on the ceiling in beam pockets or the bottom of the beams is acceptable, either location providing comparable response to alarm for flaming fires
- **Sidewall Mount or Center of Corridor**
  - Keeping smoke detector locations 12 inches below or away from a beam-ceiling corner appears unsubstantiated. No stagnant zone or locations are observed that would preclude smoke detector alarm. Temperature and smoke optical density are relatively uniform and well-mixed throughout the volume of the beam pocket within seconds after the initial ceiling jet passes.

Thanks for Your Attention
Questions?