Halon 1211 Stratification/ Localization in Aircraft

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International Aircraft Systems Fire Protection Working Group
May 23-24, 2012
Koeln, Germany

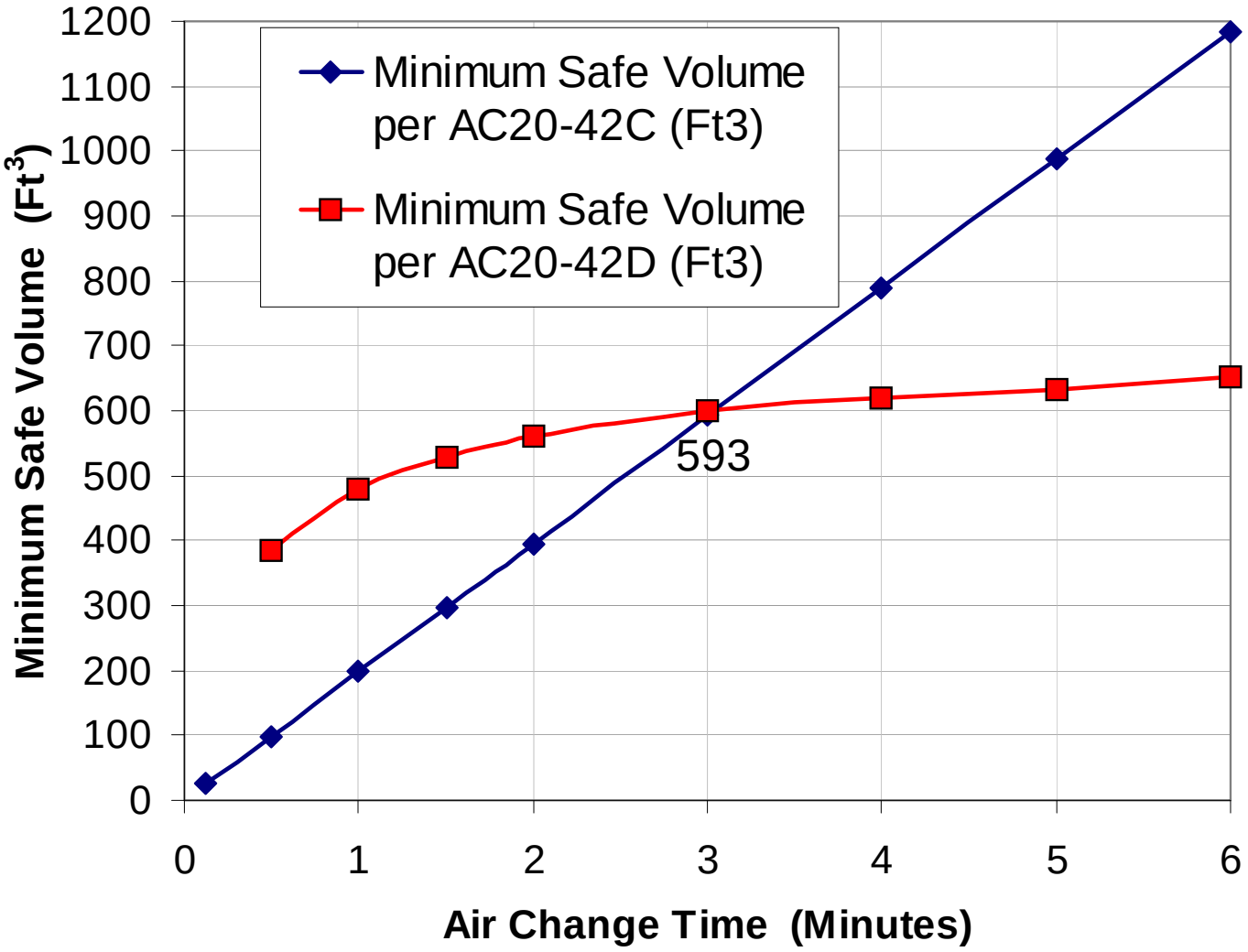
Federal Aviation Administration

Background

Per AC20-42D - Halon 1211, Halotron 1, and BTP are unsafe for use in Boeing airplane flight decks and other small volumes.

AC 20-42D, Chapter 4.4b(3), (4) states that concentrations may be adjusted to account for agent localization/ stratification…a report will be published at the FAA Technical Center with method to adjust safe-use concentrations.

Comparison of Minimum Safe Volumes for 2.5 lb Halon 1211



Minimum Safe Compartment Volume for One Extinguisher in Unventilated Compartments *(from AC 20-42D)*

Agent	Agent Weight[a] (lbs)	Minimum Safe Volume for One 5 B:C Extinguisher (ft^3)					
		Sea Level (info only)	Pressurized Aircraft 8,000 ft CPA	Non-Pressurized Aircraft			
				12,500 ft	14,000 ft	18,000 ft	25,000 ft
HCFC Blend B[b]	5.5	1102	1482	1768	1877	2209	2973
HFC-227ea[b]	5.75	104	141	167	177	209	280
HFC-236fa[b]	4.75	79.8	107	128	136	159	214
Halon 1211[c]	2.5	1116	1502	1790	1908	2232	3016
Halon 1211[d,e]	2.5	558	**751**	895	954	1116	1508
Halon 1301[b]	5.0	192	258	308	327	385	517

a Agent weight for a 5B:C extinguisher is extinguisher dependent. Nozzle design, pressurization differences and other factors can result in different agent weights for extinguishers using the same agent. The tabulated minimum safe volumes should be corrected for the actual agent weight if different from the agent weight in this figure.

b Values based on the safe human concentration. See reference report appendix 3, paragraph 7.m.of this AC.

c Values are based on the Halon 1211 NOAEL concentration of 0.5% (v/.v)

d Values are based on the Halon 1211 LOAEL concentration of 1.0 % (v/v).

e Safe human concentrations are not available for Halon 1211 using the same criteria as for other agents. However, the Halon 1211 LOAEL concentration of 1% (v/v) has been shown to be safe for humans. See report mentioned in note b above. Also, the safety factor is smaller than that set for other agents.

Multiplication Factors ($MF_{Ventilated}$) for Ventilated Compartments *(from AC 20-42D)*

Agent	Air Change Time, τ (minutes)								
	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	>6[a]
HCFC Blend B	2.80	2.33	2.14	2.02	1.89	1.79	1.70	1.62	1
Halon 1211 [b]	**1.96**	**1.57**	**1.42**	**1.34**	**1.25**	**1.21**	**1.17**	**1.15**	**1**
HFC-227ea [c]	1.90	1.53	1.39	1.32	1.24	1.19	1.16	1.14	1
HFC-236fa [c]	1.98	1.58	1.42	1.34	1.25	1.20	1.17	1.15	1
Halon 1301 [c]	1.96	1.57	1.42	1.34	1.25	1.21	1.17	1.15	1

a *No $MF_{Ventilated}$ is applied if air change time is greater than 6 minutes.*
b *Lower $MF_{Ventilated}$ than actual. Based on Halon 1301 $MF_{Ventilated}$.*
c *Multiplication factors are similar for all non-chlorinated halocarbons.*

Test Ventilation: τ_{Cabin} = 4.1 min; $\tau_{Flight\ Deck}$ = 1.08 min

Goal

- Develop test- based multiplication factors ($MF_{\textbf{Stratification-Localization}}$) to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization:

  - Small aircraft
  - Flight decks
  - Large cabins

- Tests evaluate stratification/ localization of Halon 1211 discharged from one extinguisher.

Method

Small aircraft: Use concentration histories from existing reports.

- Flight deck and cabin: B 737 Tests

- Multiplication factors (MF) will be based on maximum computed human arterial blood concentrations, B_{Max}: Compare B_{Max} for theoretical perfect mixing (ventilated) to test (ventilated) B_{Max}.

$$\mathbf{MF}_{\text{Stratification \& Localization}} = \frac{B_{Max}(\text{Ventilated} - \text{PerfectMixing})}{B_{Max}(\text{Ventilated} - \text{Stratification} - \text{Localization})}$$

- This $\mathbf{MF}_{\text{Stratification \& Localization}}$ will be a multiplier for the maximum agent W/V in AC 20-42D, after $\mathbf{MF}_{\text{Ventillation}}$ is applied.

- Compute separately for Halon 1301 kinetics and Halon 1211's guesstimated kinetics (Halon 1211 kinetics is based on unreferenced parameters).

Determination of Stratification Multiplication Factors: Agent Gas Concentrations

- Determine air change time for the B-747 compartments with 1 air pack on.
- Discharge 1 circa 2.5 lb Halon 1211 hand extinguisher at selected targets in each compartment.
- Obtain experimental Halon 1211 Halon 1211 concentration histories for each sampling position.
- Calculate theoretical Halon 1211concentration histories for that same extinguisher, if discharged into that compartment, with the same air flow, assuming perfect mixing.

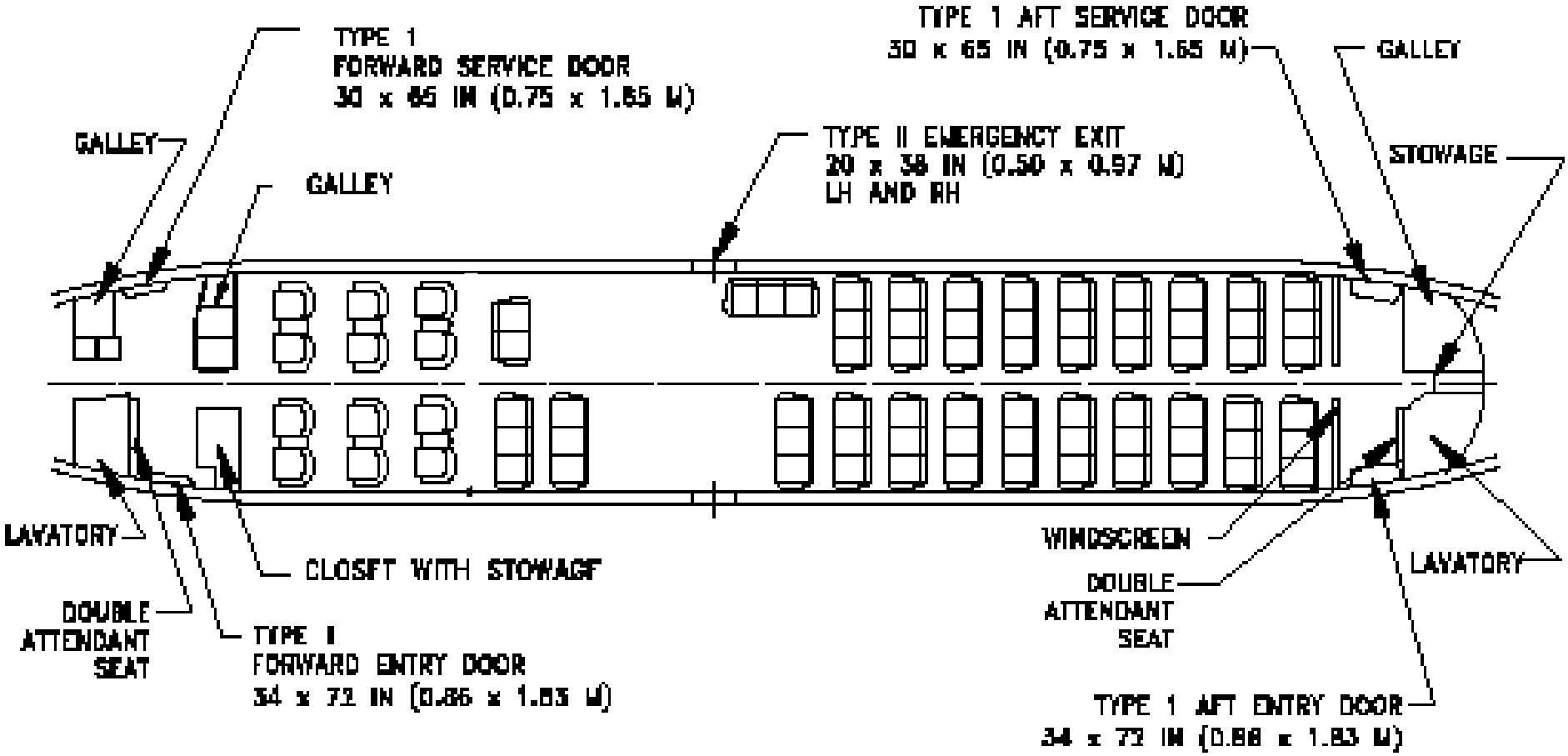
Determination of Stratification Multiplication Factors: Arterial Blood Concentrations

Perform following steps based on Halon 1301 kinetics and then guesstimated (unsubstantiated) Halon 1211 kinetics

- Calculate arterial concentration histories for the theoretical and actual discharge assuming Halon 1301 kinetics.
- The ratio of the theoretical peak arterial concentration to the peak experimental concentration is the multiplication factor


B-737 Test Article

B 737 Test Article



B 737 Test Article

- The passenger cabin is 630” long x 137” wide (52.5 ft x 11.4ft)

- Total Cabin Volume = Front Galley + Passenger Seating Area + Rear Galley
  = 215 ft^3 + 3315 ft^3 + 323 ft3
  = 3853 ft^3
- The cabin volume includes the front and rear galleys and the passenger seating area.

- The seats, overhead storage and other enclosed areas were subtracted out.

- The flight deck volume is 129 ft^3

- The firefighter volume is 5.7 ft^3

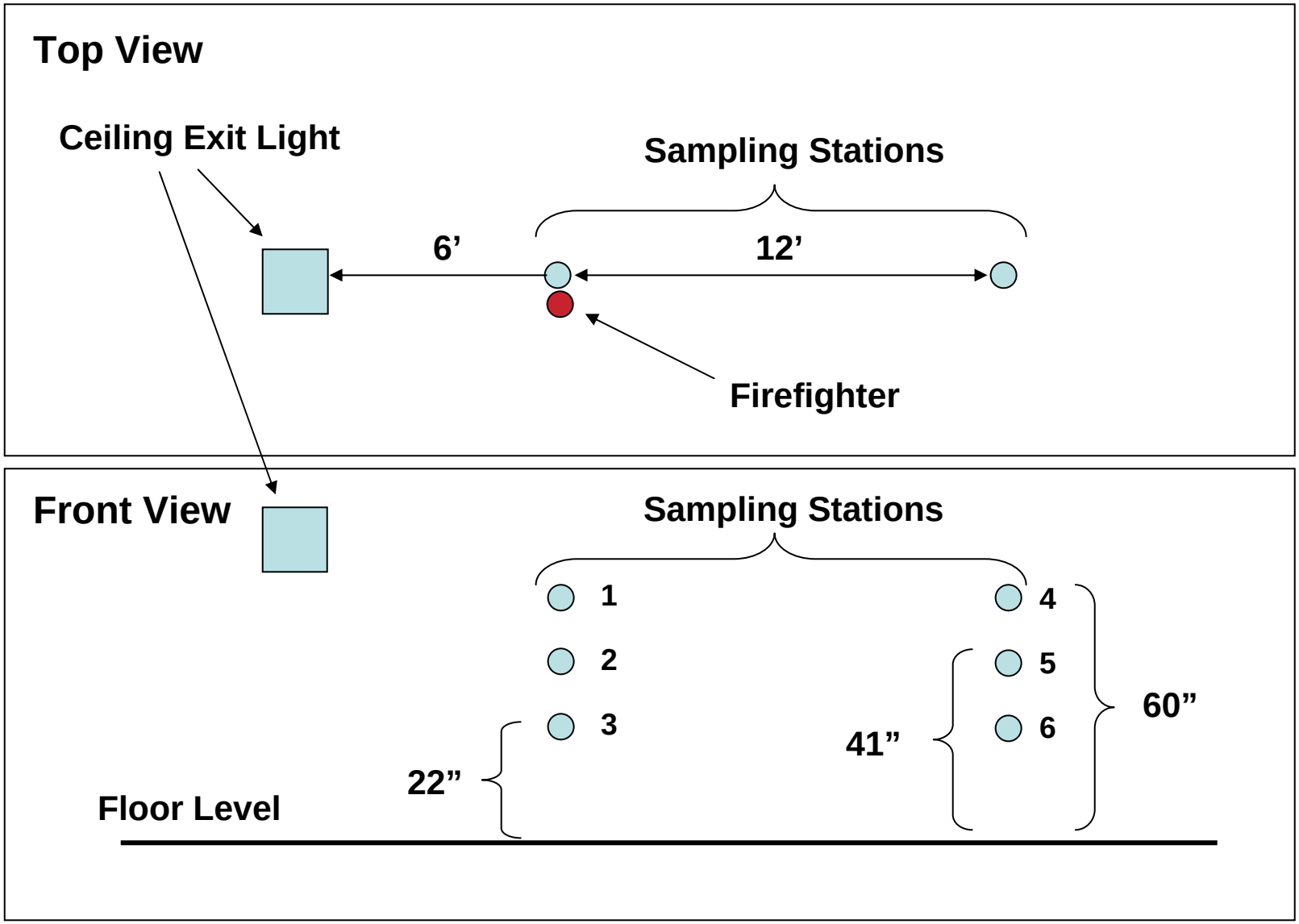
- The firefighter volume is subtracted out when calculating perfect mixing concentrations

- 1 Air Pack used, all air ports closed
- Air change time by CO_2 discharge test: τ_{Cabin} = 248s; $\tau_{Flight\ Deck}$ = 65s

Cabin Test Plan:

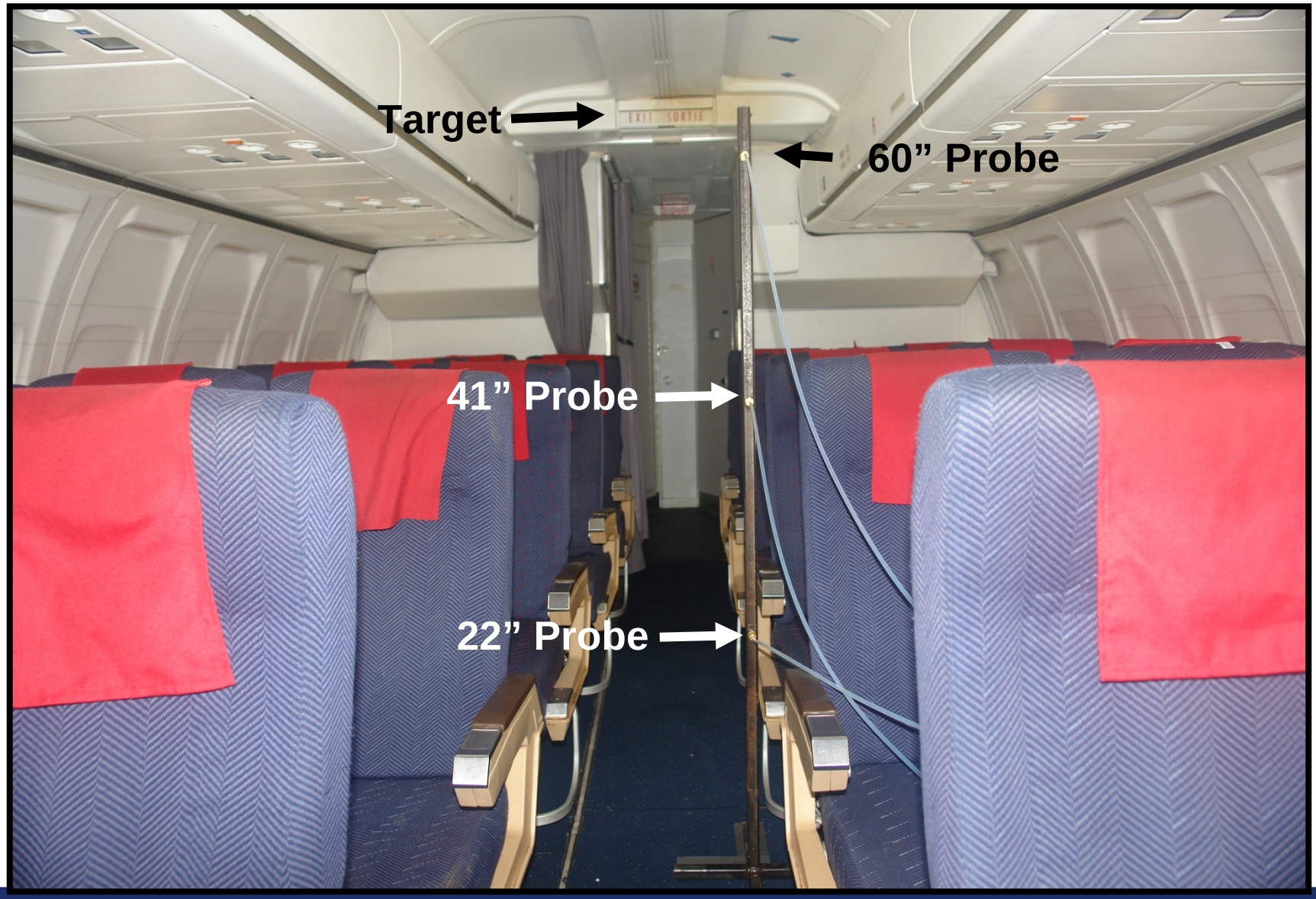
- Discharge one 5 B:C Halon 1211 extinguisher in rear of passenger compartment. Aim at exit light above entrance to the rear galley.
- Sampling stations: 1 Sampling station per discharge test.
  - 6’ horizontally from the target (at firefighter’s position)
  - 18’ horizontally from the target
  - 3 Heights: 60”, 41” and 22’ (Standing, seated and resting nose height). Extinguisher nozzle is held 6” forward of the sample tree
- Determine maximum arterial concentrations (B_{Max}) for each Halon 1211 discharge test.
- Compare to the maximum arterial concentration that would be obtained if instantaneous perfect mixing (same compartment, same ventilation).
- Determine multiplication factors for each position.

Cabin Test using Luft NDIR Gas Analyzers



Cabin Test: Target

Cabin Test

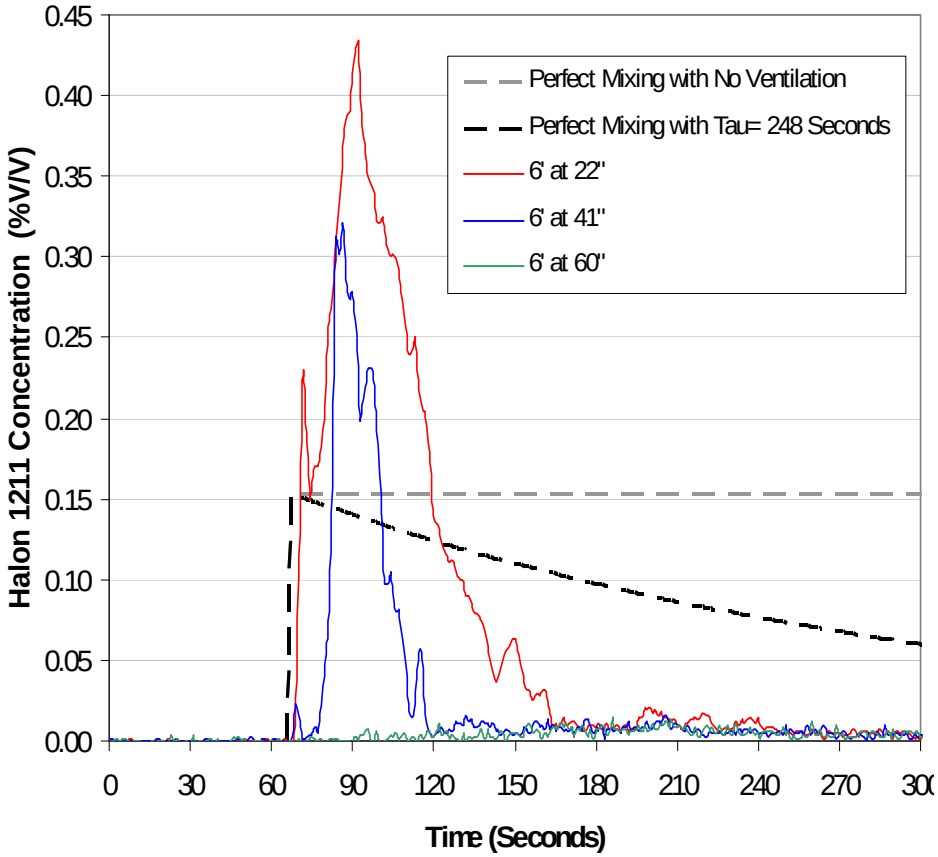


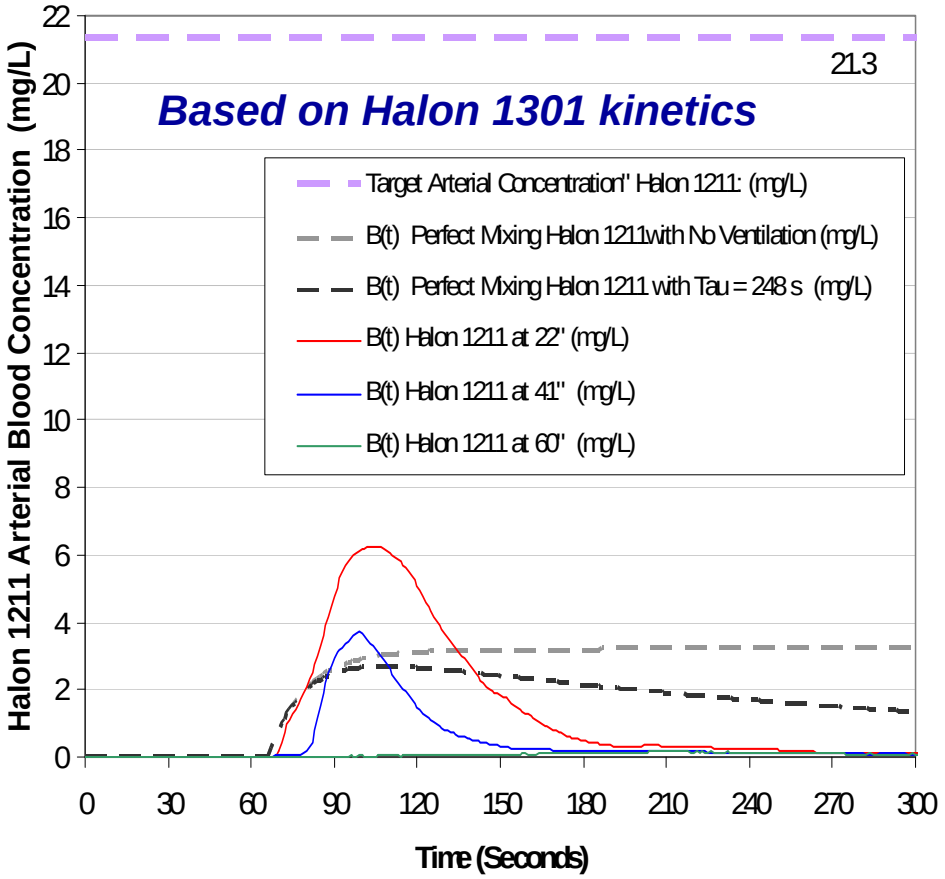
Cabin Test

Cabin Tests

Sample station: alongside firefighter, 6’ from target- Test 1

$MF_{\text{Stratification \& Localization}} = \mathbf{0.43\ ,\ 0.73\ ,\ 15.2\ ,\ \ (22”, 41”, 60”)}$

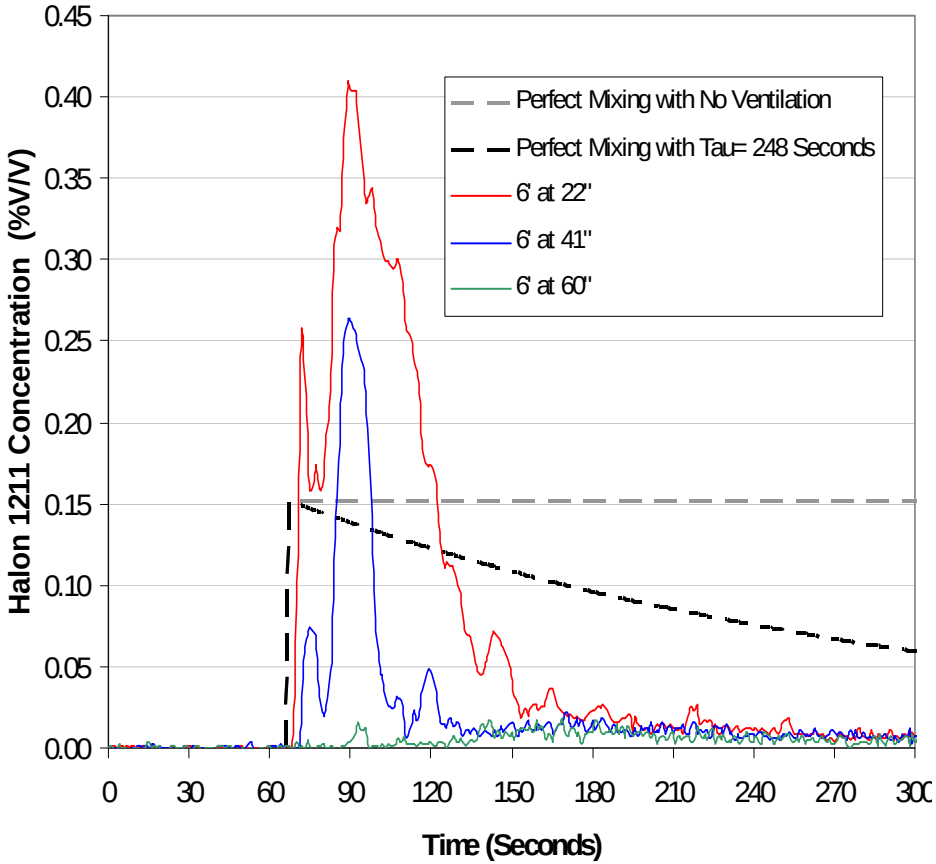


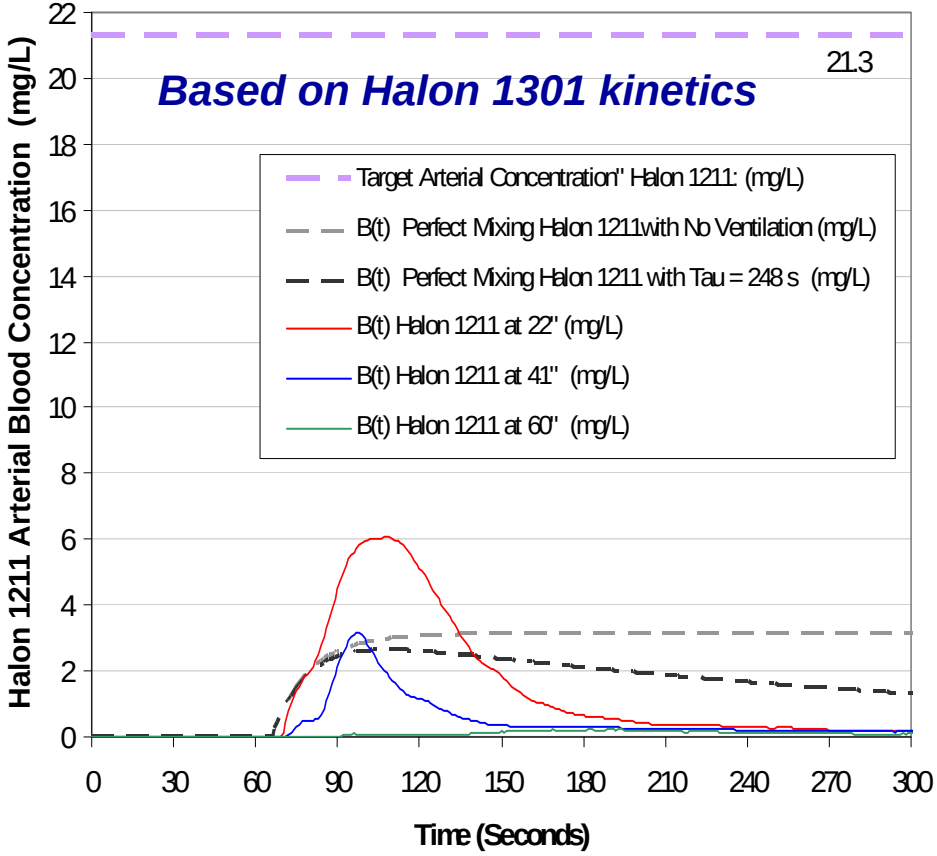


Cabin Tests

Sample station: alongside firefighter, 6’ from target- Test 2

$MF_{\text{Stratification \& Localization}} = \mathbf{0.44\ ,\ 0.84,\ 12.2\ ,\ (22”, 41”,60”)}$

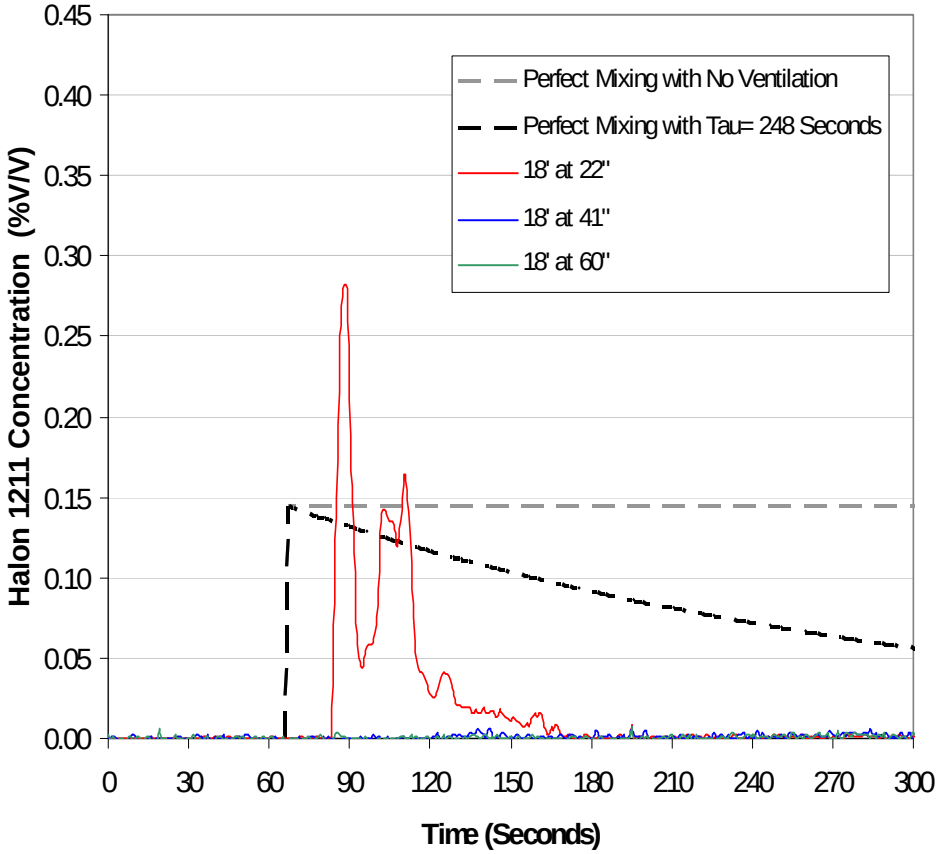


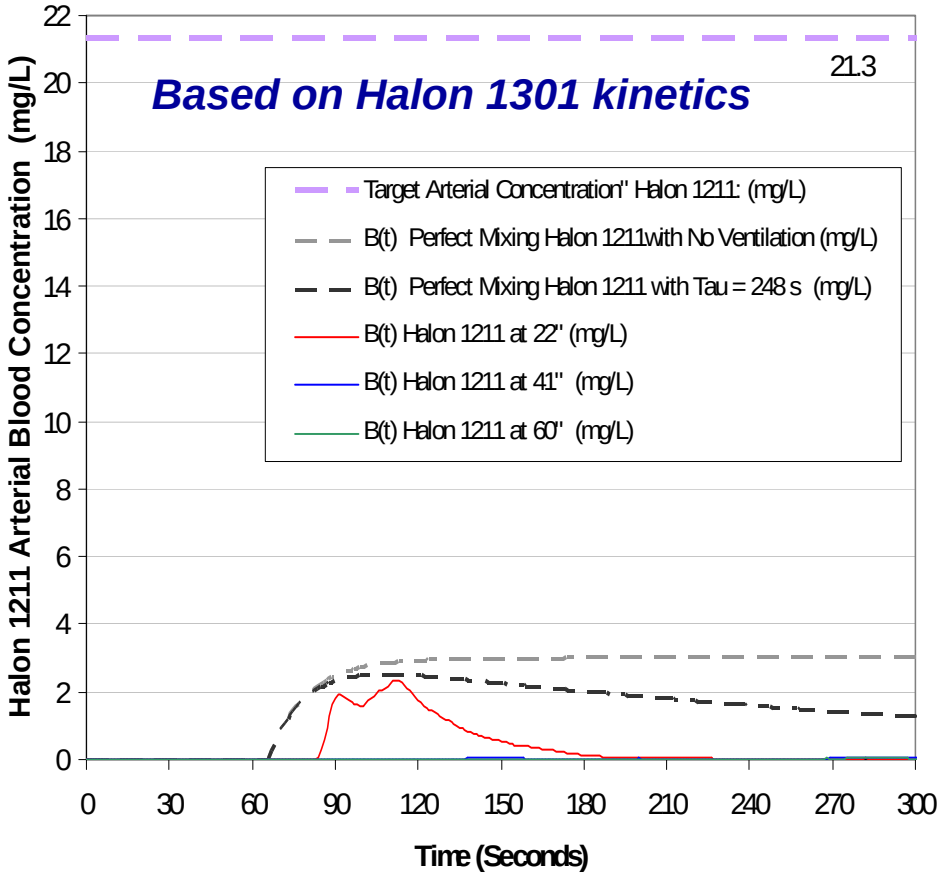


Cabin Tests

Sample station: 18’ from target- Test 3

$MF_{\text{Stratification \& Localization}} = 1.08,\ 49,\ 62,\ (22”, 41”, 60”)$

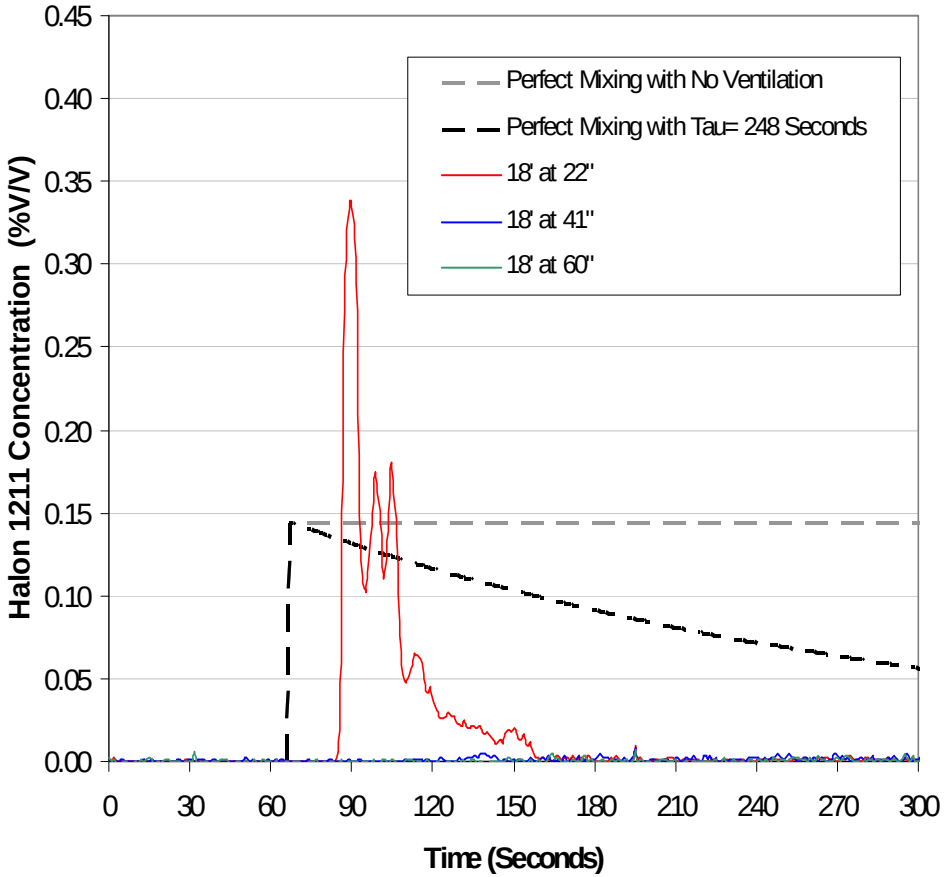


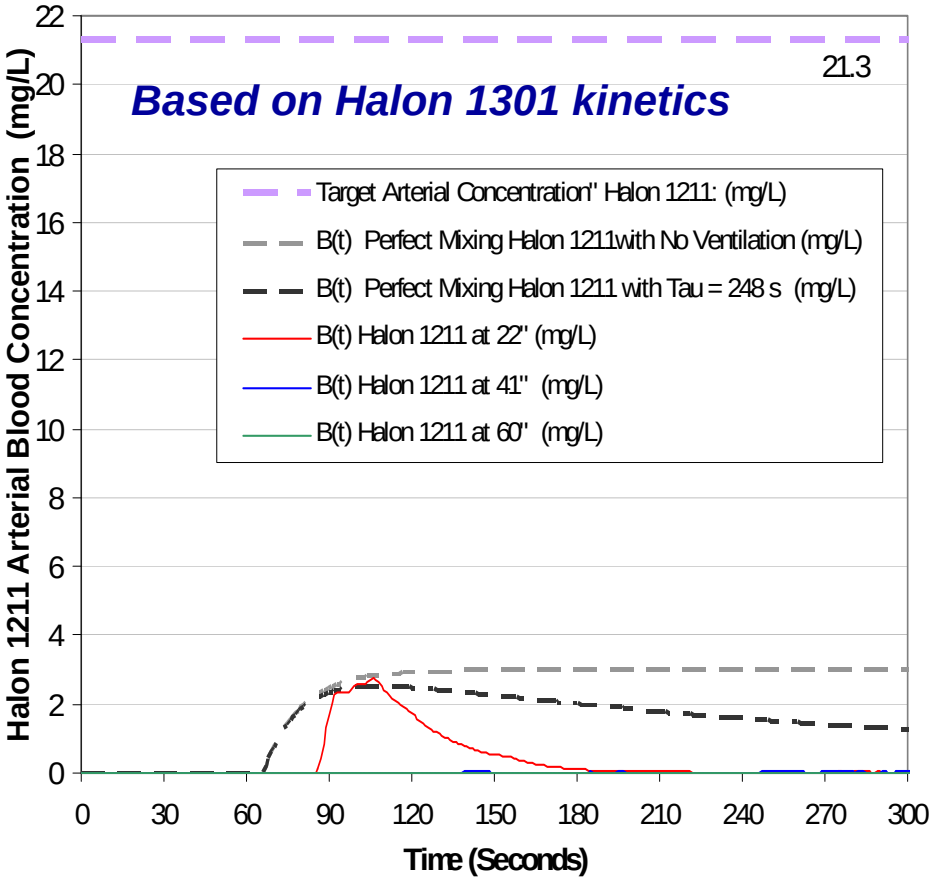


Cabin Tests

Sample station: 18’ from target- Test 4

MF **Stratification & Localization** = **0.92, 61, 99, (22”, 41”,60”)**



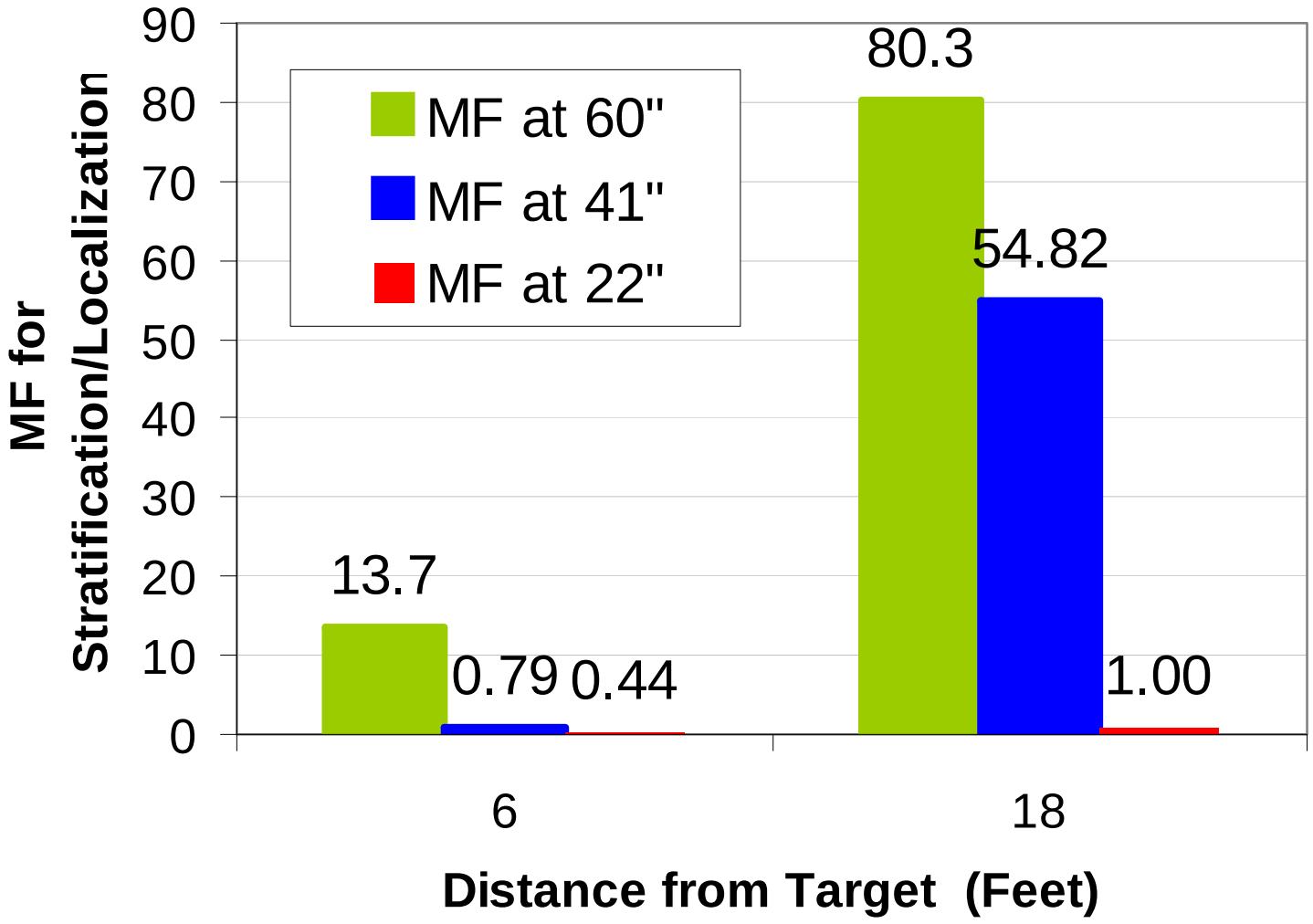


Cabin Tests: Stratification/ Localization MFs Based on Halon 1301 Kinetics

Test	Sampling Station: Distance From Target (Feet)	MF at 22"	MF at 41"	MF at 60"
1	6	0.43	0.73	15
2	6	0.44	0.84	12
Average		**0.44**	**0.79**	**14**
3	18	1.08	49	62
4	18	0.92	61	99
Average		**1.00**	**55**	**80**

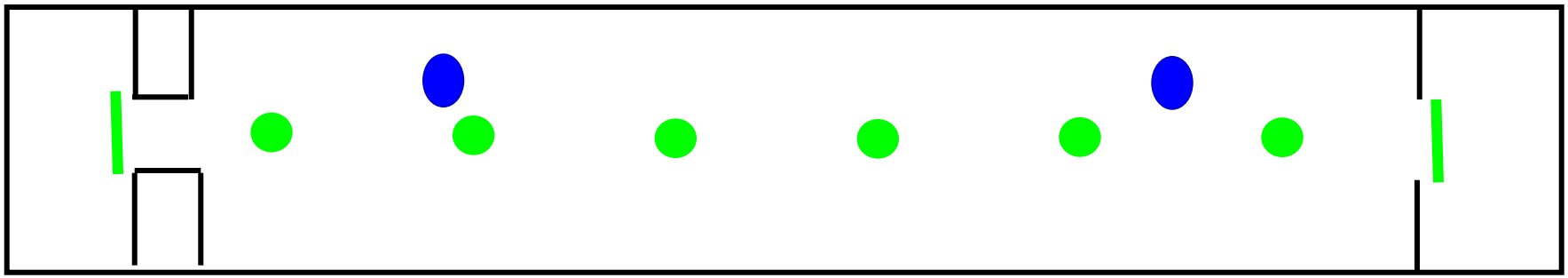
Cabin Tests: Stratification/ Localization MFs

Based on Halon 1301 Kinetics



Cabin: Ventilation Rate Measurement

- 6 fans in center aisle floor, facing upward, evenly dispersed, 18” diameter blades.
- A large fan at each galley exit, facing each other, 28” and 26” blades. Height from hub to floor: 47” and 55”.
- 2 firefighters, each is 10’ from galley entrance. (50’ cabin)



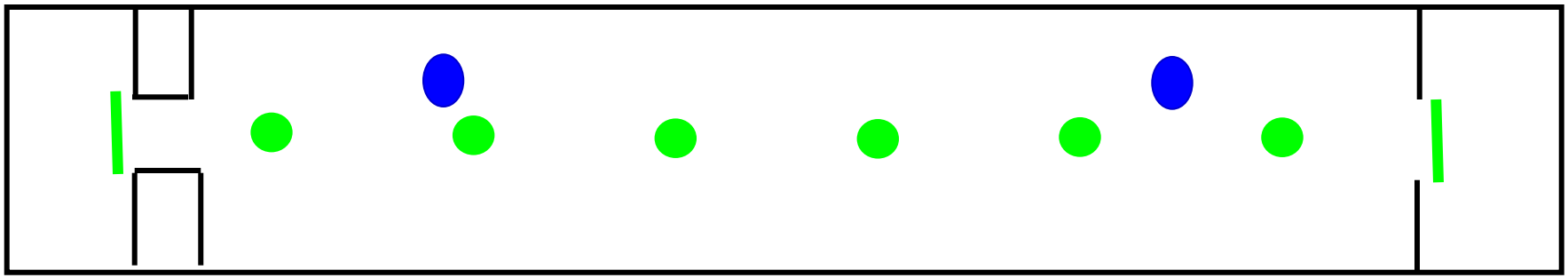
Large Fan

Small Fan

Firefighter

Cabin: Ventilation Rate Measurement

- Both extinguishers are discharged simultaneously, aiming above the other firefighter
- At 9 seconds, firefighters turn quickly 180 degrees, not interrupting the discharge.
- Stopped discharge 30- 40s after initiation.
- Gas sampling system optimized to provide quick response.



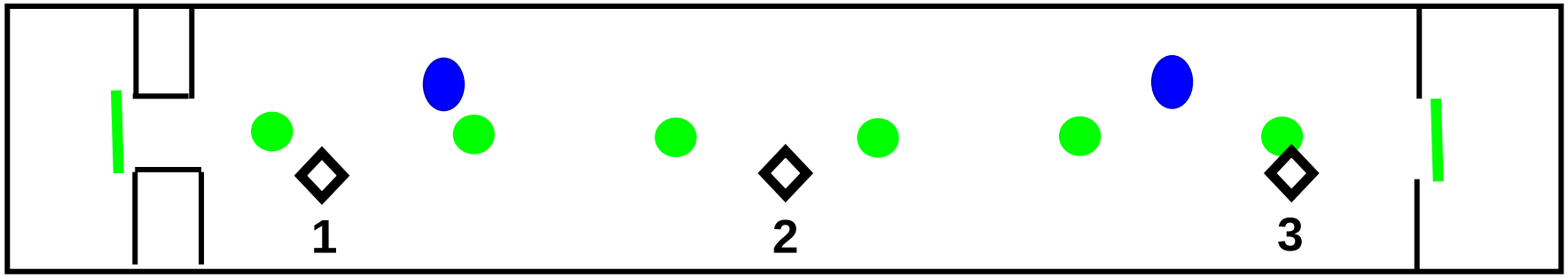
Large Fan

Small Fan

Firefighter

Cabin: Ventilation Rate Measurement

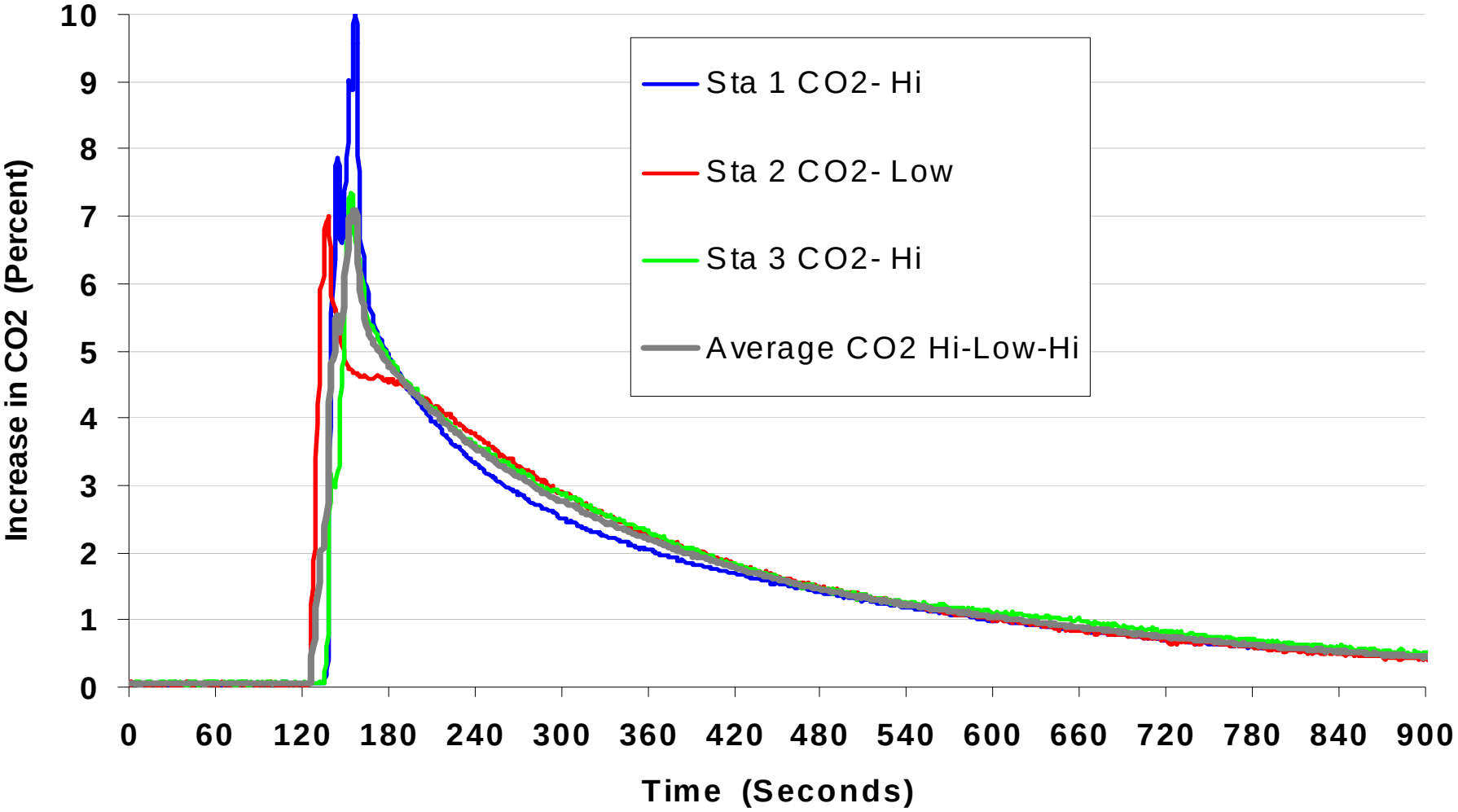
- 3 CO_2 analyzers, 3 stations
- Stations 5’ from exit lights above entrances to the forward and aft galleys. 6” inboard of center isle.
- Sample at 2 heights:
  - High: 3” off celing.
  - Low: 3” off floor.
- Run 2 tests: Hi, Low, Hi and Low Hi Low



◇ Sampling Station

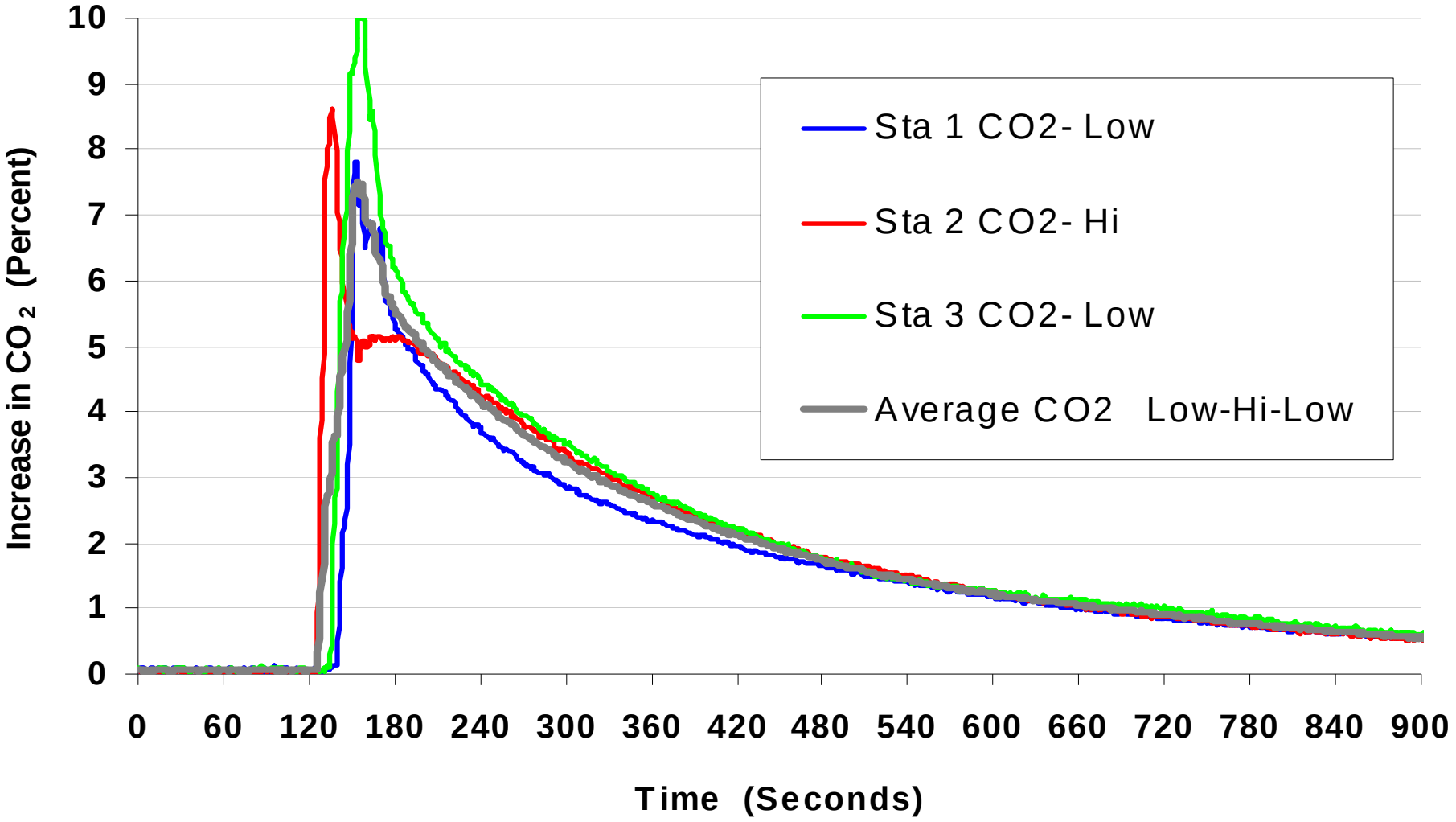
Cabin: Ventilation Rate Measurement

CO_2 Concentration Histories – Test 3: Hi- Low- High.



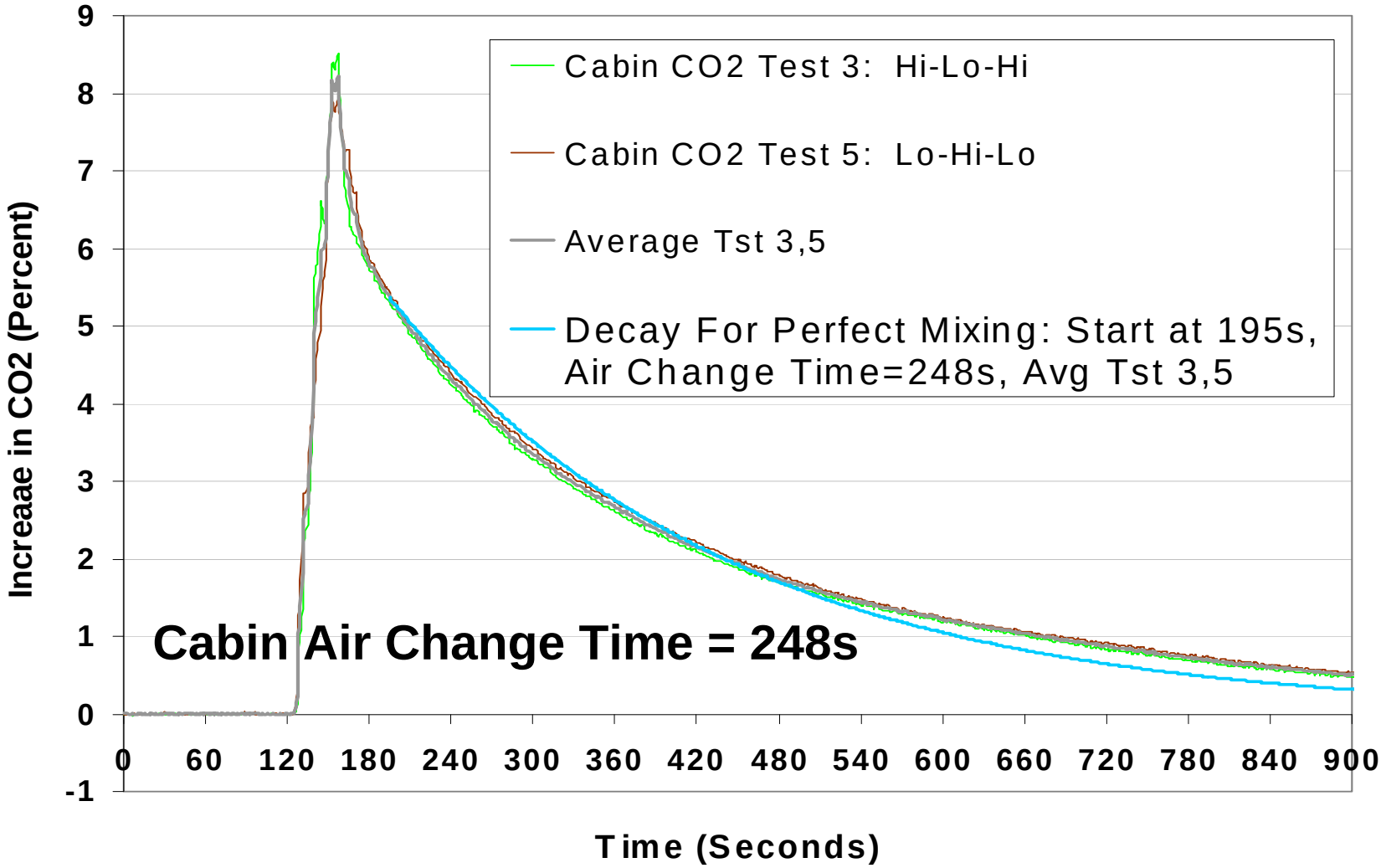
Cabin: Ventilation Rate Measurement

CO_2 Concentration Histories – Test 5: Low- Hi- Low



Cabin: Ventilation Rate Measurement

CO_2 Concentration Histories Normalized for 40 lb. Total Discharge.



B 737 Flight Deck

Flight Deck: Plan:

- Discharge one 5 B:C Halon 1211 extinguisher with side to side sweeping motion.

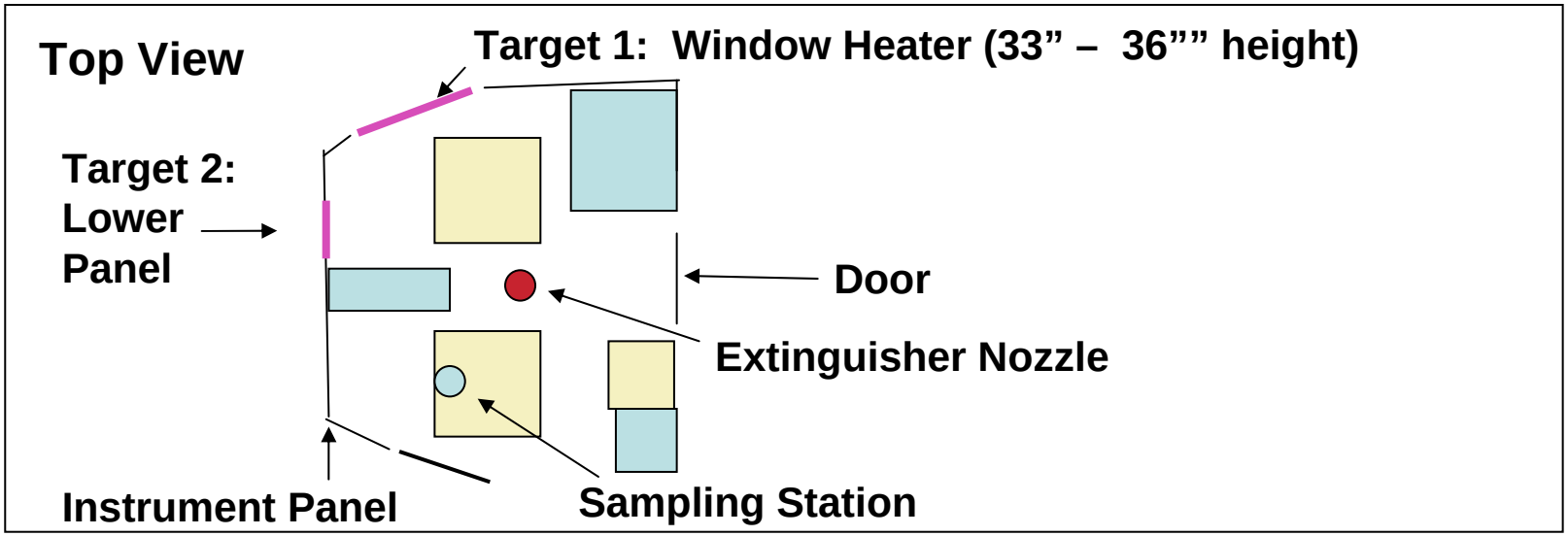
- Firefighter seated in aft port seat behind pilot. Nozzle height= 36”,
  - Scenerio 1: Target: copilot’s window heater.
    Target: 33” to 36” height, width of target=17”. Target is 38” from nozzle.
  - Scenerio 2: Target: copilot’s instrument panel. 17” to 25” off floor, 10” width, Target distance from centerline: 9” to 19”. Target is 42” from nozzle.

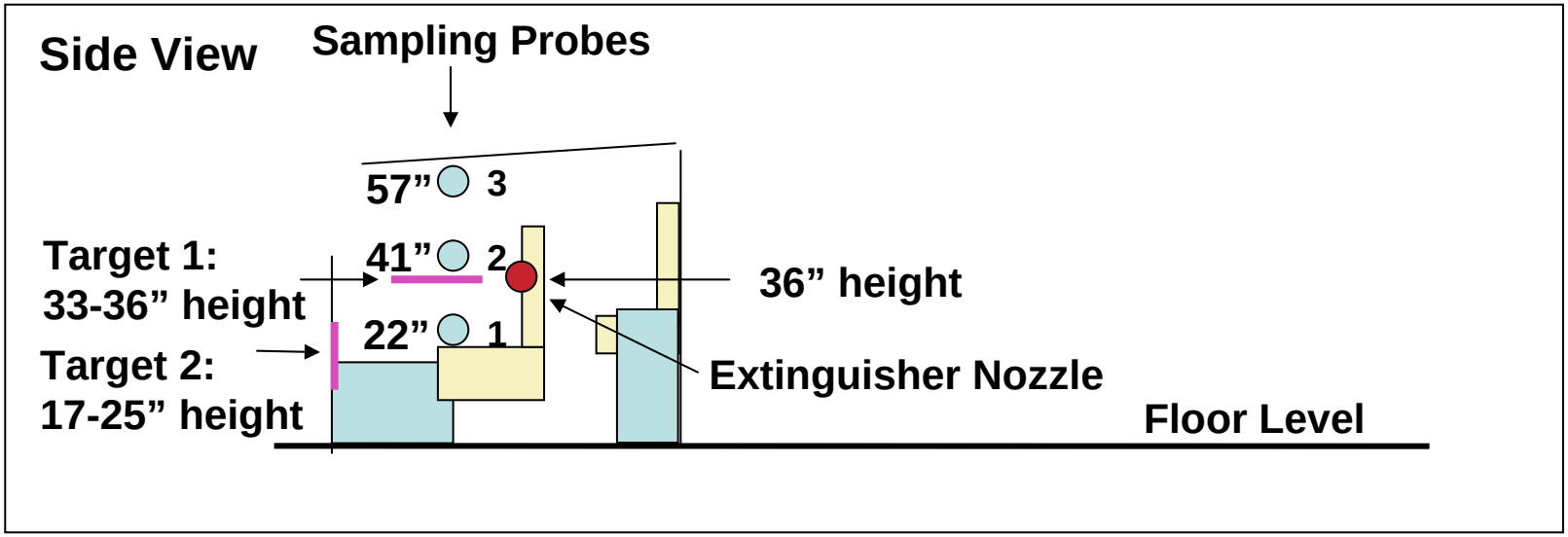
- Sample position: Pilots nose position
  - 3 Heights:
    - 57” Standing
    - 41” Seated
    - 22’ Resting nose height

- Predict maximum arterial concentrations (B_{Max}) for each Halon 1211 discharge test.

$$MF(Stratification\&Localization) = \frac{B_{Max}(Ventilated - PerfectMixing)}{B_{Max}(Ventilated - Stratification - Localization)}$$

Flight Deck Tests using NDIR Gas Analyzers





Flight Deck Targets

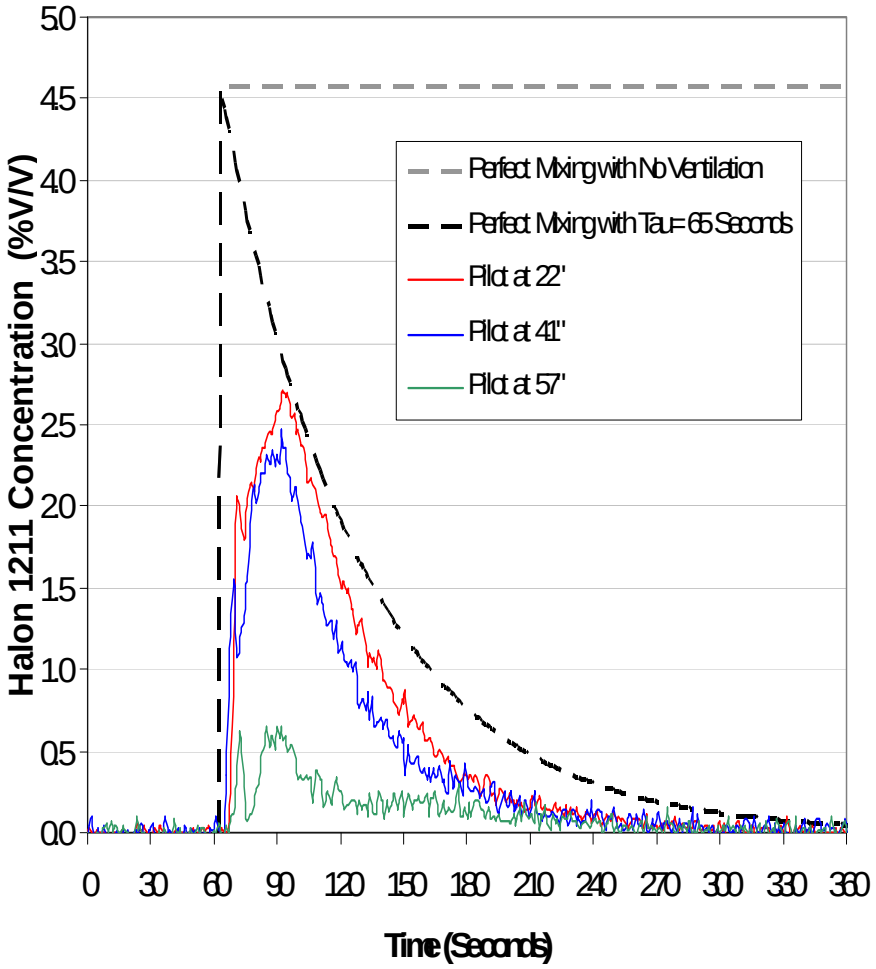
Flight Deck Sampling Position : Above Pilot's Seat

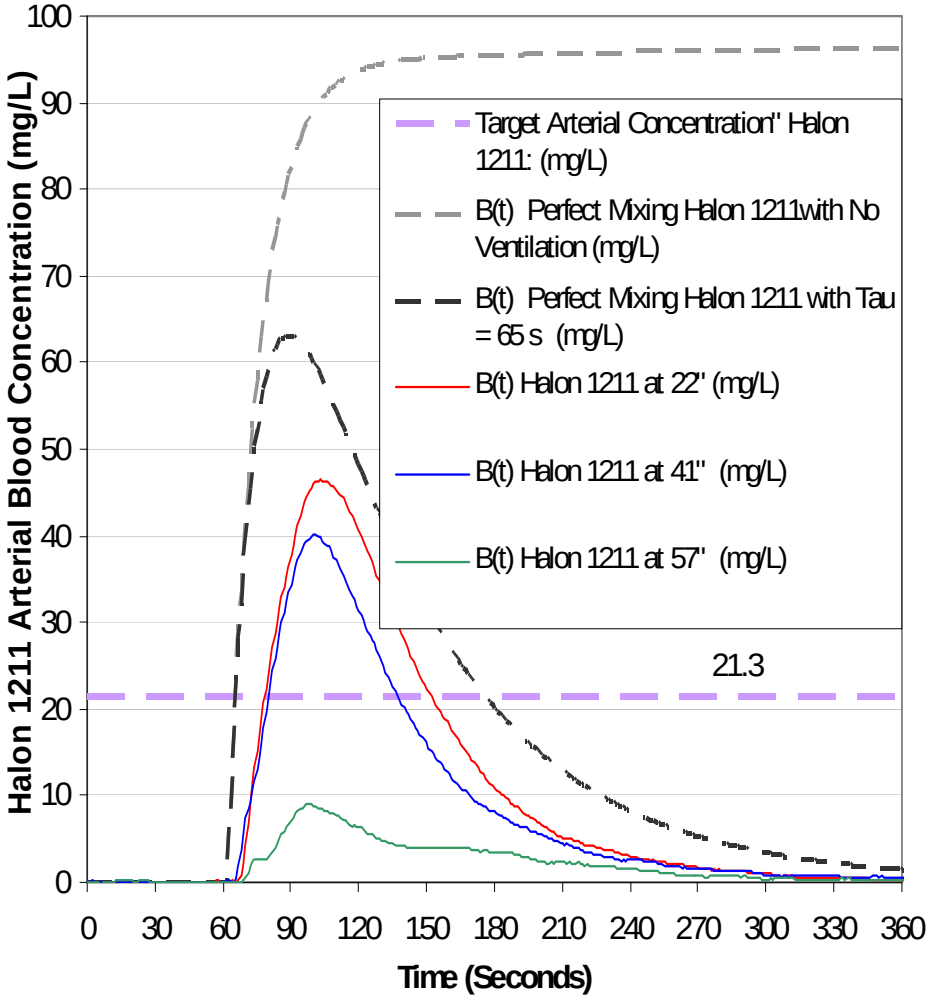
Flight Deck Tests: Target: Copilot's Window Heater

Flight Deck Test 1: Target: Copilot's Window Heater

$MF_{\text{Stratification \& Localization}} =$ **1.36, 1.57, 6.99, (22", 41",57")**

Based on Halon 1301 kinetics

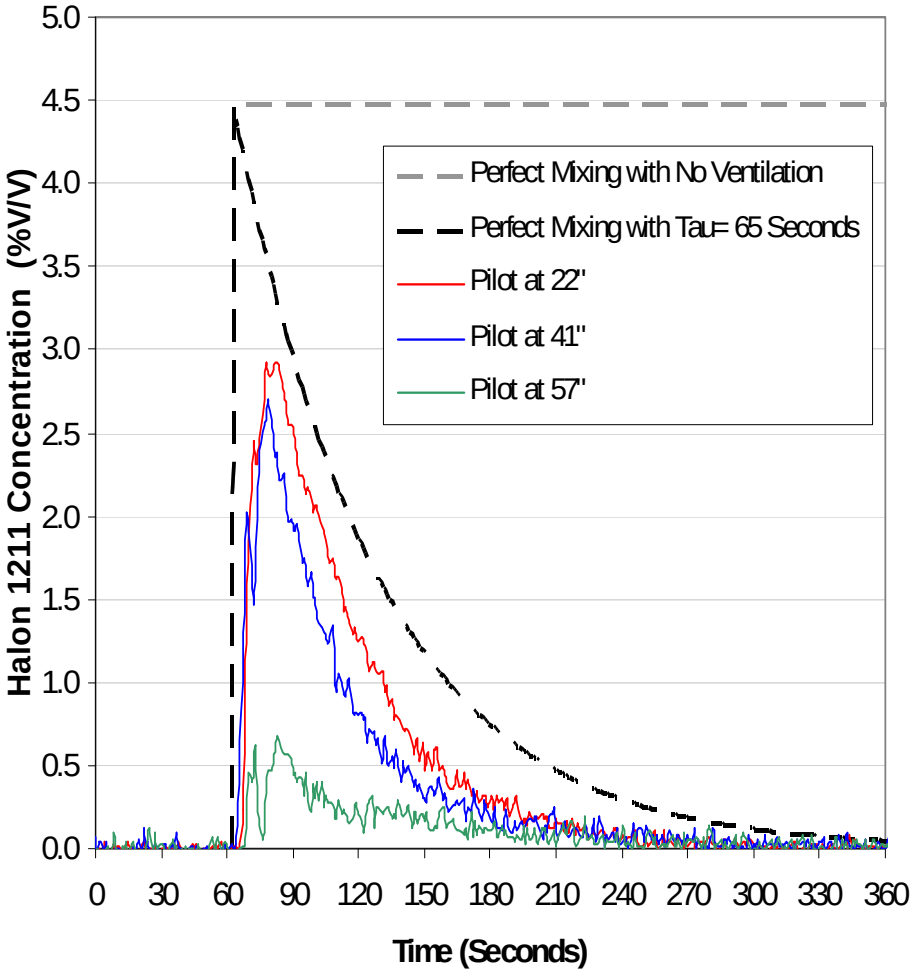


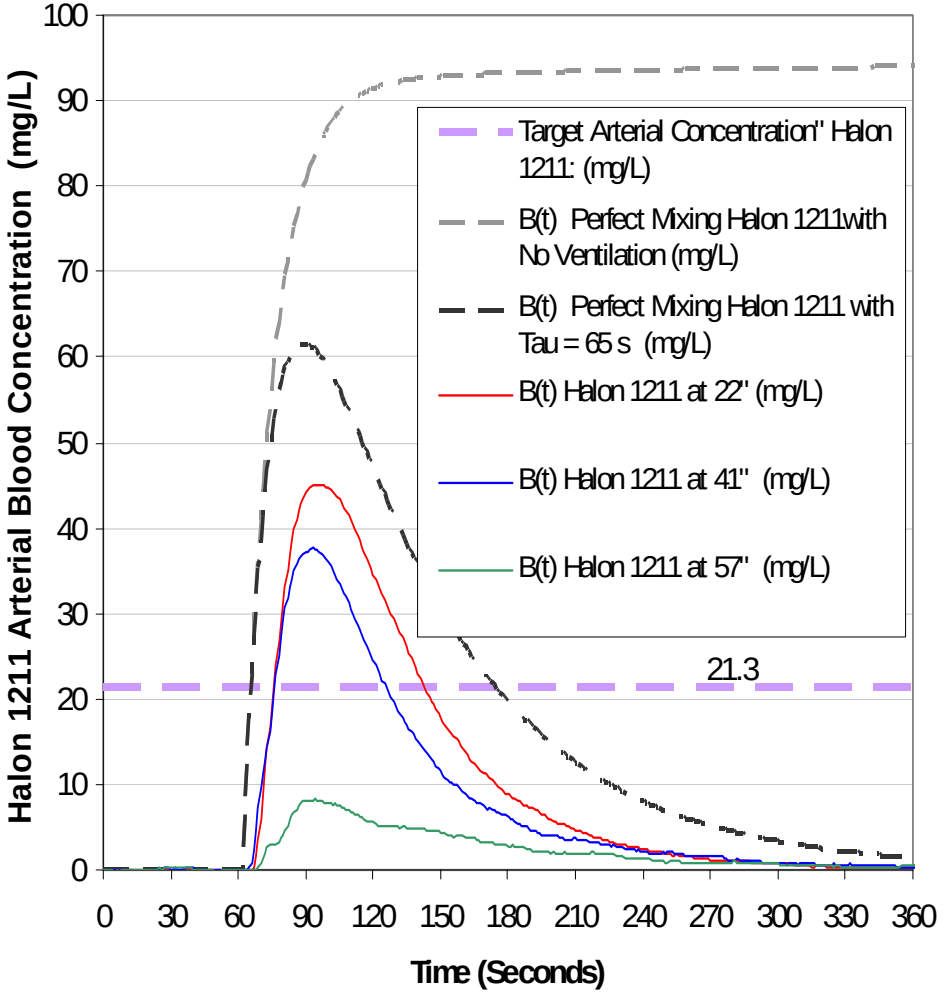


Flight Deck Test 5: Target: Copilot's Window Heater

$MF_{\text{Stratification \& Localization}} =$ **1.36, 1.63, 7.47 (22", 41",57")**

Based on Halon 1301 kinetics



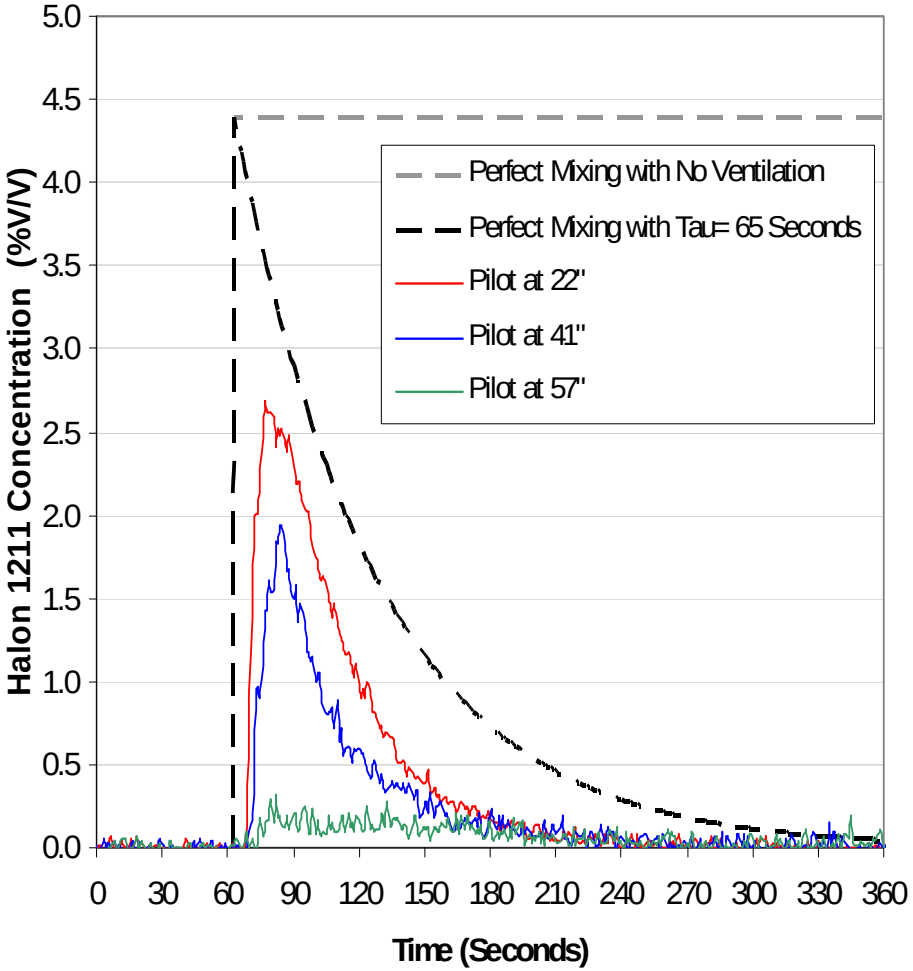


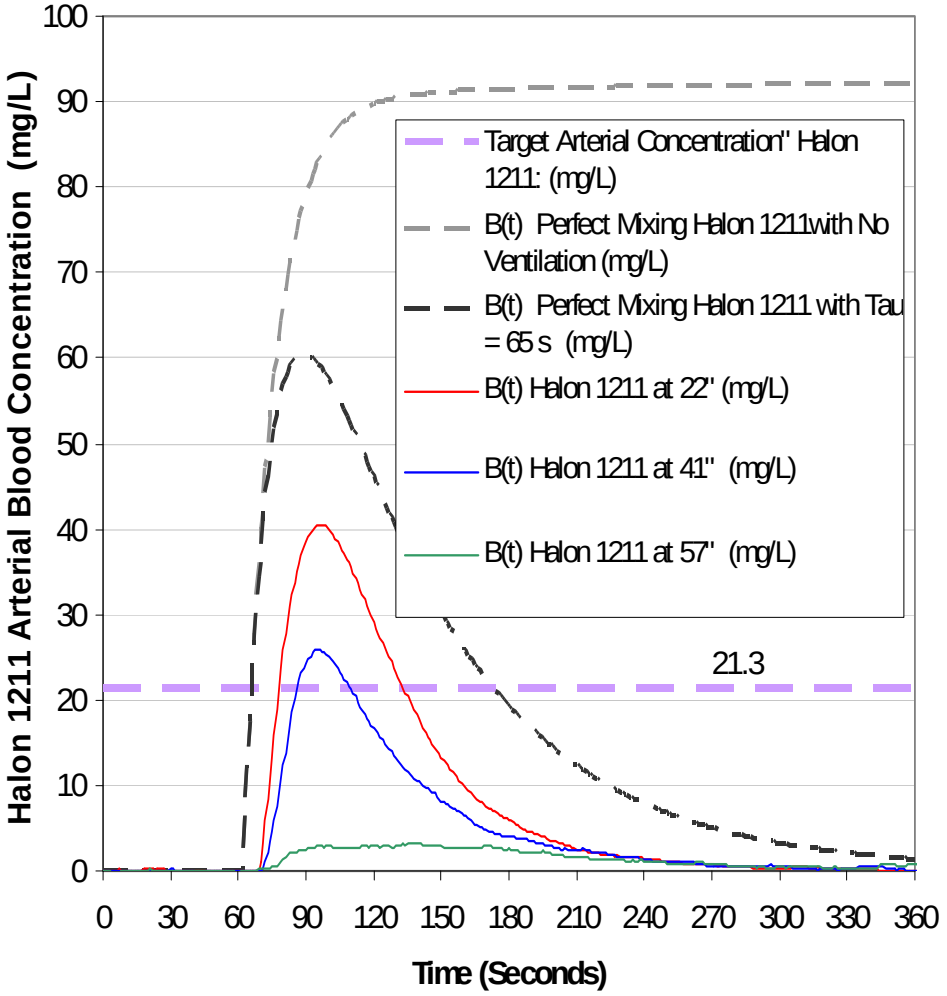
Flight Deck Tests: Target: Copilot's Instrument Panel

Flight Deck Test 3:Target: Copilot's Instrument Panel

MF $_{\text{Stratification \& Localization}}$ = **1.49, 2.33, 18.7 (22", 41", 57")**

Based on Halon 1301 kinetics

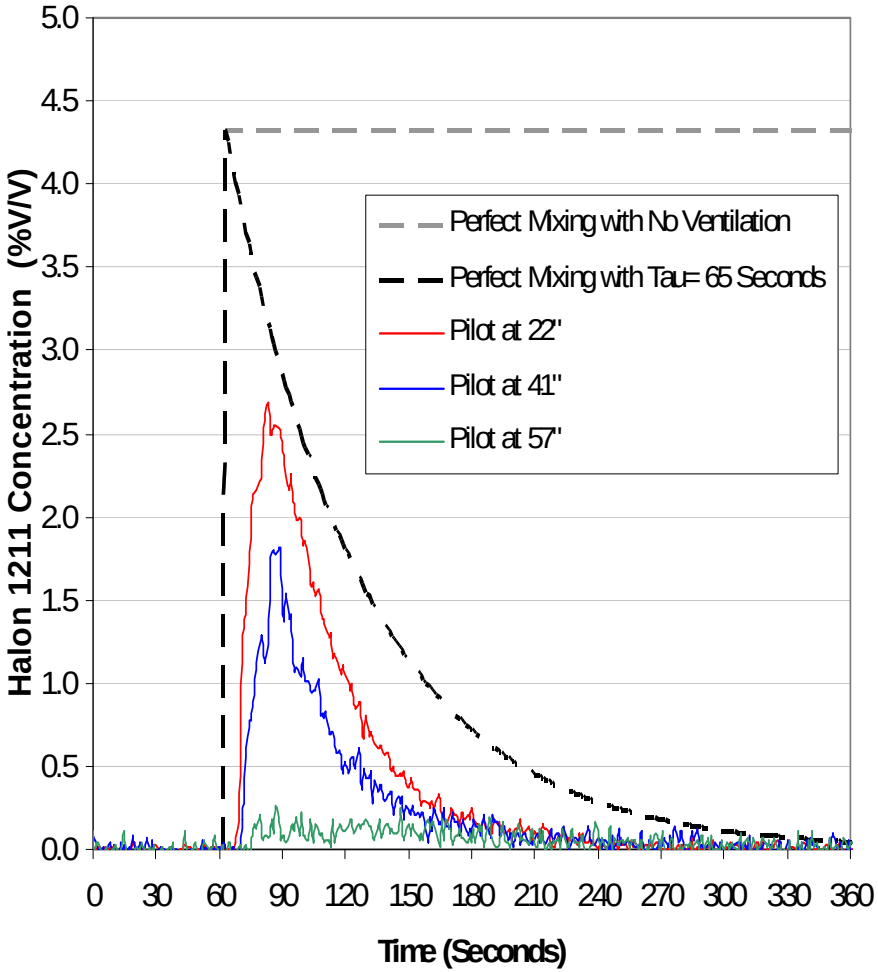


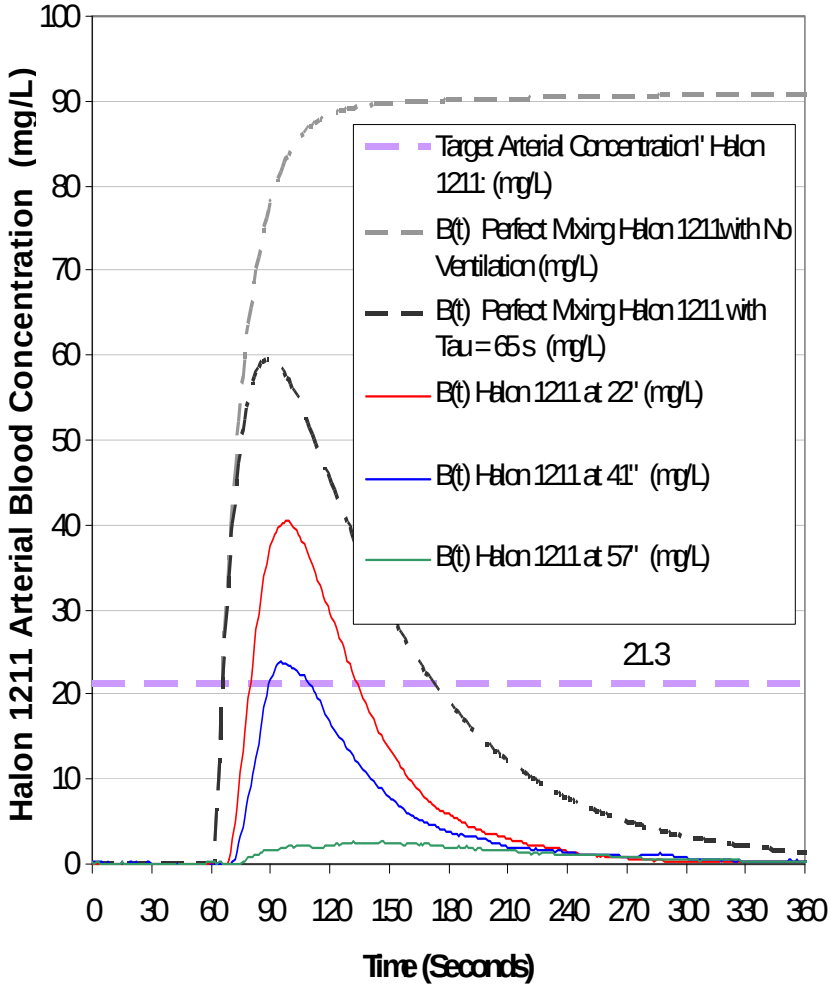


Flight Deck Test 4 :Target: Copilot's Instrument Panel

$MF_{\text{Stratification \& Localization}} = 1.47,\ 2.49,\ 22.3\ \ (22", 41", 57")$

Based on Halon 1301 kinetics





Flight Deck Test Results:

Stratification/ Localization MFs

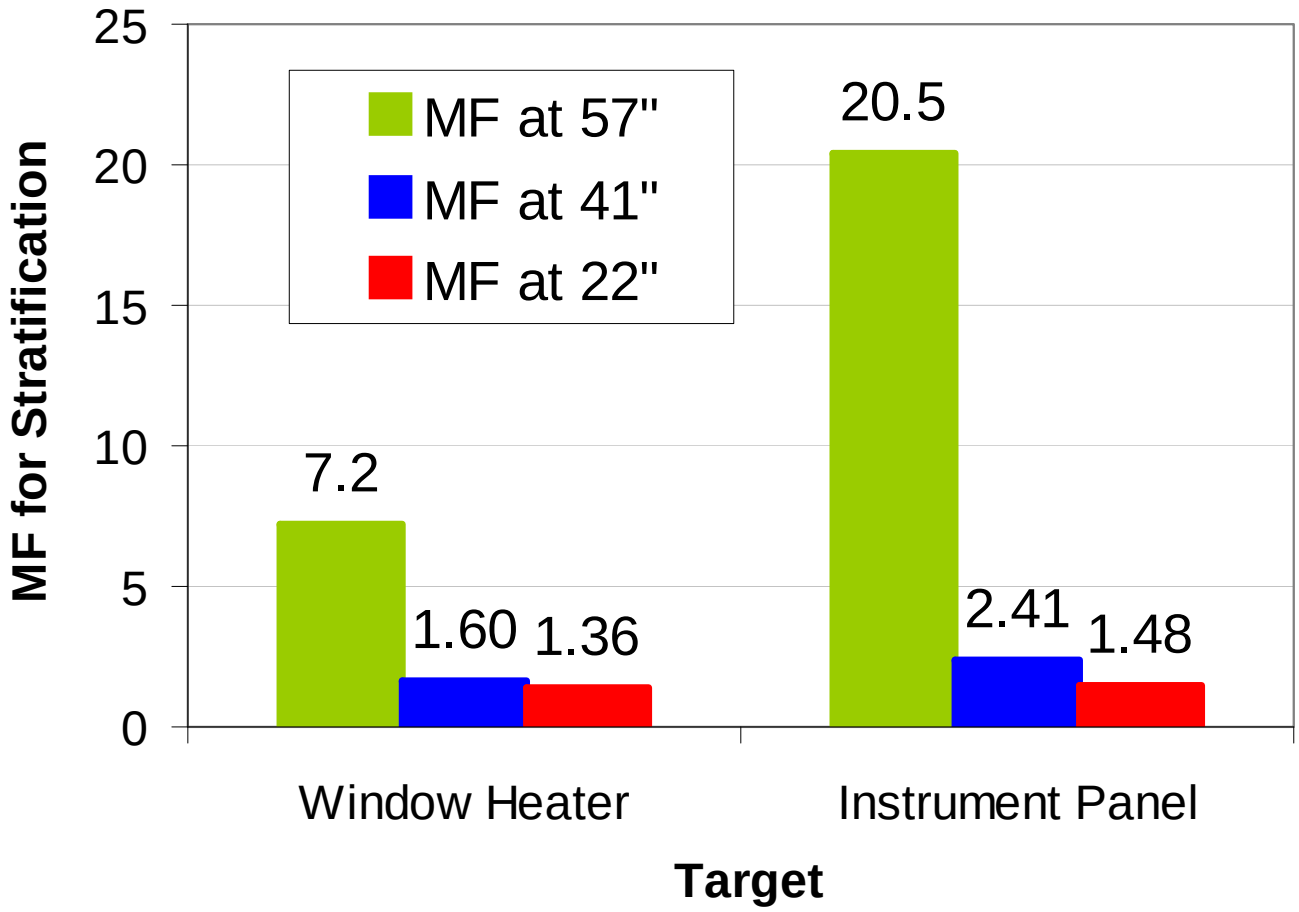
Based on Halon 1301 Kinetics

Target	Test	MF at 22"	MF at 41"	MF at 57"
Copilot's	1	1.36	1.57	6.99
Window	5	1.36	1.63	7.47
Heater	**Average**	**1.36**	**1.60**	**7.23**
Copilot's Lower	3	1.49	2.33	18.7
Instrument	4	1.47	2.49	22.2
Panel	**Average**	**1.48**	**2.41**	**20.5**

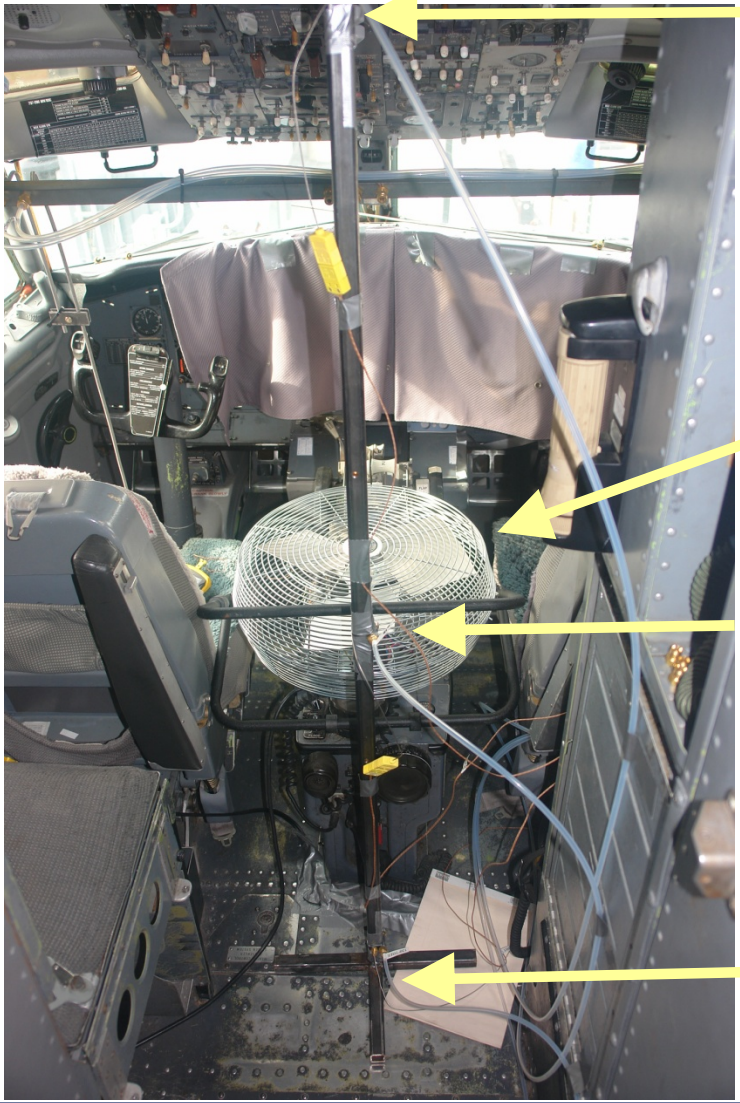
Flight Deck Test Results:

Stratification MFs

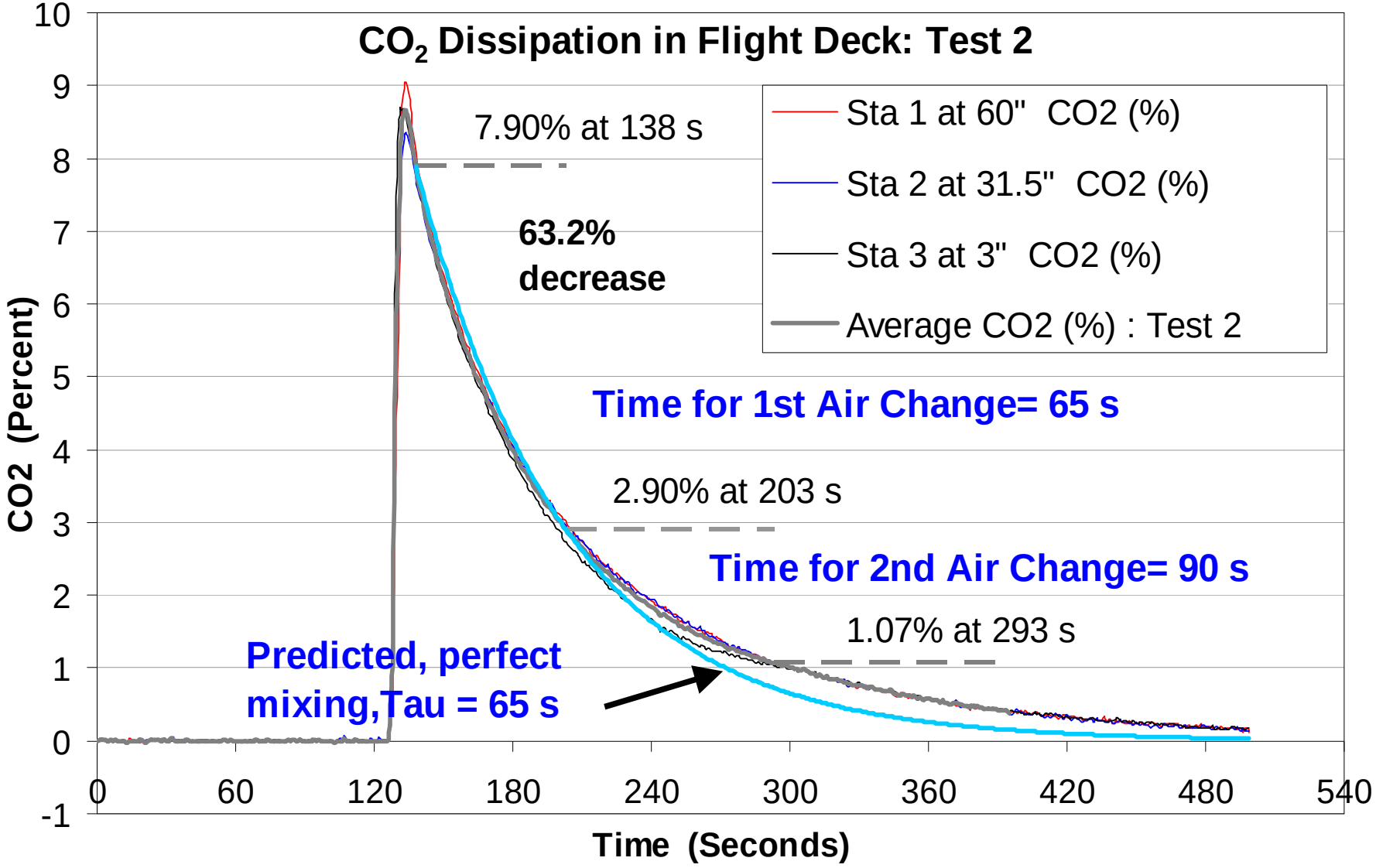
Based on Halon 1301 Kinetics



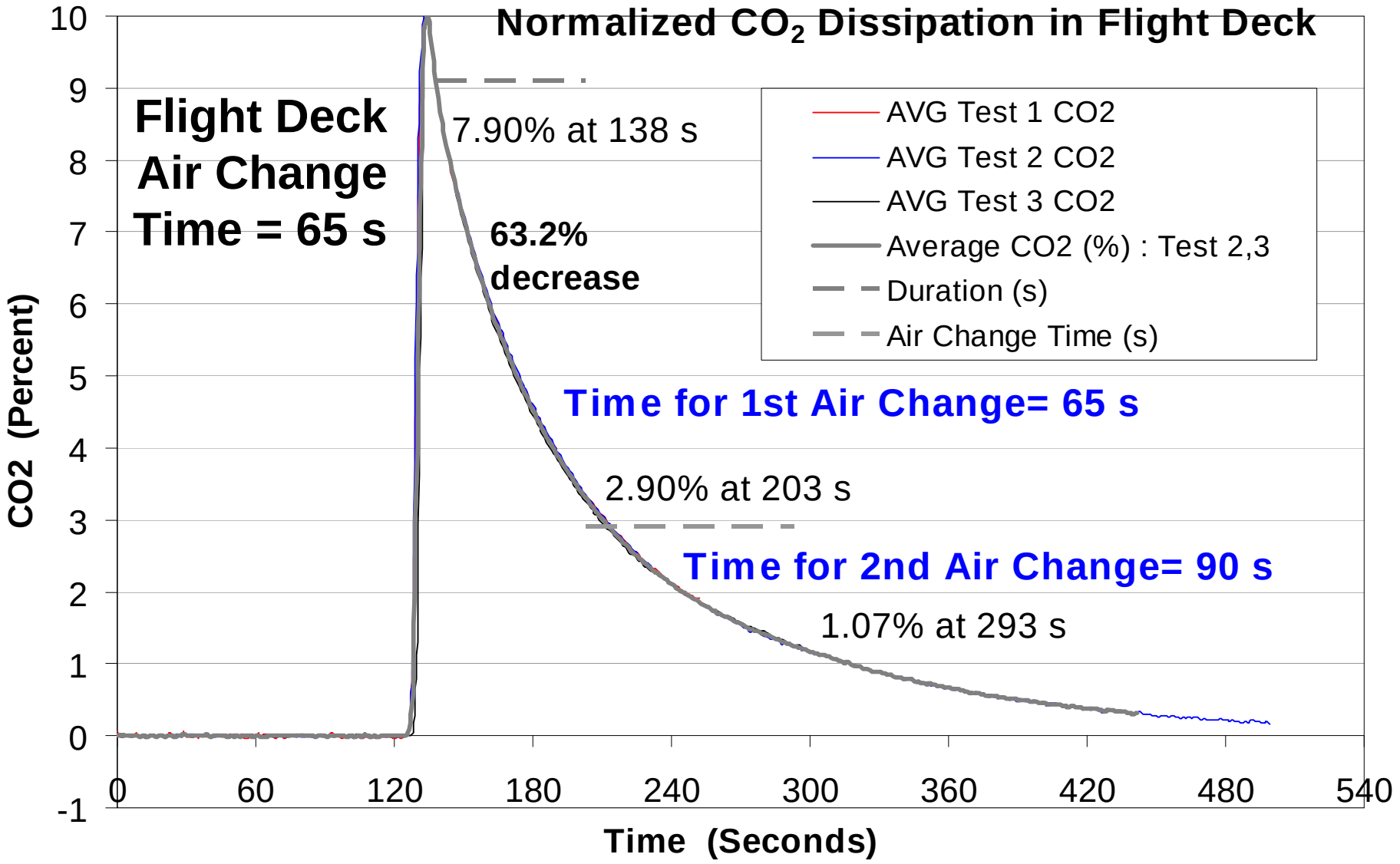
Flight Deck: Ventilation Rate Measurement



Flight Deck: Ventilation Rate Measurement



Flight Deck: Ventilation Rate Measurement



Summary of MFs Ventillation & Stratification and General Guidance *(based on Halon 1301 kinetics)*

B-737 Cabin:

- **Firefighter's position: MFs: (60", 41" and 22" heights): 13.7, 0 .79, 0. 44**
- **12' behind the firefighter: MFs: (60", 41" and 22" heights): 80.3, 54.8, 1.0**
- ***Provide guidance to passengers to move away from the fire and to sit upright or stand for 5 minutes.***
- ***If above guidance is followed, cabin $MF_{localization/stratification}$ can be set based on the size of the aircraft, providing a safety actor.***

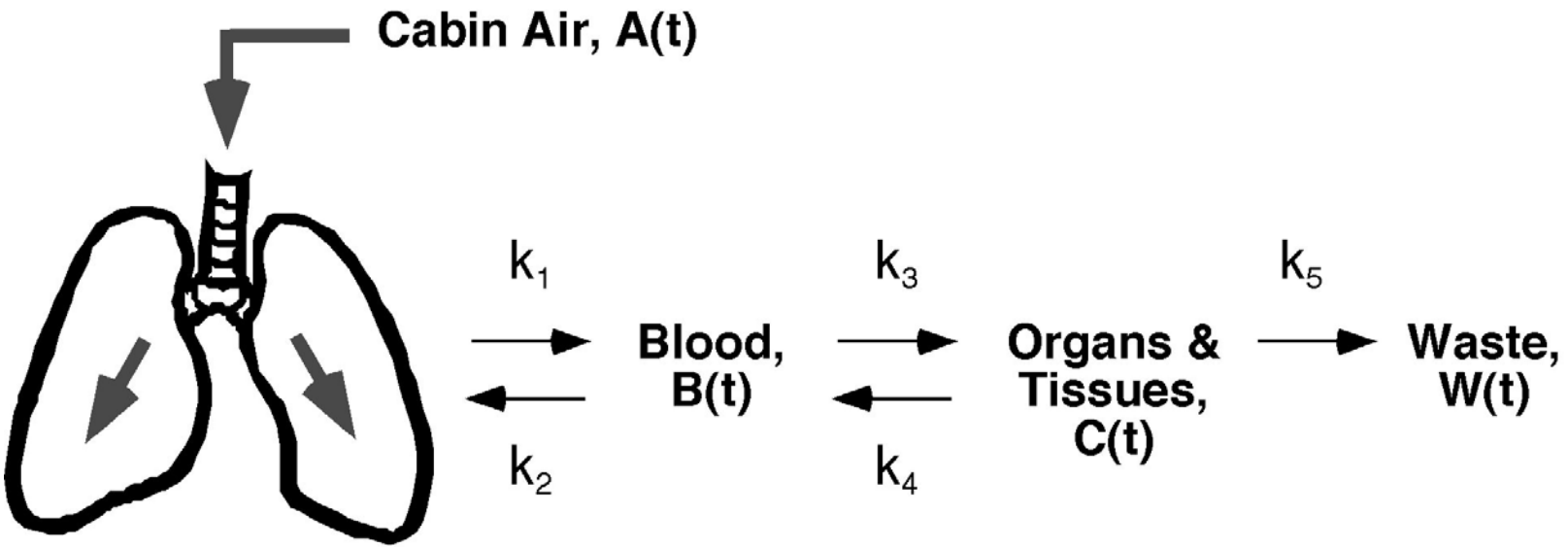
Flight Deck :

- **Pilot's Position: MFs: (57", 41" and 22" heights): 7.2, 1.60, 1.36**
- **Provide guidance to crew to move away from the fire and to sit upright or stand for 3 minutes.**
- ***If the above guidelines are followed, MF can be safely set to 1.6.***

Conclusions

- **Localization is significant for the cabin tests, resulting in higher than theoretical perfect mixing Halon 1211 concentrations at the firefighter's position at 41" and 22" resulting in corresponding S&L MFs less than one : 0.79 and 0.44 respectively.**
- **Stratification is significant for the cabin and flight deck tests.**
- **Multiplication factors for stratification/ localization were determined by test to allow safe use of higher charge weights of extinguishant. Calculations were based on Halon 1301 kinetics.**
- **Multiplication factors would be higher, if Halon 1211 kinetics was used.**

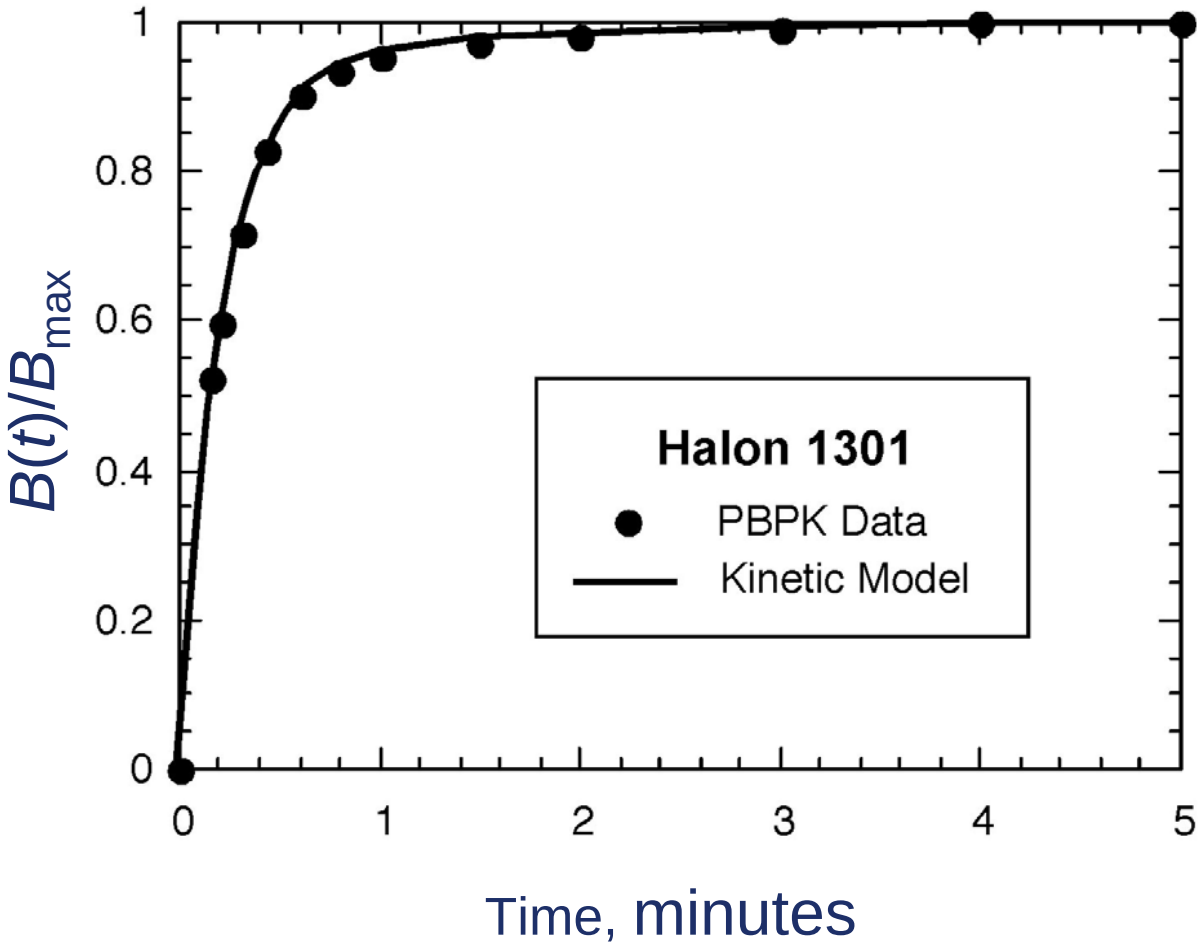
Simplified Kinetic Model



Simulates human arterial blood concentration histories from inhaled constant or dissipating halocarbon concentrations

Comparison of Kinetic Models for Halon 1301:

Unventilated Compartment, constant concentration ($\tau = \infty$)



Arterial Blood Concentration, B(t)

General equation for changing Halocarbon Concentrations:

$$B(t) = k_1 \int_0^t A(x) e^{-k_{23}(t-x)} dx +$$

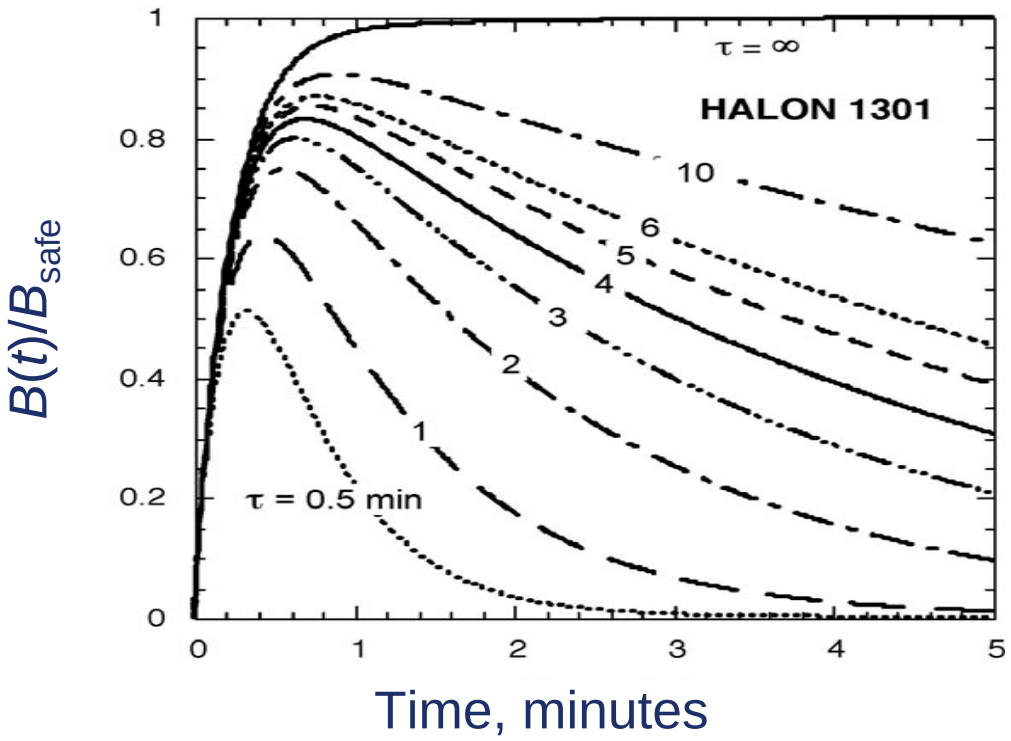
$$k_3 k_4 P_{BA} \int_0^t \left(\int_0^t A(x) e^{-k_4(t-x)} dx \right) e^{-k_{23}(t-y)} dy$$

From:

1) Lyon, R.E. and Speitel, L.C., "A kinetic model for human blood concentrations of gaseous fire-extinguishing agents", *Inhalation Toxicology,* Volume 22, No. 14, December 2010, pp. 1151-1161.

2) Speitel, L.C. and Lyon, R.E, "Guidelines for safe use of gaseous halocarbon extinguishing agents in aircraft", FAA report DOT/FAA/AR-08/3, August 2002., **http://www.fire.tc.faa.gov/pdf/08-3.pdf**

1st Order Kinetic Modeling of Halon 1301 in Ventilated Compartments



Ratio of the Arterial Blood Concentration of Halon 1301 to the Target Value B_{safe} for Simulated Human Exposures to A_{safe} in a Ventilated Cabin at the Indicated Air Exchange Times