Stratification/Localization Guidance for Handheld Halon 1211 Agent in Aircraft

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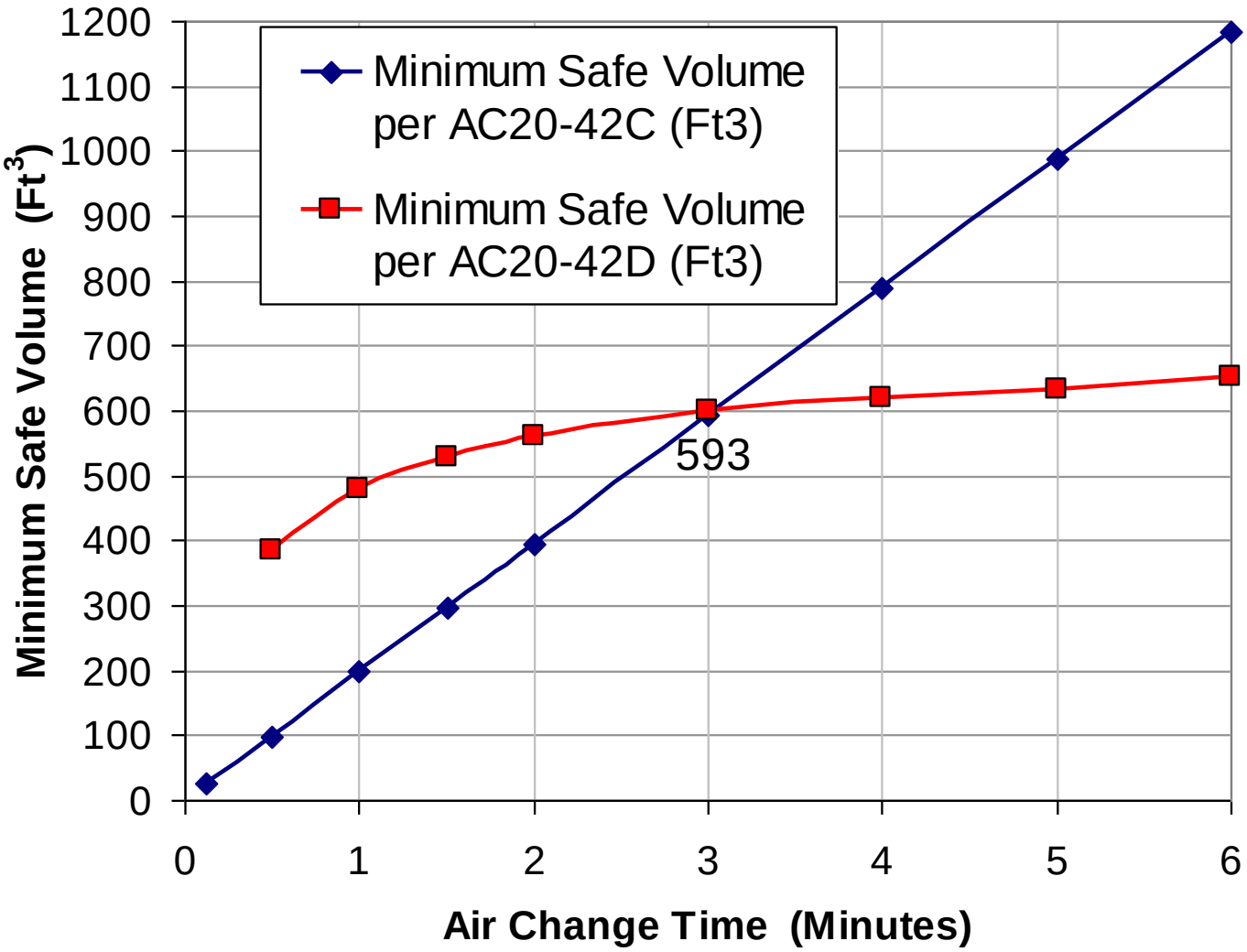
Background

- Per AC20-42D, Halon 1211, Halotron, and BTP do not meet the safe-use guidance for use in flight decks and other small volumes.

- AC 20-42D, Chapter 4.4b(3), (4) states that concentrations of halocarbons 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.

- Safe use guidance for all halocarbons is based on not exceeding a target arterial concentration of that halocarbon.

Comparison of Minimum Safe Volumes for 2.5 lb Halon 1211 (Perfect Mixing)



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 AC20-42D

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.

Ventilation Multiplication Factors ($MF_{Ventilated}$) *(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 *$MF_{Ventilated}$ are similar for all non-chlorinated halocarbons.*

B737 Cabin: τ = 1.08 min, Flight Deck: τ = 4.13 min Cessna 210C : τ = 1.16 min

Objective

Provide guidance in the form of test- based multiplication factors *MF Stratification & Localization* to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization.

- ***MF Stratification & Localization*** **indicates the increased safety relative to perfect mixing concentrations (ratio of maximum arterial blood concentrations):**

$$\mathbf{MF}_{\text{Stratification \& Localization}} \equiv \frac{B_{Max}(\text{Ventilated, Perfect Mixing})}{B_{Max}(\text{Ventilated, Stratification \& Localization})}$$

- **Test-based multiplication factors *($MF_{Stratification\text{-}Localization}$)* can be applied (after *$MF_{Ventilated}$* are applied).**

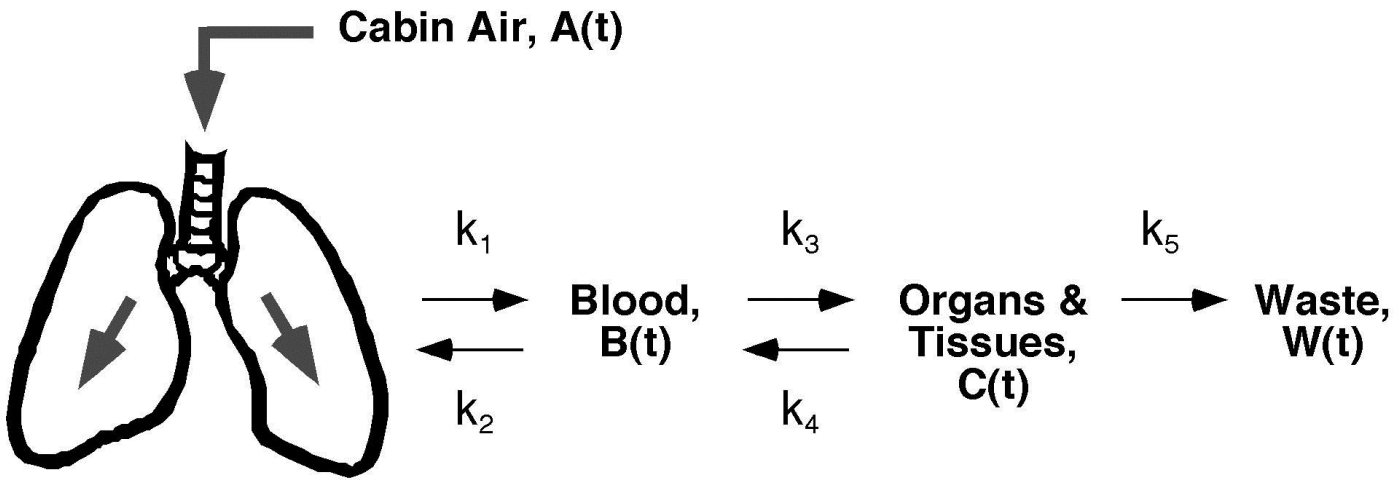
- ***MF Stratification & Localization*** **is to be applied only to streaming agents with boiling points ≥ Halon 1211 boiling point.**

Method

- $MF_{Stratification\ \&\ Localization}$ is a multiplier for the maximum agent perfect mixing W/V in AC 20-42D, after $MF_{Ventillation}$ is applied.

- An accurate air change time and accurate free space volume are needed to determine $MF_{Ventilation}$ *(perfect mixing)* and $MF_{Stratification\text{-}Localization.}$

- Compute arterial blood concentration histories for exposures to constant agent concentrations **using FAA's Simplified Kinetic Model and Halon 1301 kinetics . (results match pharmocokinetic modeling)**



Arterial Blood Concentration, B(t)

General equation for changing Halocarbon Concentrations:

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

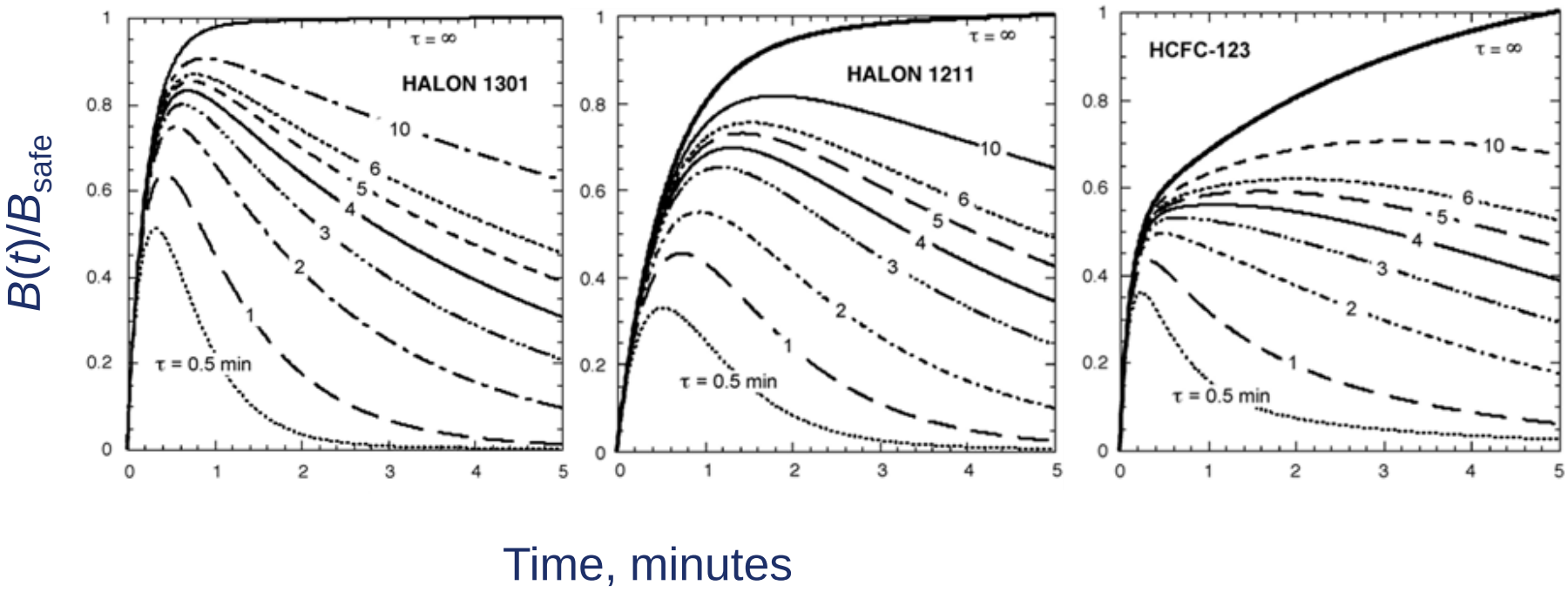
$$k_3 k_4 P_{BA} \int_0^t \left(\int_0^t A(x) e^{-k_4 (t-x)} dx \right) e^{-k_{23}(t-y)} dy$$

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 2009, http://www.fire.tc.faa.gov/pdf/08-3.pdf

1st Order Kinetic Modeling of Halocarbons in Ventilated Compartments



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

Method

Narrow Body Aircraft

- **Conduct B-737 discharge tests in a ventilated aircraft**
  - **Flight Deck:** 129 ft^3 - volume Firefighter = **123 ft^3** free space volume
  - **Rear Cabin:** 3853 ft^3 - volume Firefighter= **3847 ft^3** free space volume

General Aviation Aircraft

- **Retrospective study of discharge tests in a Cessna 210C in a wind tunnel with an airspeed of 120 mph**.
  - 1984 Empty Aircraft: 140 ft^3
  - 1986 Loaded Aircraft: **4 Seated Mannequins + Luggage**


B-737 Tests

B 737 Flight Deck: 129 ft^3 τ = 1.08 Min

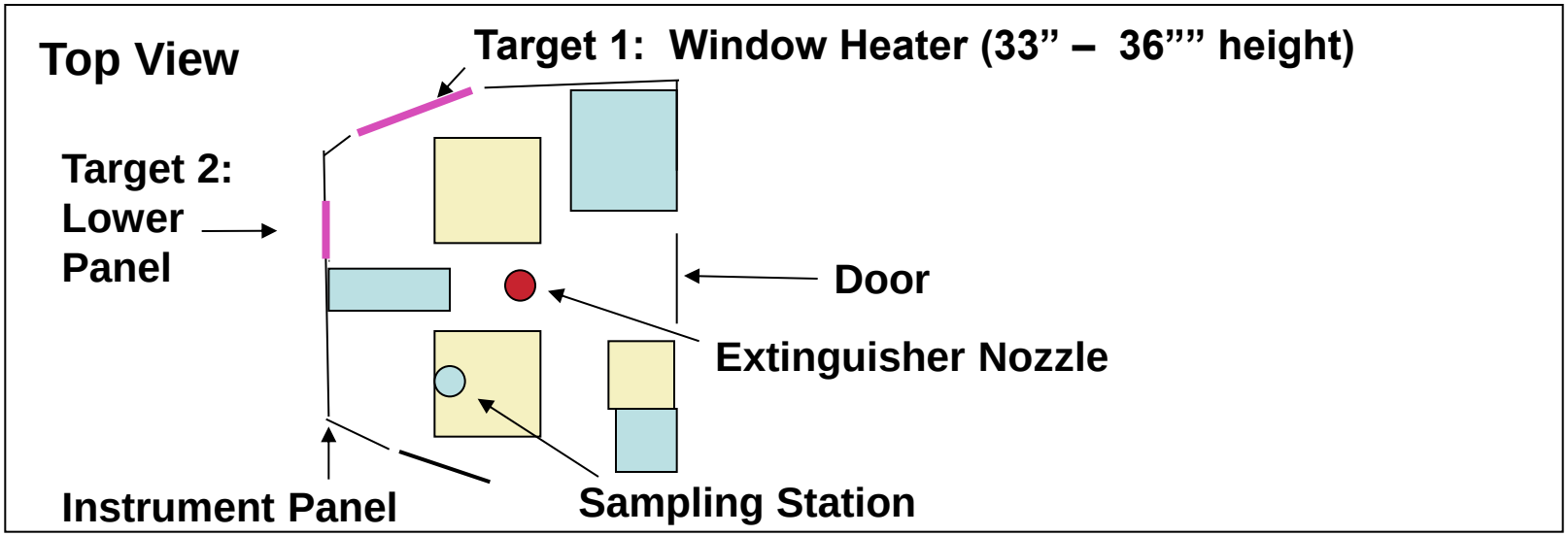
B 737 Flight Deck

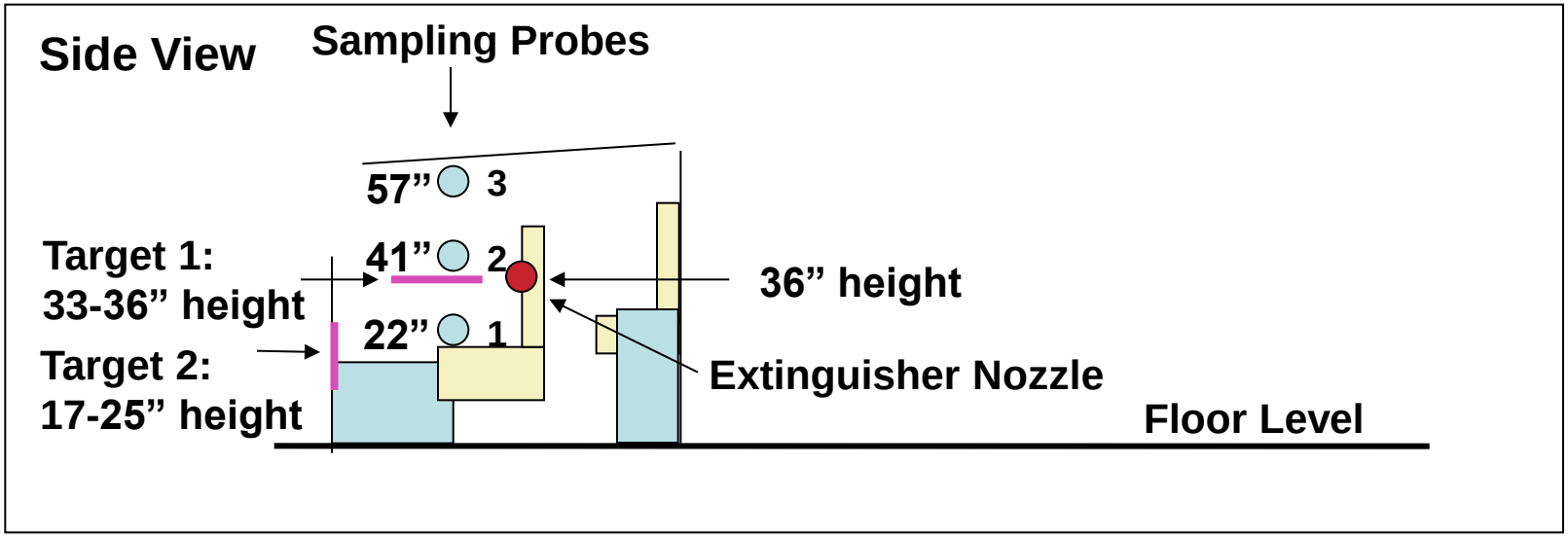
- The seats and enclosed areas were subtracted out.
- The flight deck volume is 129 ft^3
- The firefighter volume (5.7 ft^3) is subtracted out when calculating perfect mixing concentrations
- 1 air pack used, all gasper overseat airports closed
- Air change time by CO_2 discharge test with firefighter:

$\tau_{\text{Flight Deck}}$ = 65s (1.08 min)

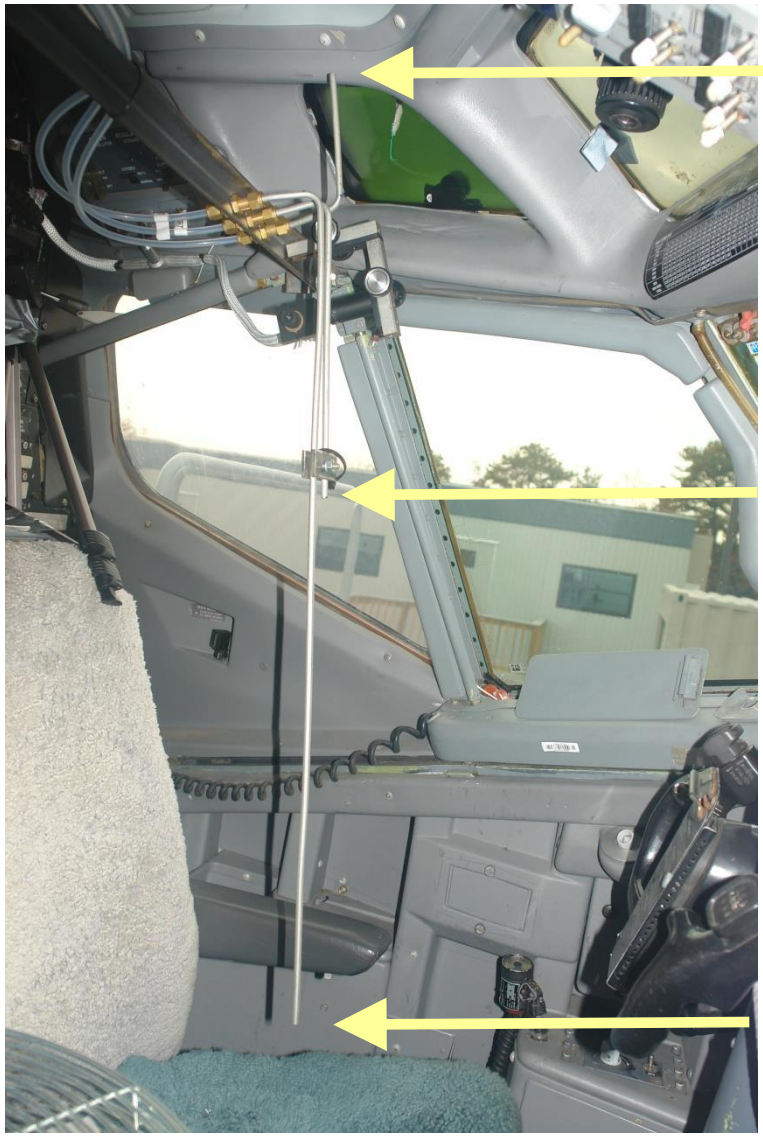
Flight Deck Targets

Flight Deck Tests using NDIR Gas Analyzers





Flight Deck Sampling Position : Above Pilot's Seat

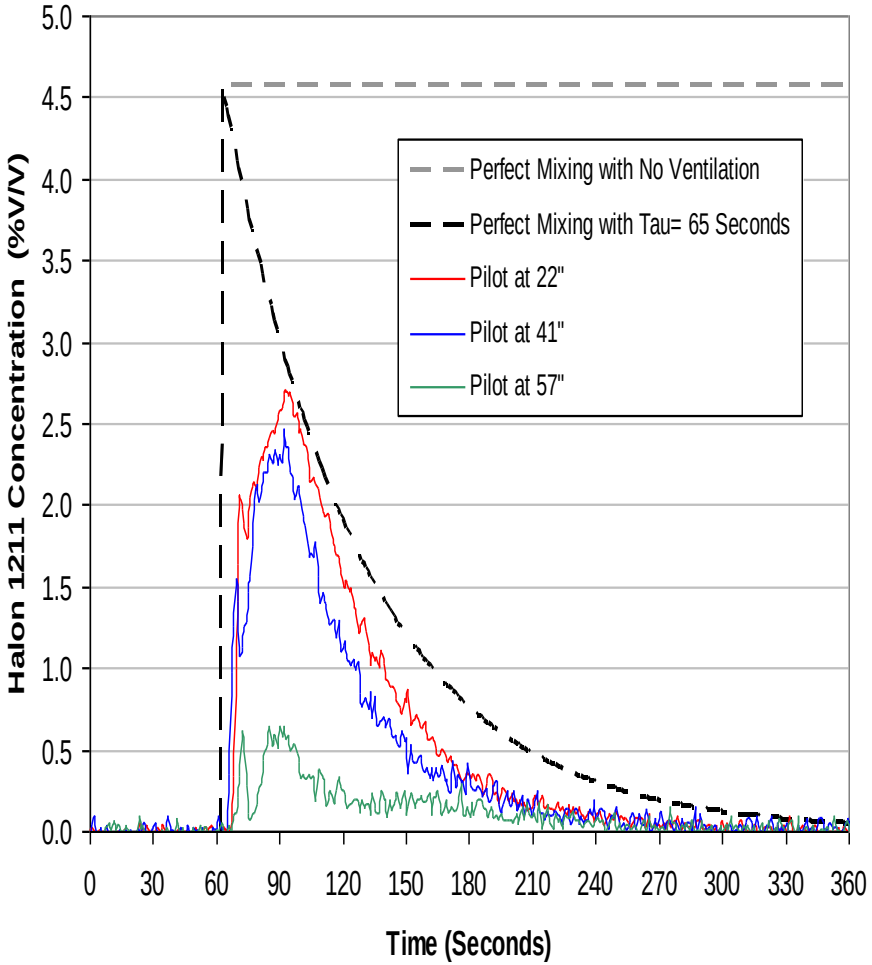


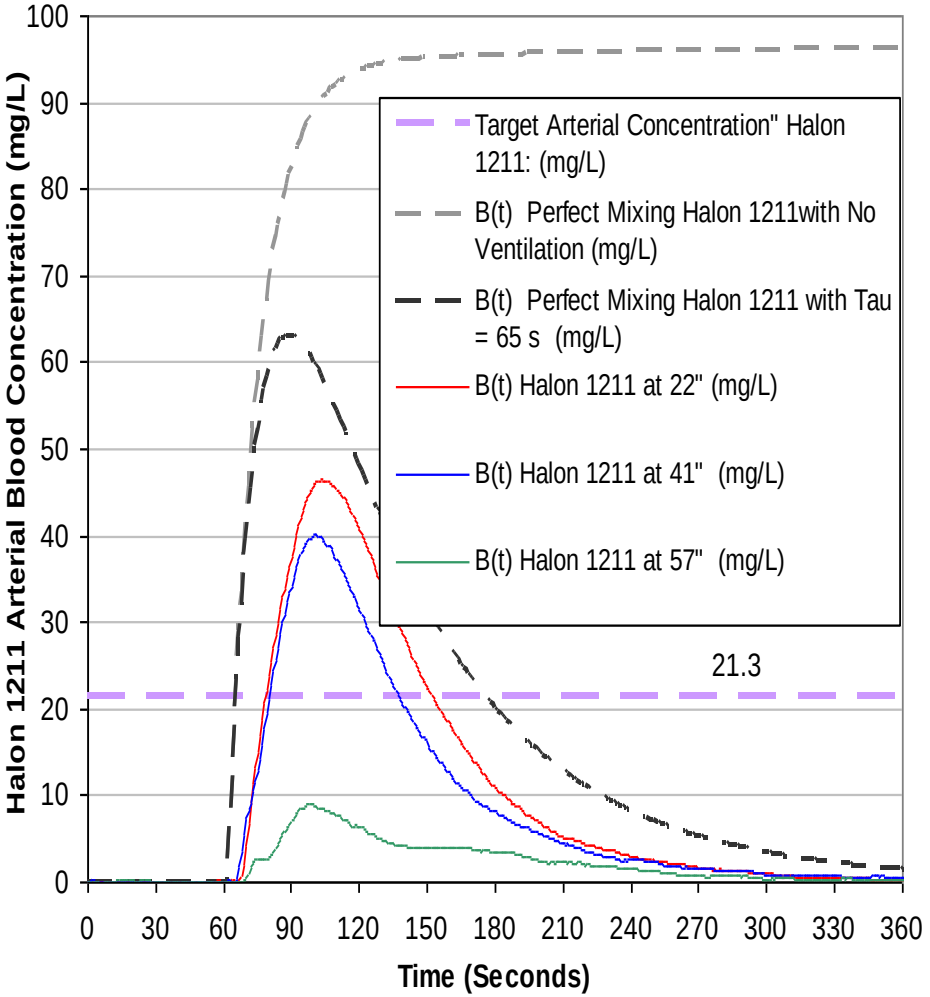
Flight Deck Tests: Target: Copilot's Window Heater

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 Tests: Target: Copilot's Instrument Panel

Flight Deck Test Results:

Stratification/ Localization MFs

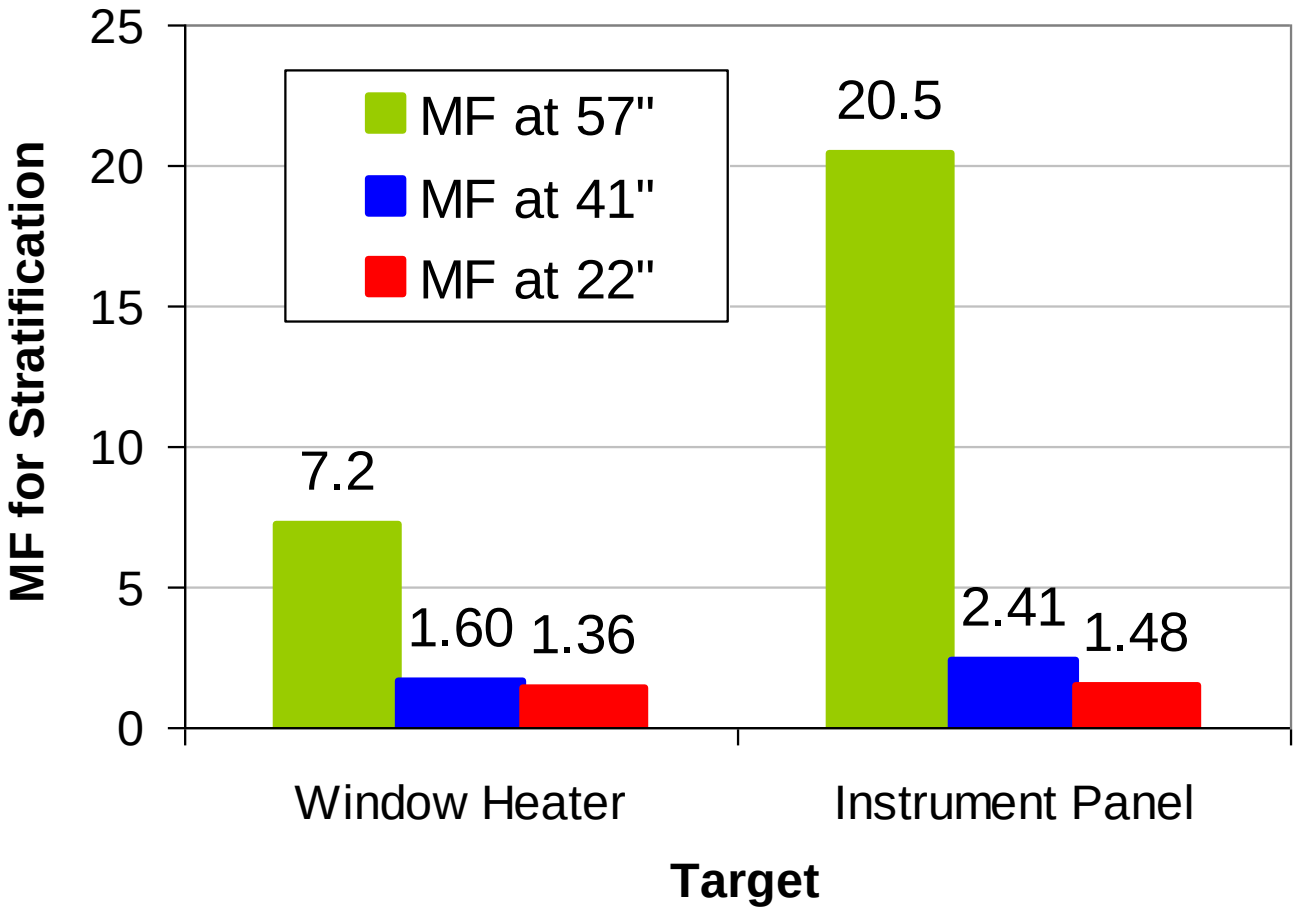
Based on Halon 1301 Kinetics

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**

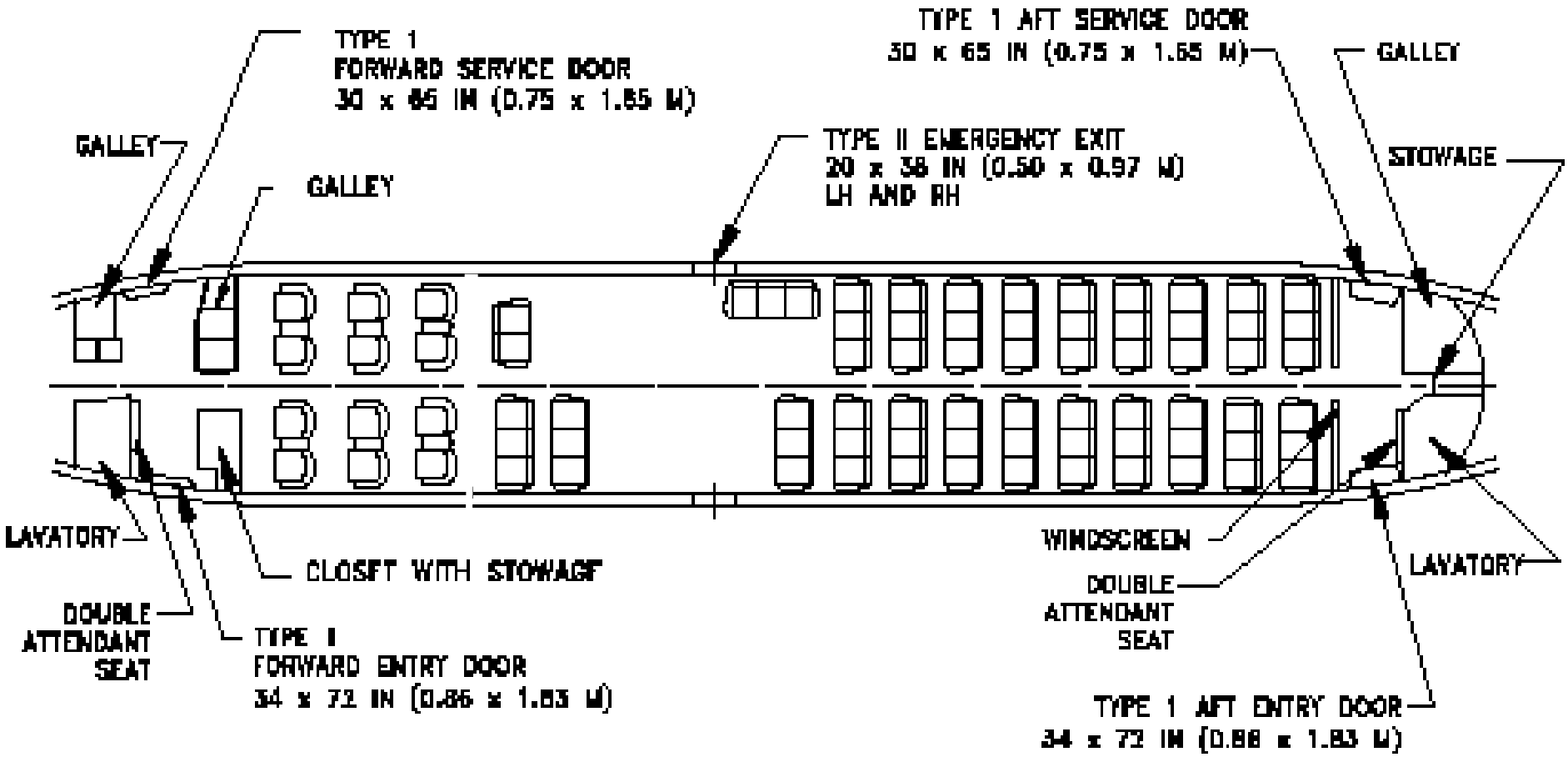
Flight Deck Test Results:

Stratification MFs

Based on Halon 1301 Kinetics



B 737 Cabin: 3853 ft^3 τ = 4.13 min



NOTES:
* 14 FIRST CLASS PASSENGERS, 4-ABREAST SEATING AT 38-IN (0.97-M) PITCH
* 88 ECONOMY CLASS PASSENGERS, 6-ABREAST AT 34-IN (0.86 M) PITCH OR

B 737 Cabin

- The passenger cabin is 52.5 ft long x 11.4 ft wide

- Total Cabin Volume = Front Galley + Passenger Seating Area + Rear Galley = 3853 ft^3

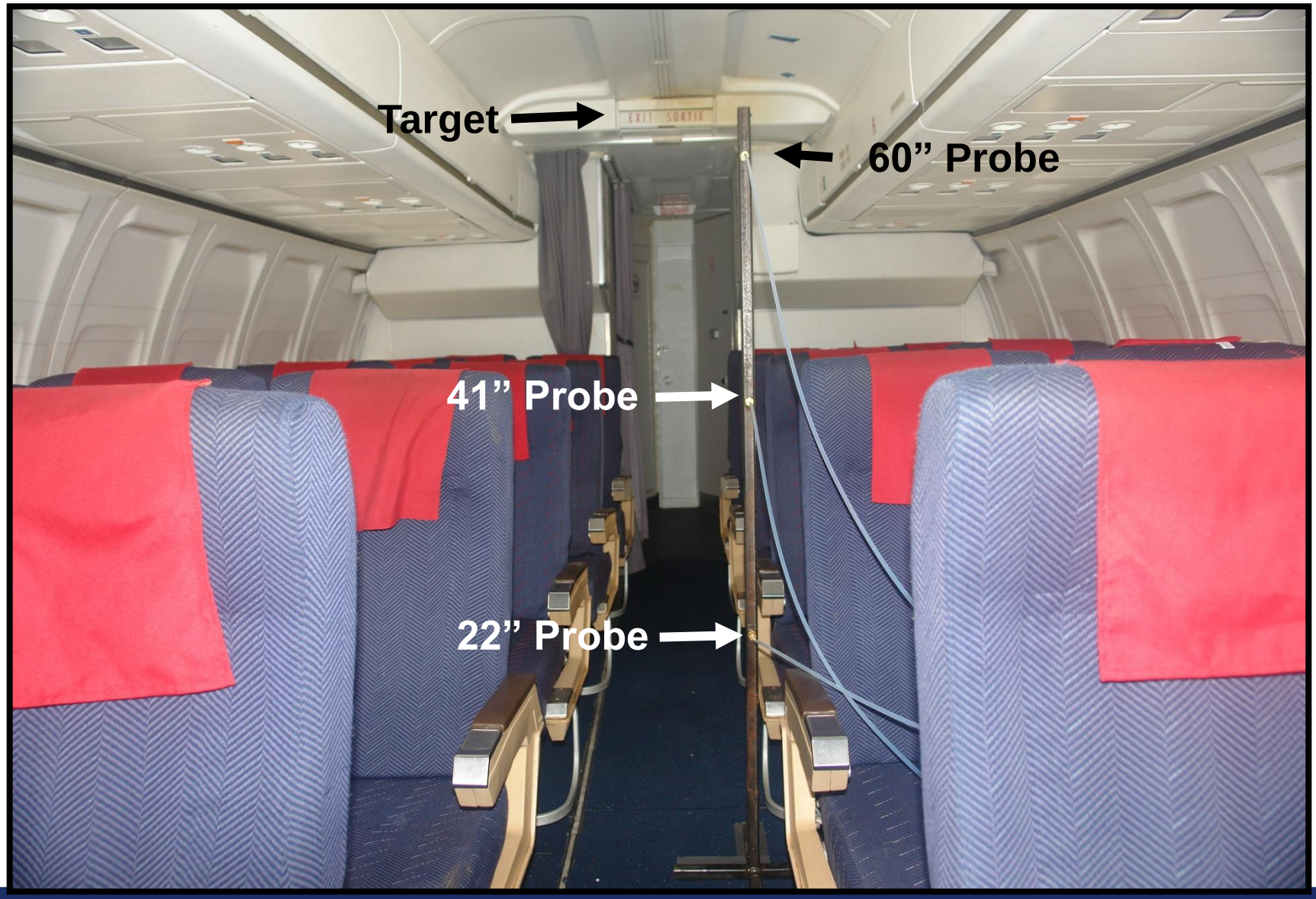
- The seats, overhead storage and other enclosed areas were subtracted out.

- The firefighter volume (5.7 ft^3) is subtracted out when calculating perfect mixing concentrations

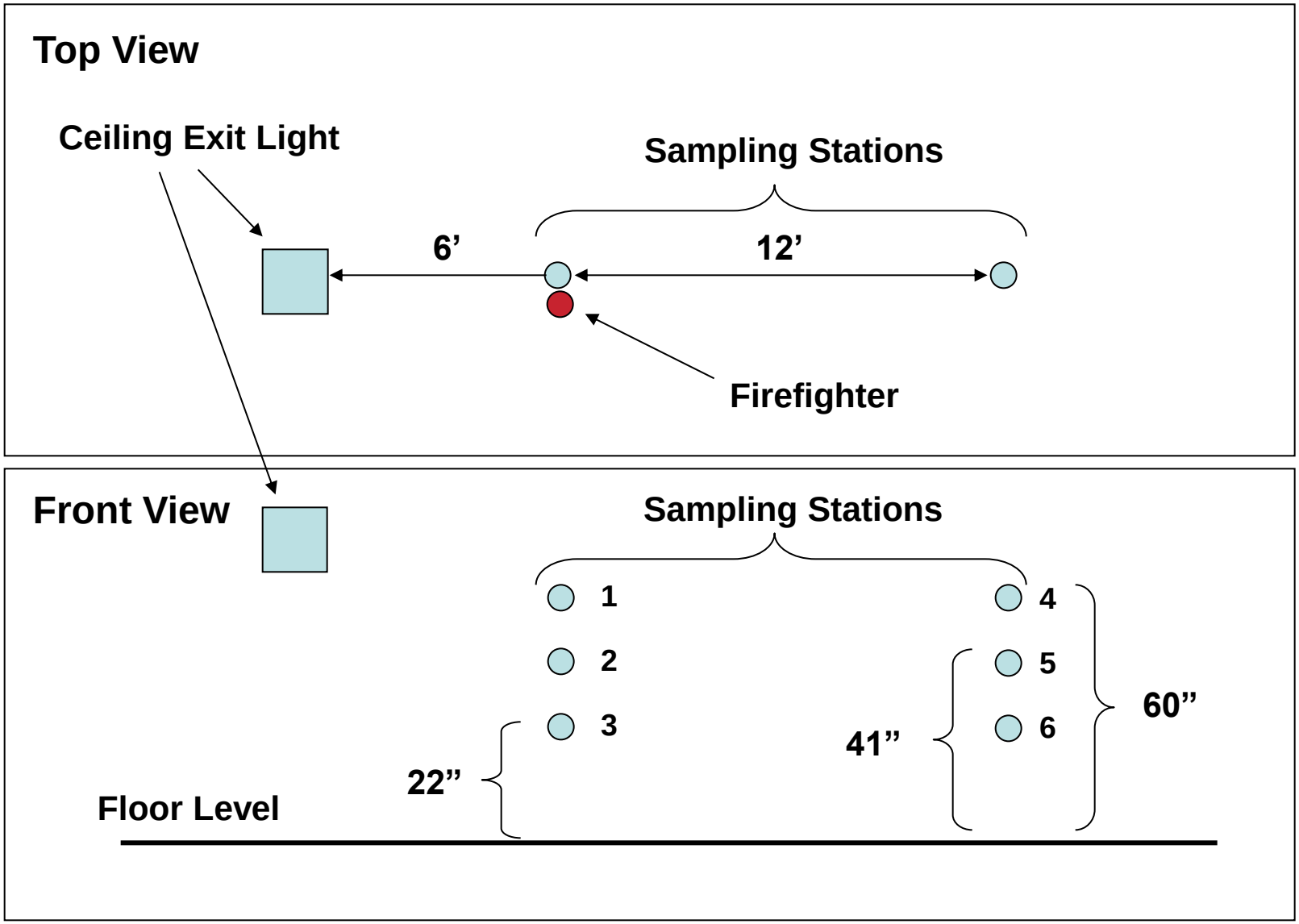
- 1 air pack used, all gaspers (over-seat air ports) closed

- Air change time by CO_2 discharge test: T_{Cabin} = 248s (4.13 min)

Cabin Test



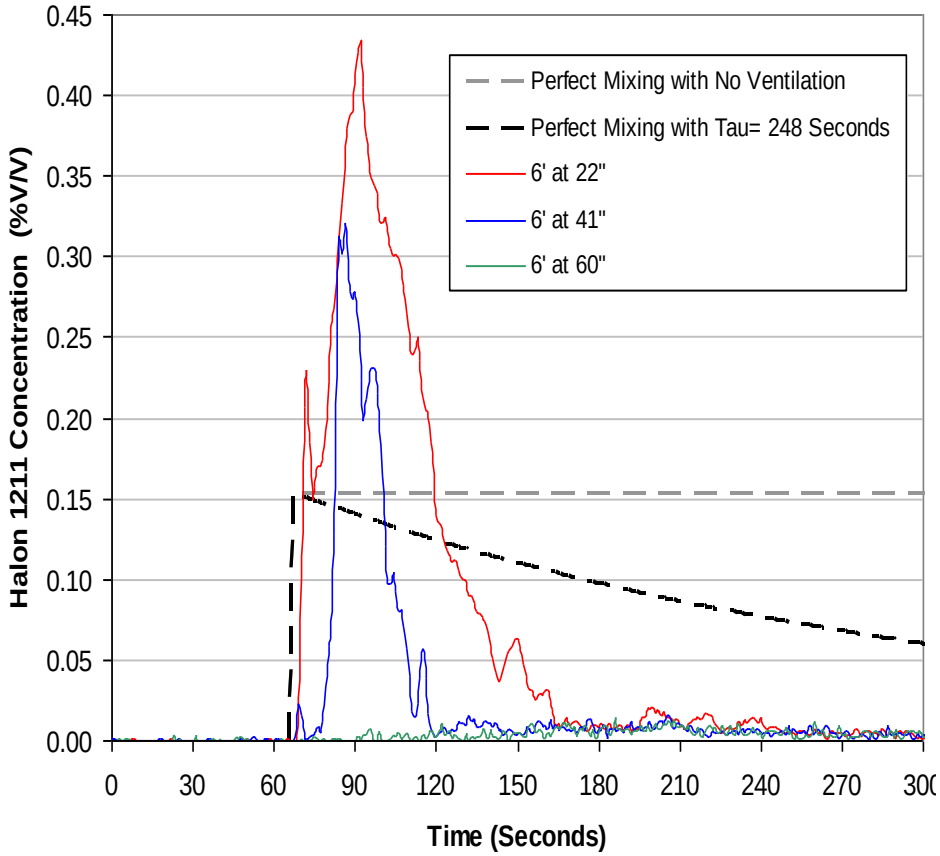
Cabin Test

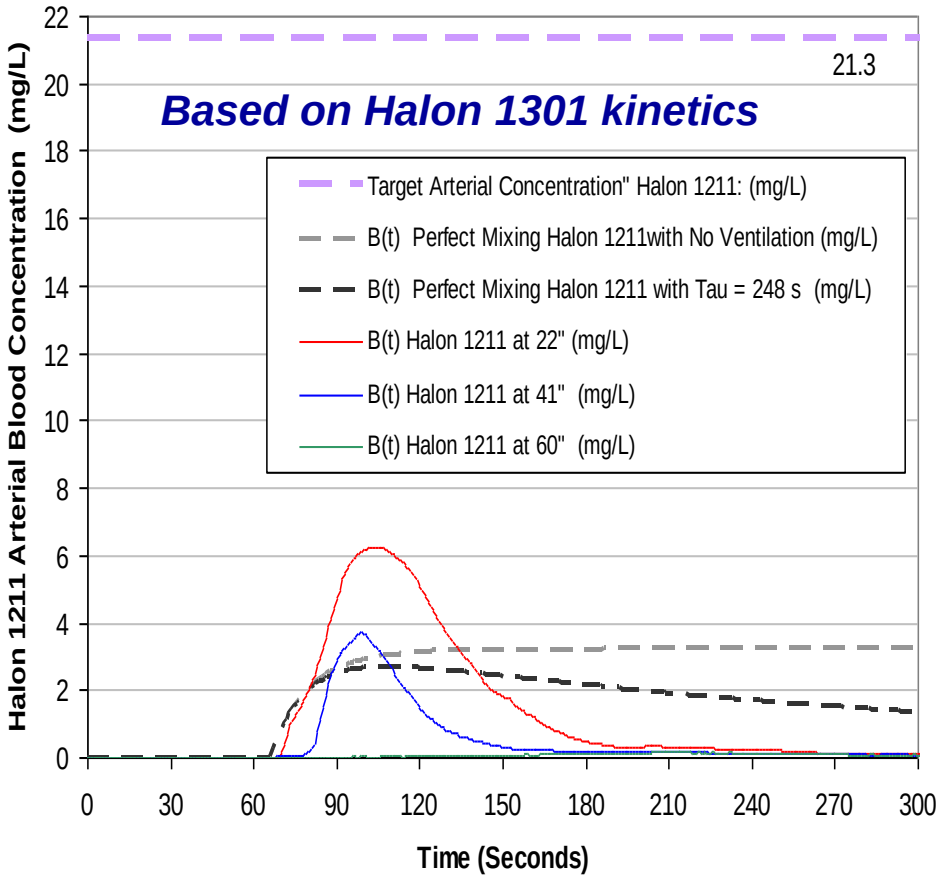

Top View
Ceiling Exit Light
Sampling Stations
6’
12’
Firefighter
Front View
Sampling Stations
1
2
3
4
5
6
22”
41”
60”
Floor Level

Cabin Tests

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

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

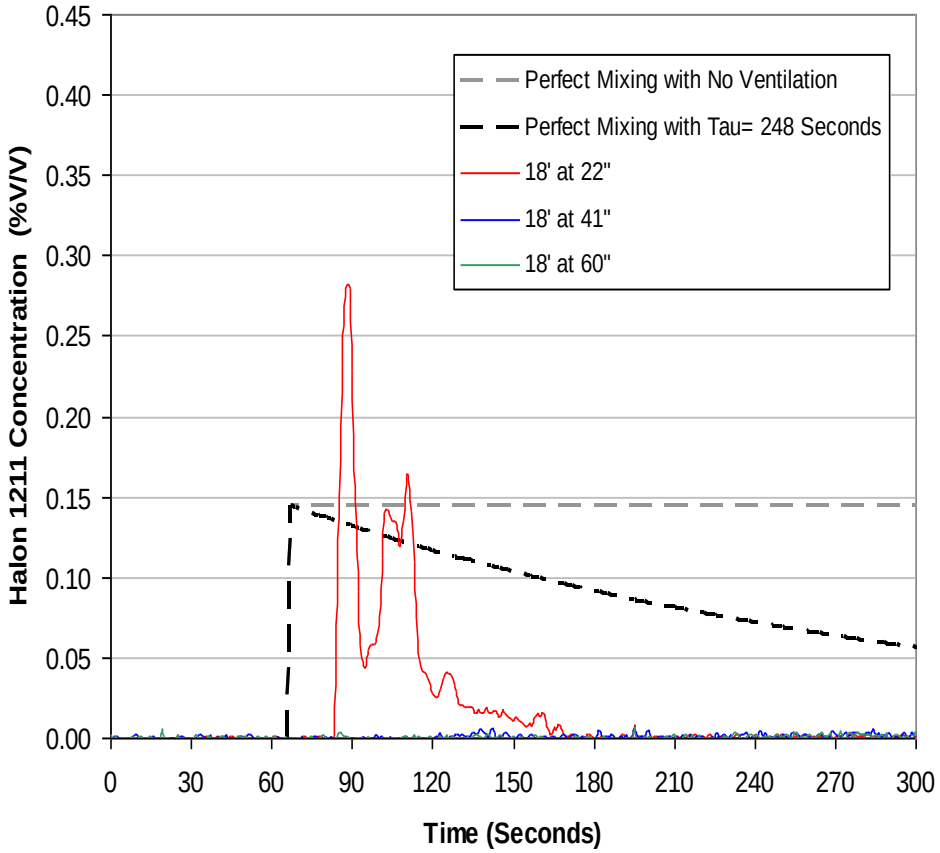


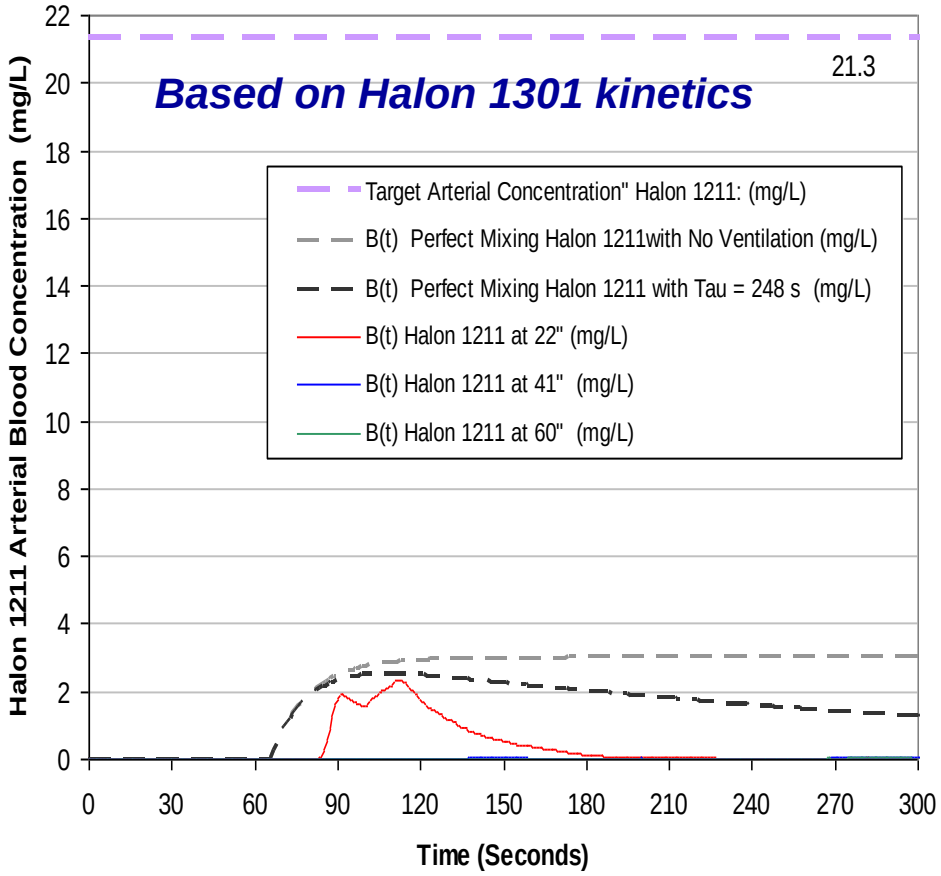


Cabin Tests

Sample station: 18’ from target- Test 3

MF **Stratification & Localization** = **1.08 , 49, 62 , (22”, 41”,60”)**



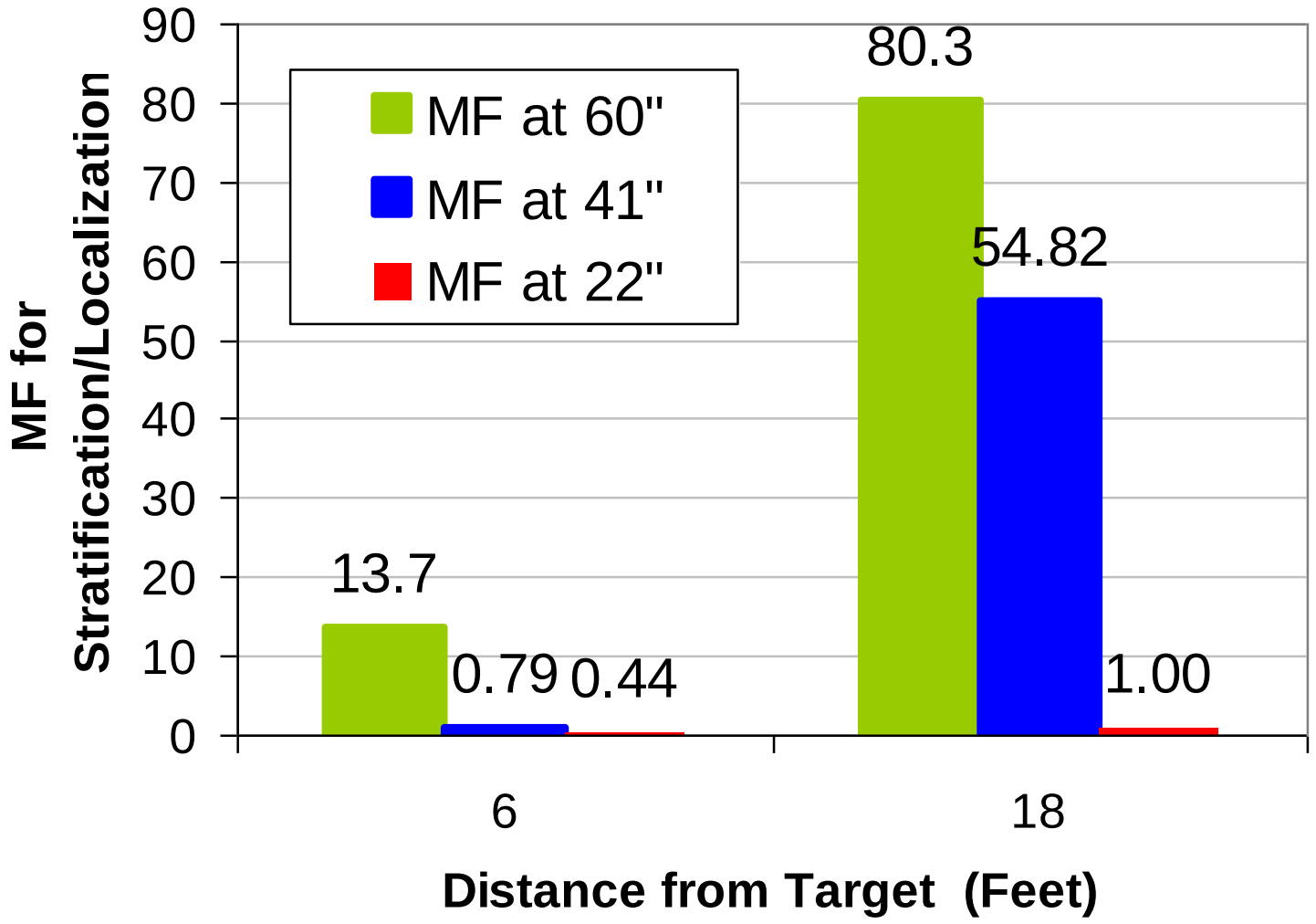


Cabin Tests: Stratification/ Localization MFs Based on Halon 1301 Kinetics

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



Summary of MFs Stratification& Localization 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 3 minutes.***
- ***If above guidance is followed, cabin $MF_{localization/stratification}$ can be set to 1.6***

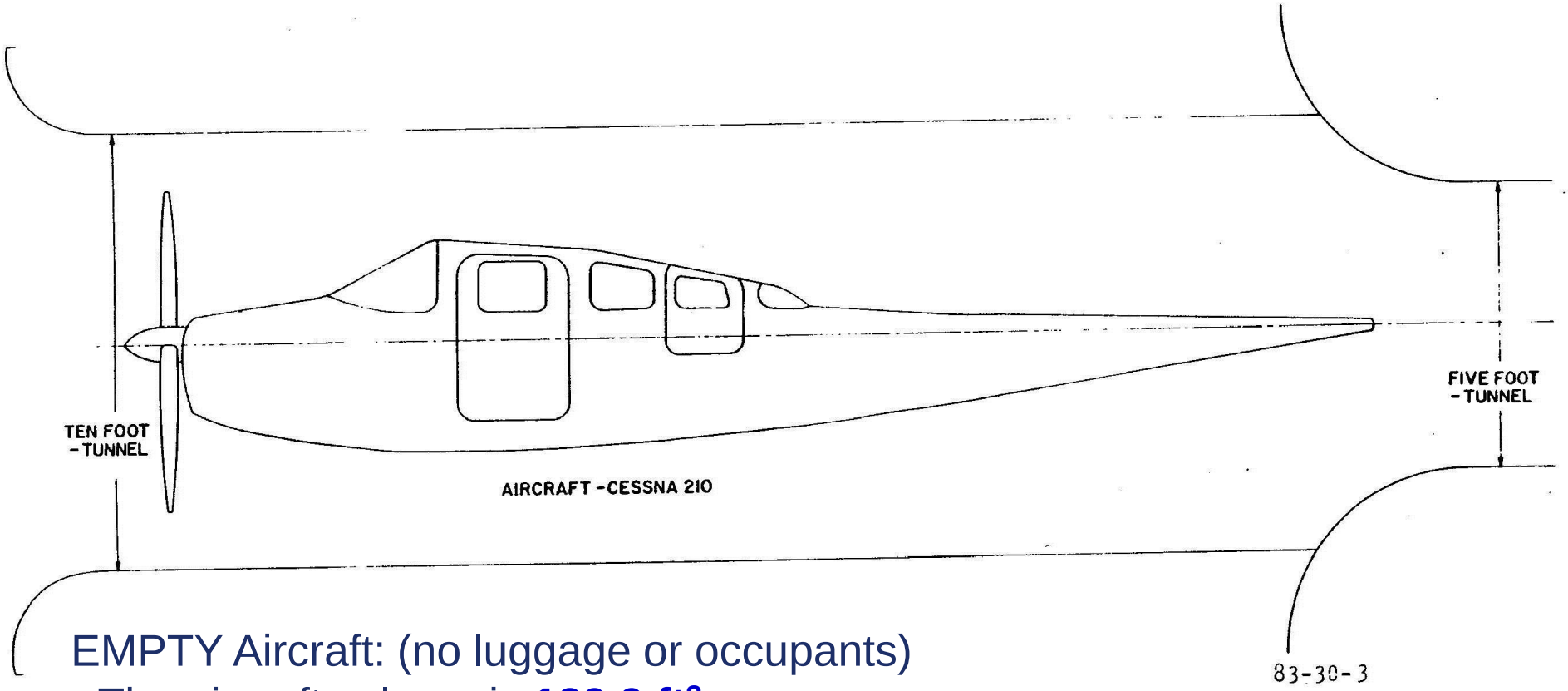
Flight Deck :

- **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.***

Small GA Aircraft
Retrospective Analysis of Past Cessna 210C Tests

- Use concentration histories and air change times from existing reports:
  - Slusher et al, “Extinguisher Agent Behavior in a Ventilated Small Aircraft”, FAA Report DOT/FAA/CT-83/30, January 1984.
  - Slusher et al, “ Halon Extinguisher Agent Behavior in a Ventillated Small Aircraft, FAA Report DOT/FAA/CT-86/5

Wind Tunnel Profile with Unpressurized Cessna 210C



EMPTY Aircraft: (no luggage or occupants)

- The aircraft volume is **139.9 ft^3**
- Four Overhead Vents
- At 120 mph, the air change time, **τ = 1.16 minutes**, overhead vents open
- Air exits the tailcone area through openings where control cables pass through. Openings were not documented in report.

Air Change Time with Airspeed = 120 mph, Empty Aircraft

- An accurate air change time and accurate free space volume are needed to determine $MF_{Ventilation}$ and $MF_{Stratification\text{-}Localization.}$
- Air change times were determined using pitot-static probes at 4 overhead vents in empty aircraft with only overhead vents open, τ = 1.16 minute. C_o= 3.86% for 2.50 lb. Halon 1211 discharge. **Concentrations at pilot's nose height are lower than predicted at τ = 1.16 min**

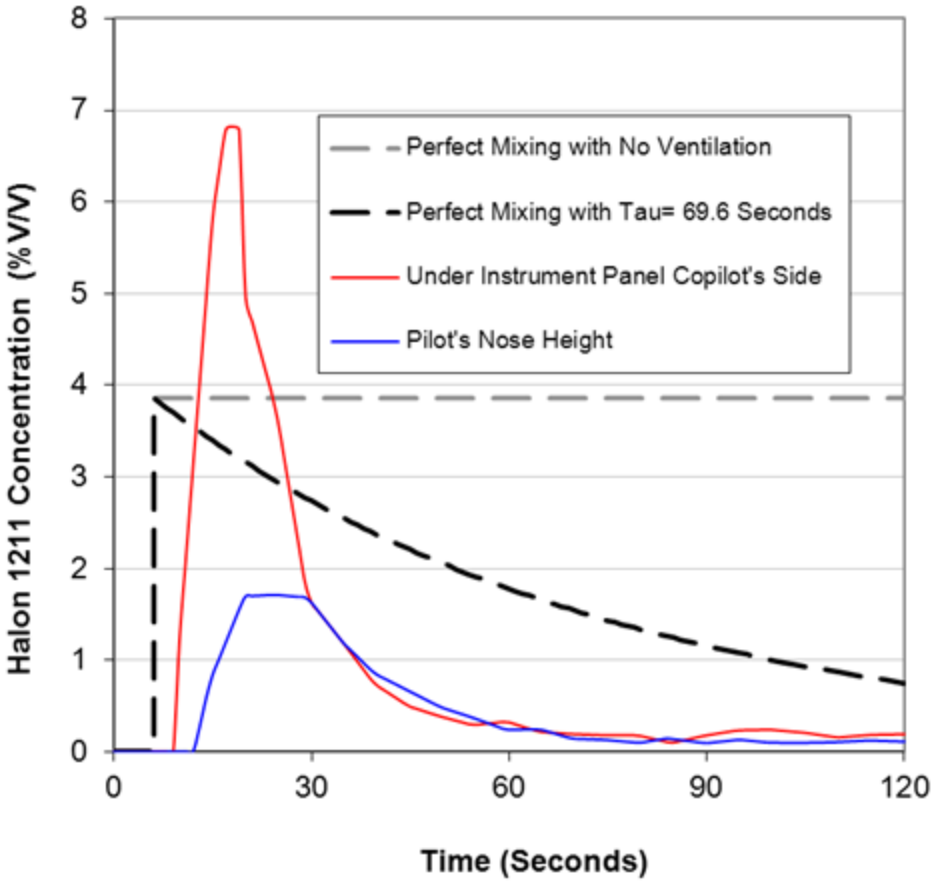
Cessna 210C Tests

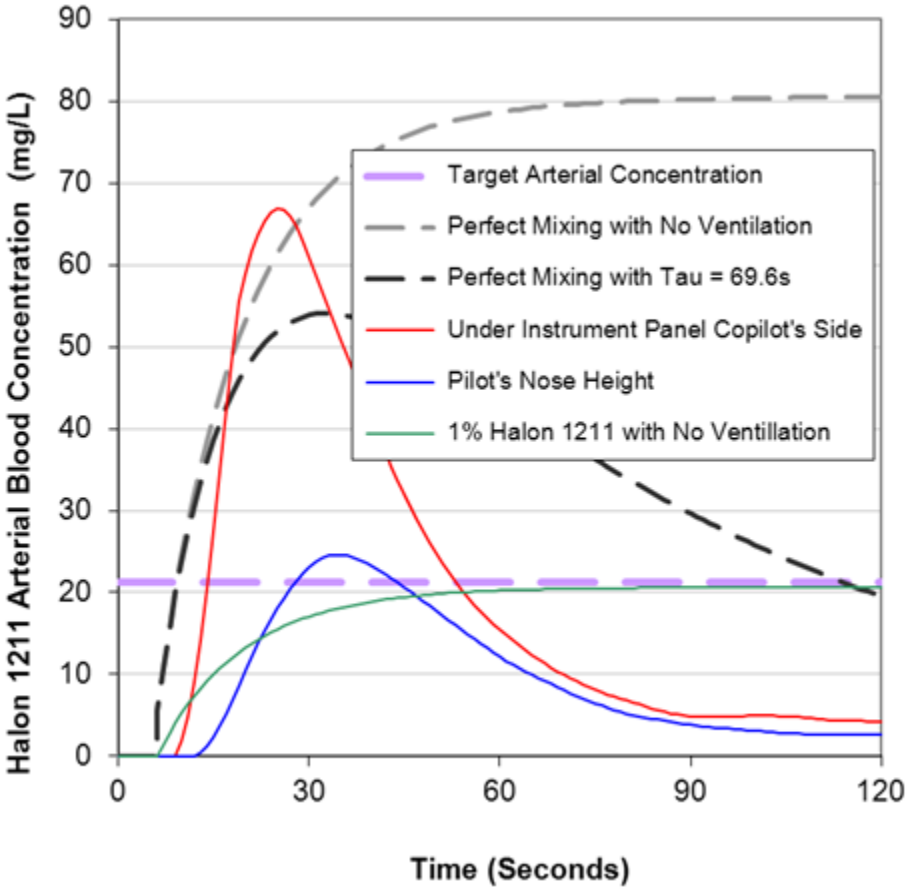
- **Discharge location: Under instrument panel, copilot's side**
- **Discharge circa 2.5 lb Halon 1211 under instrument panel.**
- **2 ventilation conditions at 120 mph air speed**
  - Overhead vents open, output through tailcone area openings, perhaps others.
    - Air change time, empty aircraft : τ = 1.16 minutes
    - Air Change Time, loaded aircraft: τ = unknown < 1.16 min.
  - All vents closed
- **Gases measured at pilot's nose level and under instrument panel**
- **Plotted Halon 1211 gas and arterial concentration histories are based on a 2.50 lb discharge.**

Empty… Target: Under Instrument Panel, Copilot's Side

Overhead Vents Open, τ = 1.16 min.

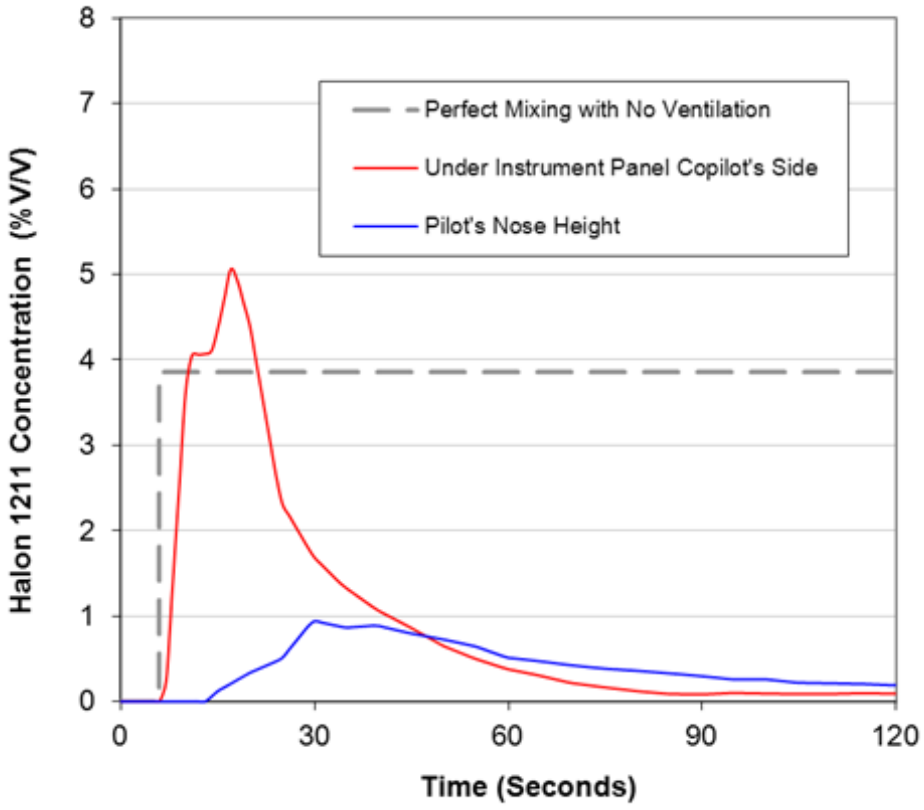
MF $_{\text{Stratification \& Localization}}$ = 0.81, 2.2 (Target and Pilot's Nose Height)

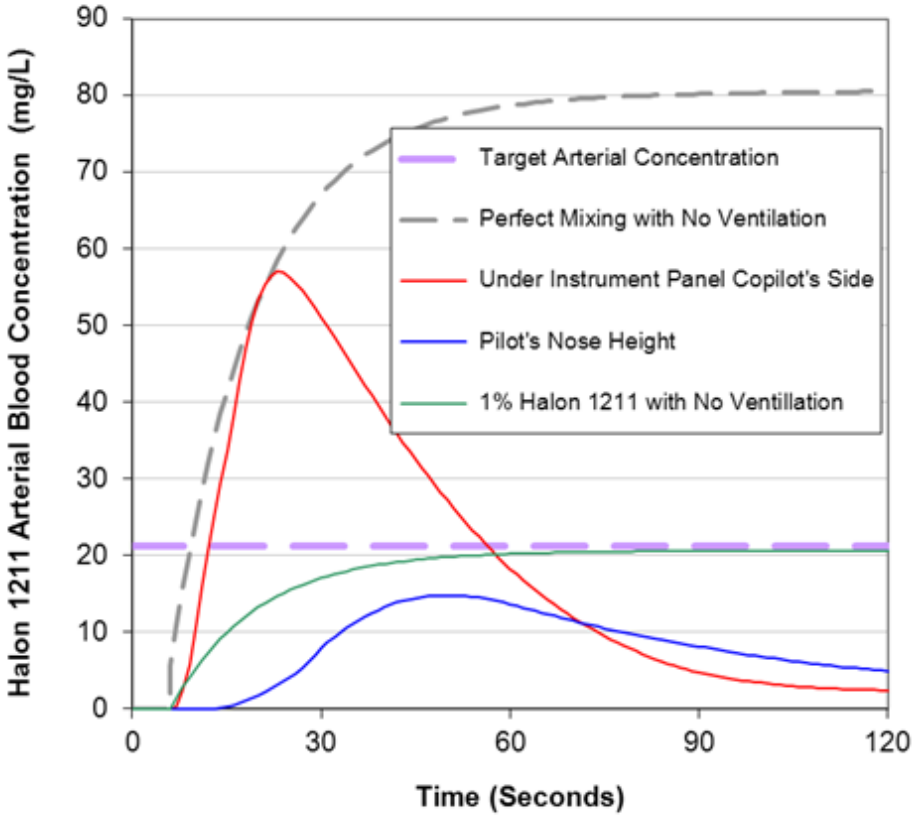




Based on data from 1984 Report, Fig 6, Test 4

Empty… Target: Under Instrument Panel, Copilot's Side
All Vents Closed



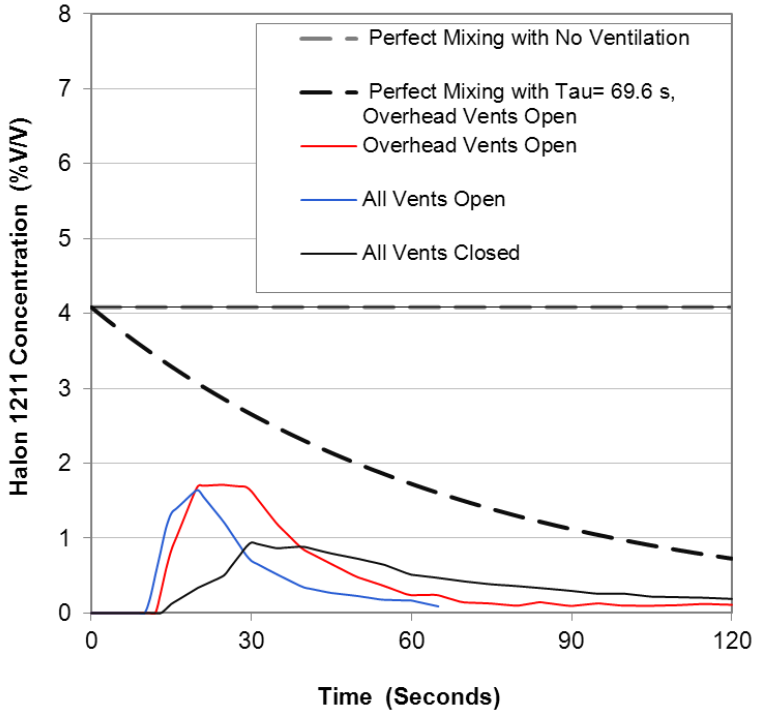


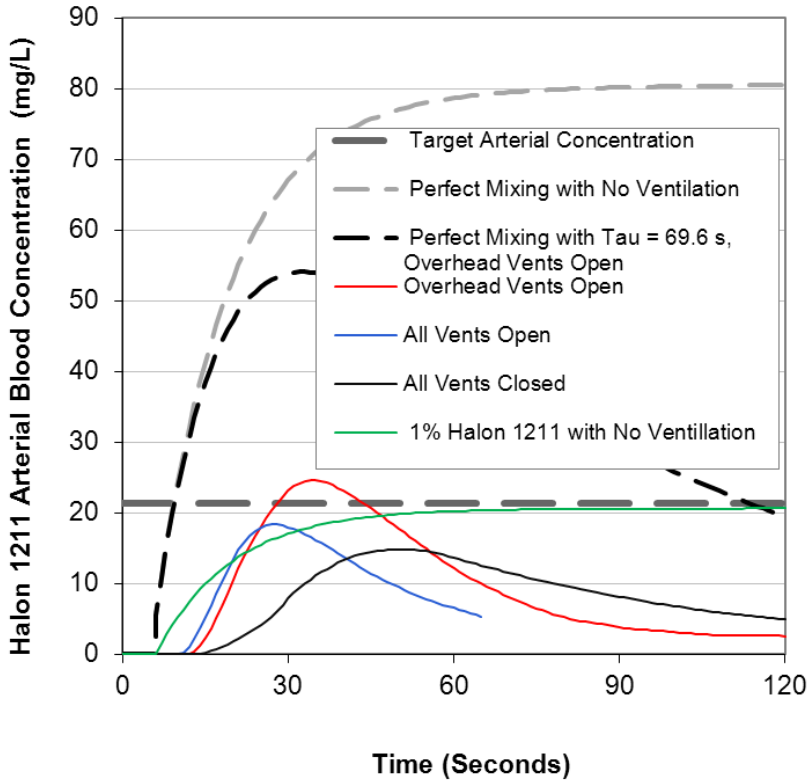
Based on data from 1984 Report, Fig 8, Test 6

Empty… Target: Under Instrument Panel, Copilot's Side

Comparison of Ventilation Methods

Halon 1211 at Nose Height





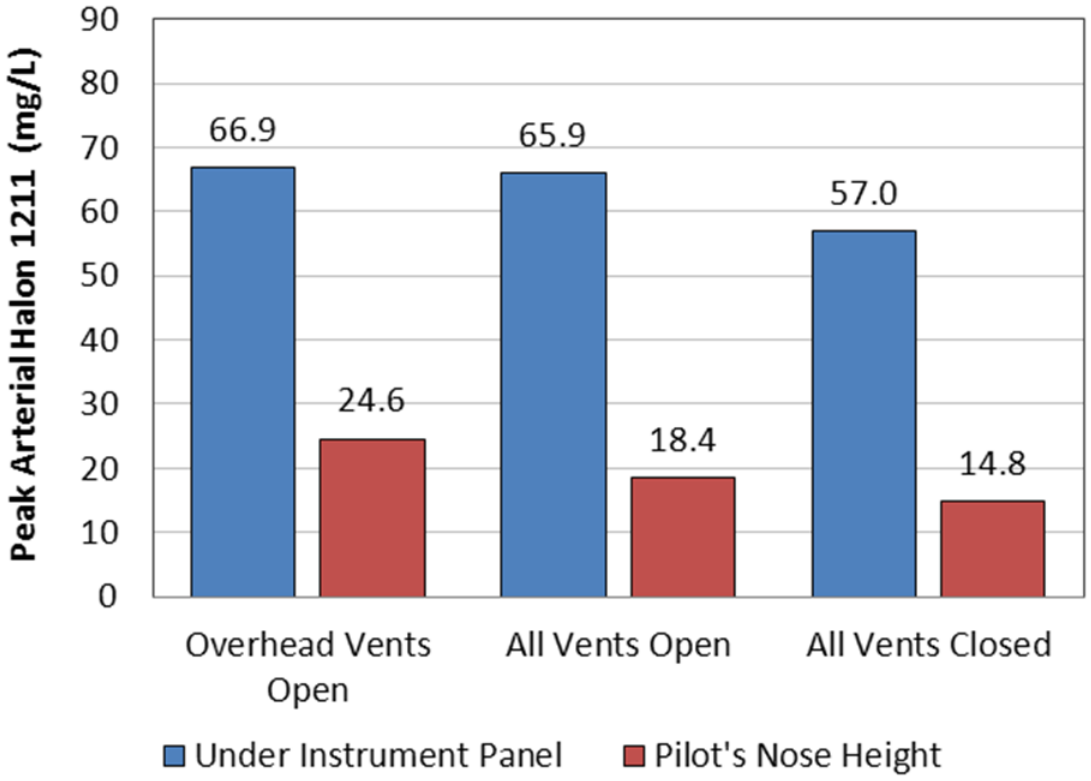
- *Perfect mixing Halon 1211 gas and arterial concentrations are shown for overhead vent open and all vents closed. The air change time is unknown for all vents open.*

Based on data from 1984 Report, Fig 6,7, and 8

Empty… Target: Under Instrument Panel, Copilot's Side

Comparison of Ventilation Methods: Peak Arterial Concentrations

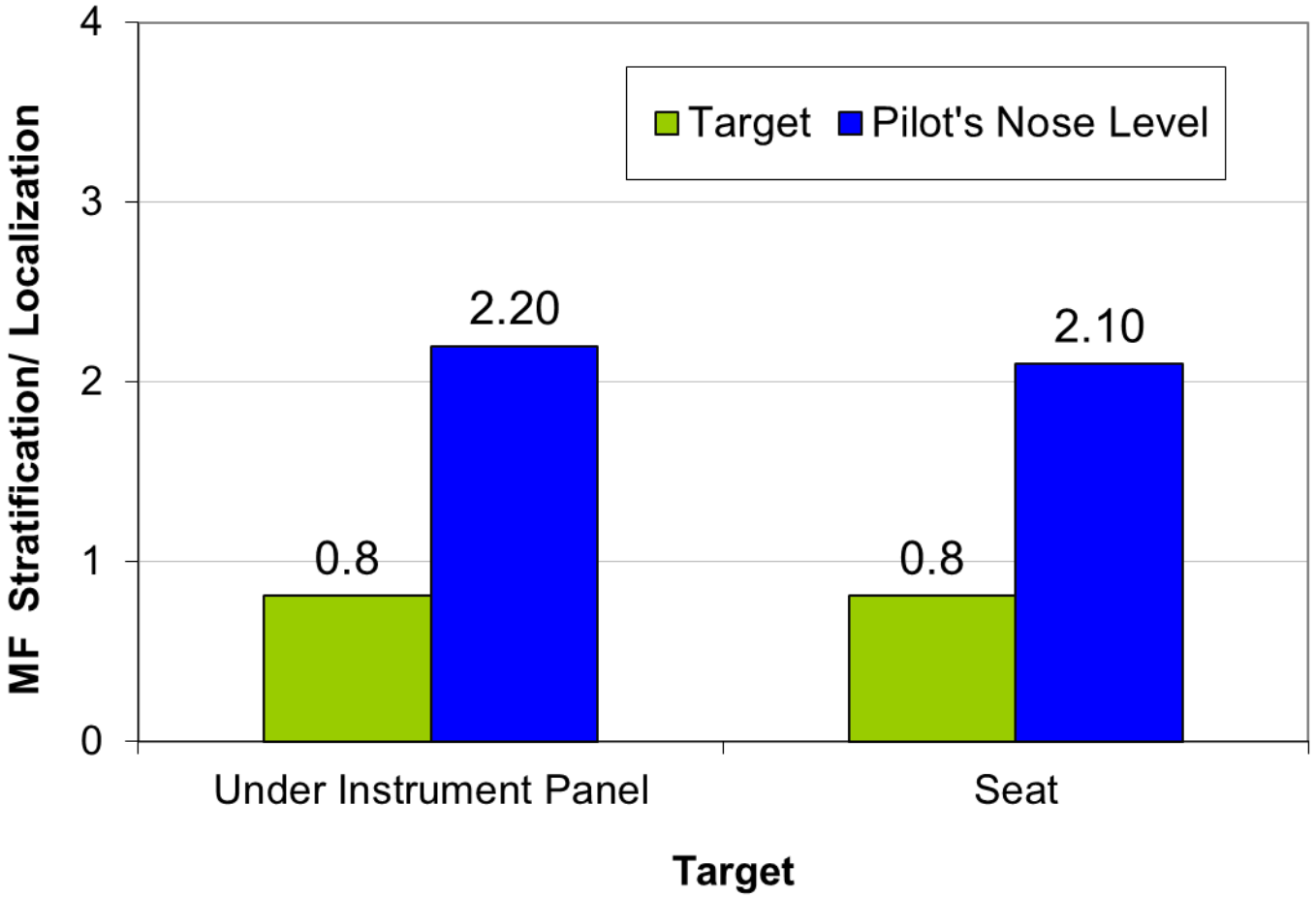
21.3 mg/L= Safe-Use Halon 1211 Arterial Concentration



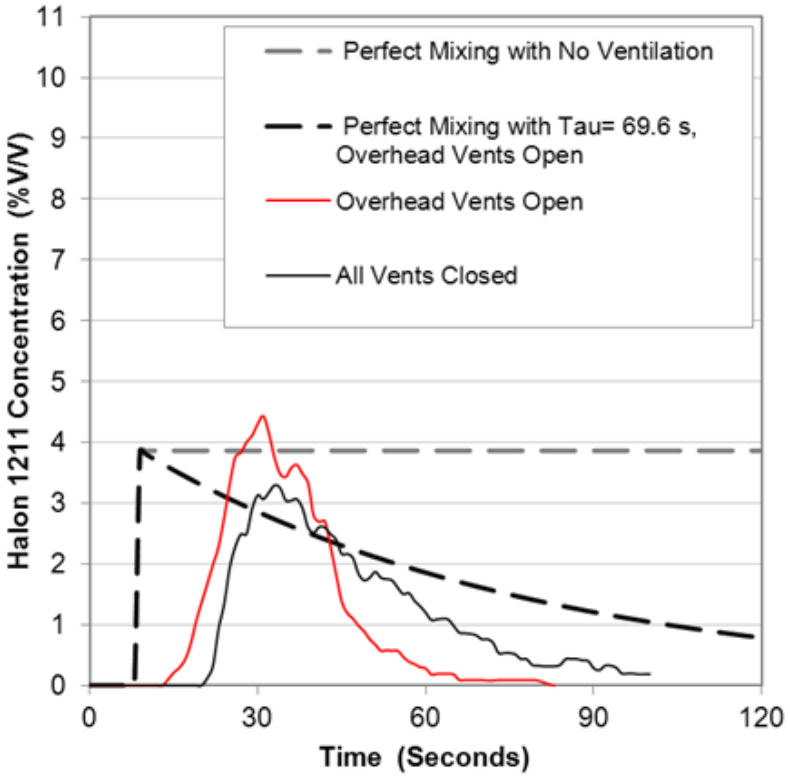
Based on data from 1984 report, Fig 6, 7, and 8

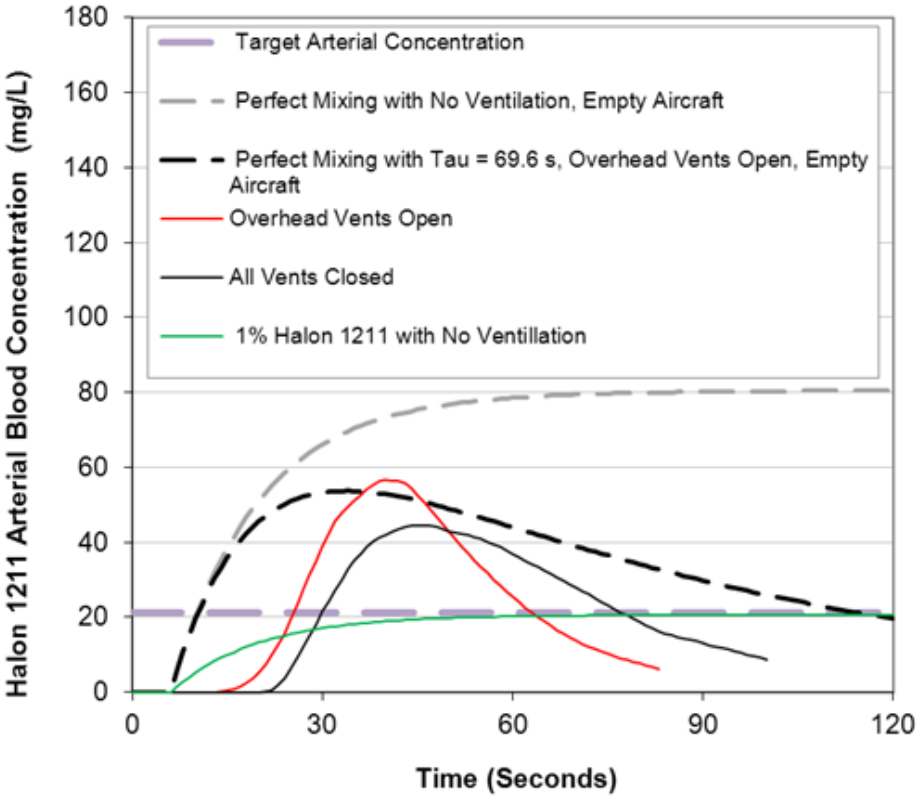
Empty… Cessna 210C Tests : Stratification/ Localization MFs

Pilots Nose Level, Overhead Vents Open, τ = 1.16 min.



Loaded… Target: Under Instrument Panel, Copilot's Side Comparison of Ventilation Methods at Pilot's Nose Height.





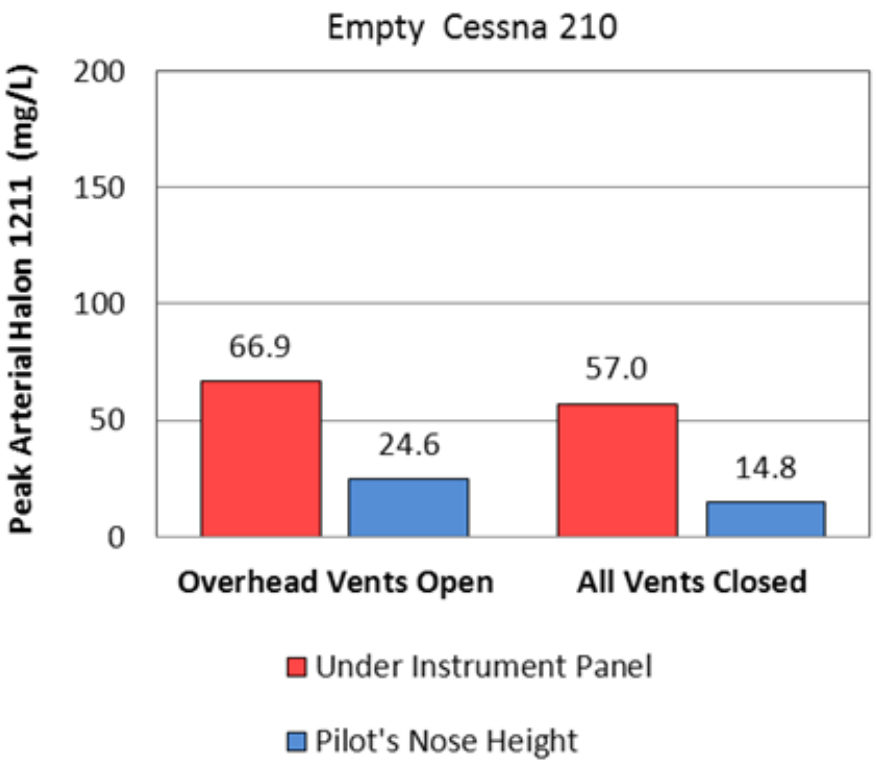
- *Halon 1211 perfect mixing gas and arterial blood concentrations are underestimated for the loaded aircraft, as the free space volume and air change time are unknown.*
- Perfect mixing ventilated concentrations are based on overhead vents open, empty aircraft.

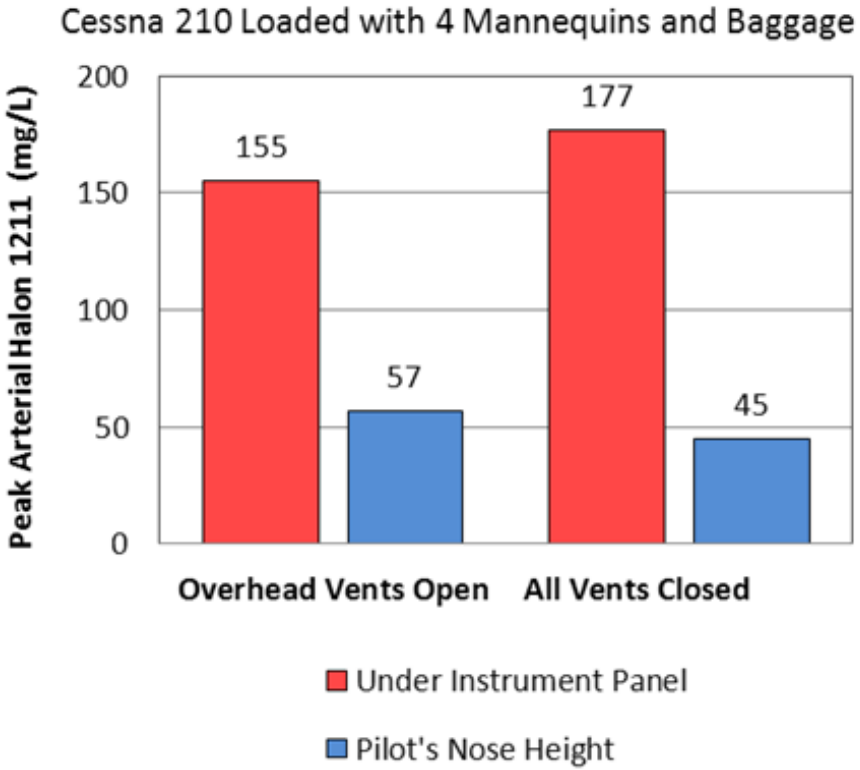
Based on data from 1986 Report, Fig 7 and 8

Halon 1211 Discharged Under Instrument Panel, Copilot's Side

Comparison of Peak Arterial Concentrations: Empty and Loaded

21.3 mg/L= Safe-Use Halon 1211 Arterial Concentration





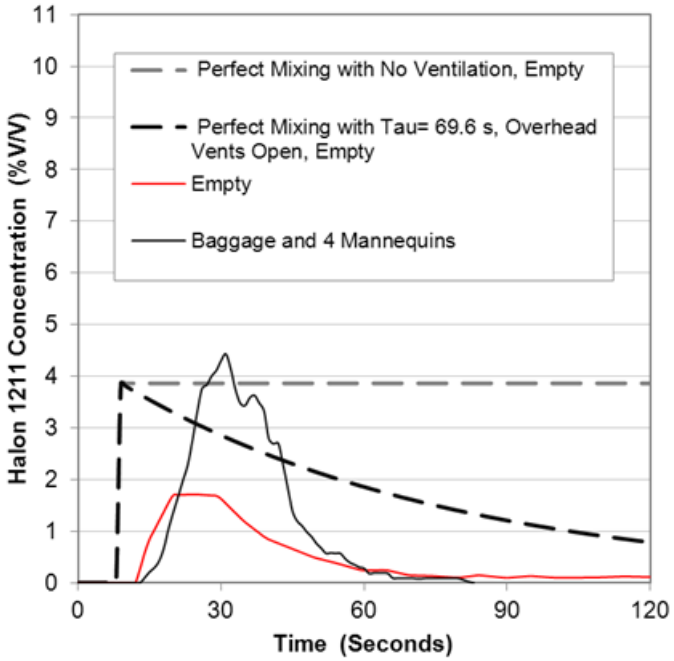
Halon 1211 arterial blood concentrations for under the instrument panel are underestimated for the loaded aircraft, as the gaseous concentrations were off-scale.

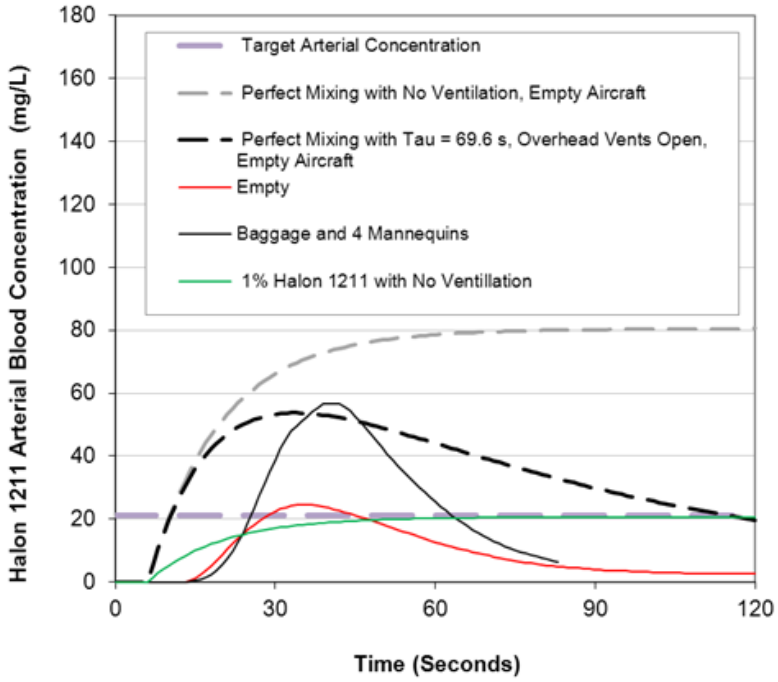
Based on data from 1984 report, Fig 6 and 8 and 1986 report, Fig 7 and 8

Halon 1211 Discharged Under Instrument Panel, Copilot's Side

Empty and Loaded, Overhead Vents Open: Pilot's Nose Height

21.3 mg/L= Safe-Use Halon 1211 Arterial Concentration





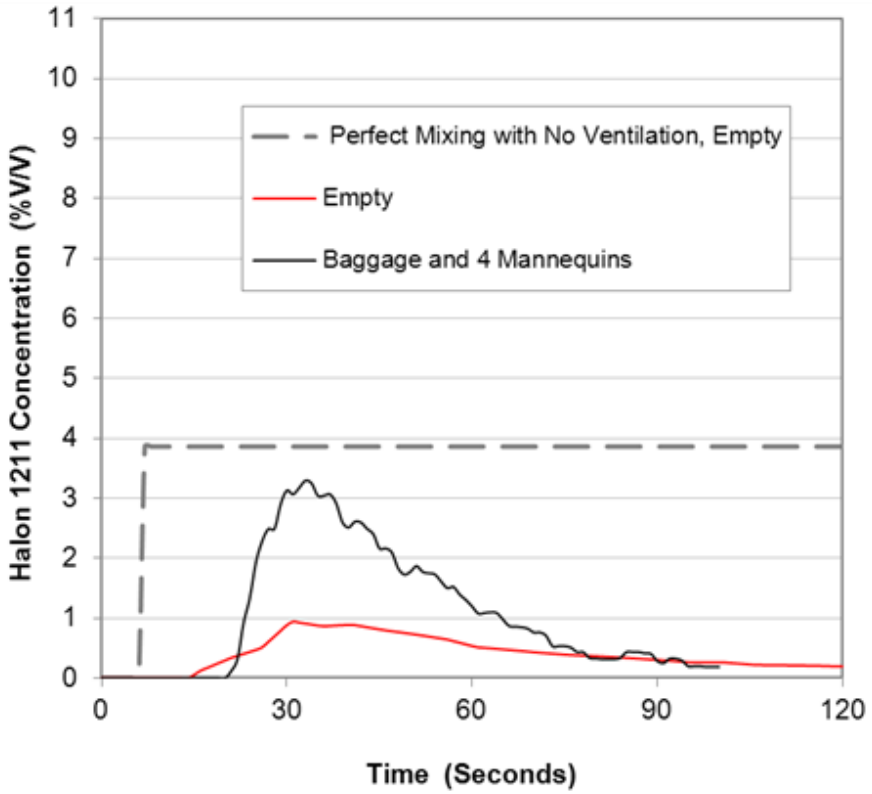
- *Perfect mixing Halon 1211 gas and arterial concentrations are higher for the loaded aircraft: Free space volume and air change time are unknown*
- Perfect mixing ventilated concentrations are based on overhead vents open, empty aircraft.

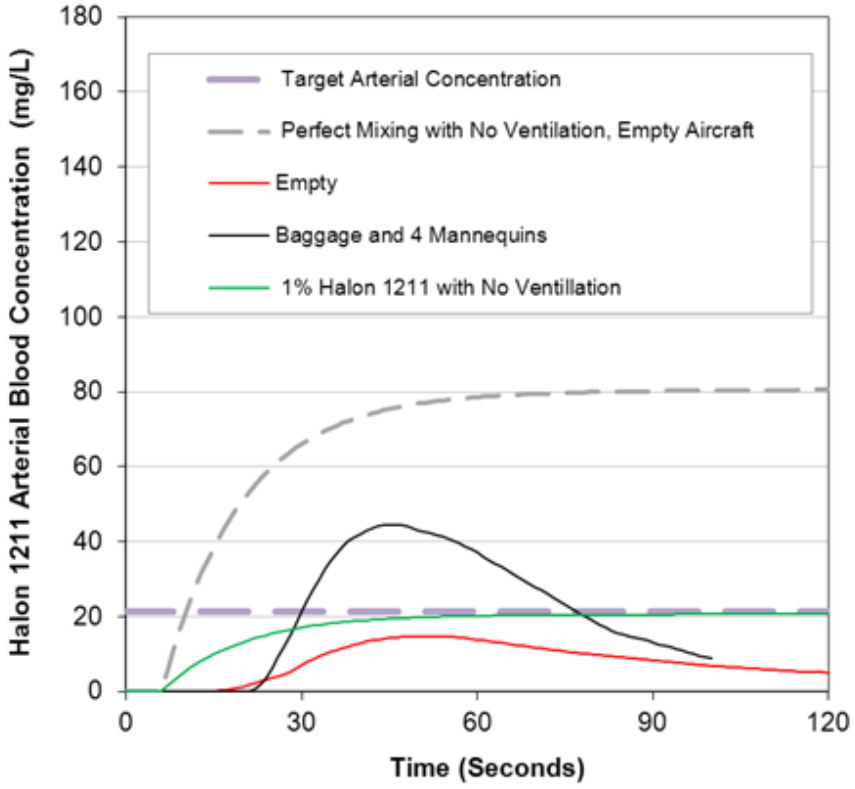
Based on data from 1984 report, Fig 6 and 1986 report, Fig 7

Halon 1211 Discharged Under Instrument Panel, Copilot's Side

Empty and Loaded, All Vents Closed: Pilot's Nose Height

21.3 mg/L= Safe-Use Halon 1211 Arterial Concentration





- *Perfect mixing Halon 1211 gas and arterial concentrations are higher for the loaded aircraft: Free space volume and air change time are unknown*

Based on data from 1984 report, Fig 8 and 1986 report, Fig 8

Conclusions: B-737 Flight Deck Tests

- **Stratification and localization benefit for the seated pilot is significant:**
  - $MF_{Stratification/Localization}$ = 1.6: target: copilot's window heater
  - $MF_{Stratification/Localization}$ = 2.4: target: copilot's lower instrument panel
- **Halon 1211 safety criterion are not met, even with with Stratification/ Localization corrections:**

For this B-737 flight deck, with $P_{altitude}$ of 8,000 ft, τ= 65s (1.08min) and a 2.5 lb discharge:

- Safe use conc of Halon $1211_{Stratification/Localization}$ (lbs/ft^3)

$$= \mathbf{0.00334\ lbs\ ft^{-3}} \times 1.56 \times 1.6 = \mathbf{0.00521\ lbs\ ft^{-3}} \times 1.6 = \mathbf{0.00835\ lbs\ ft^{-3}}$$

- Min Safe $Volume_{Stratification/Localization}$ of Halon 1211 (ft^3)

$$= \frac{\mathbf{751 ft^3}}{1.56 \times 1.6} = \frac{\mathbf{481 ft^3}}{1.6} = \mathbf{301\ ft3} > \mathbf{129\ ft^3}$$ **(Volume of B-737 flight deck)**

- **$MF_{Stratification/Localization}$ can be safely set to 1.6 for all flight decks.**

Conclusions: B-737 Cabin Tests

- **Stratification and localization is significant:**
  - $MF_{Stratification/Localization}$ = 0.8 for passengers seated alongside firefighter
  - $MF_{Stratification/Localization}$ = 14 for firefighter
  - $MF_{Stratification/Localization}$ = 55 for seated passenger 12 foot behind the firefighter
- **No multiplication factors should be applied if it is anticipated that passengers alongside the firefighter may remain in their seats.**
- **Larger $MFs_{Stratification/Localization}$ can be applied to aircraft cabins if it is believed that passengers will move away from the hazard.**
- **Setting $MF_{Stratification/Localization}$ = 1.6 may be a reasonable for any size aircraft cabin (ie. allow 1.6 x the safe use concentration in AC 20-42D)**

Conclusions: Cessna 210C Tests

- **Stratification and localization are significant for the empty and loaded Cessna 210C, resulting in lower than theoretical perfect mixing Halon 1211 concentrations at the pilot's nose level.**
  - $MF_{Stratification/Localization}$ = 2.2 for discharges under the copilot's instrument panel with overhead vents open.
- **2x higher concentrations were measured in the loaded Cessna 210C than the empty aircraft with overhead ports open and air speed of 120 mph.**
- **$MF_{Stratification/Localization}$ can be safely set to 2.2 for all small GA aircraft *using expected minimum free space volume to size extinguishers*.**

Conclusions: Cessna 210C Tests (cont.)

- **Halon 1211 safety guidance for the seated pilot is exceeded with Stratification/ Localization corrections:**

For this Cessna 210C, with $P_{altitude}$ **of 12,500 ft**, τ = 1.16 min and a 2.5 lb discharge:

- Safe use conc of Halon $1211_{Stratification/Localization}$ (lbs/ft^3)

$$= \mathbf{0.00281\ lbs\ ft^{-3}} \times 1.52 \times 2.2 = \mathbf{0.00426\ lbs\ ft^{-3}} \times 2.2 = \mathbf{0.00940\ lbs\ ft^{-3}}$$

- Min Safe $Volume_{Stratification/Localization}$ of Halon 1211 (ft^3)

$$= \frac{\mathbf{895\ ft^3}}{1.52 \times 2.2} = \frac{\mathbf{589\ ft^3}}{2.2} = \mathbf{268\ ft3} > \mathbf{140\ ft^3}$$ **(Volume of Cessna 210C)**

Conclusions: All Tests

$MF_{Stratification/Localization}$ will be much higher than prescribed if evasive actions are taken:

- Donning PBE (if air does not contain any recirculated air).
- Standing or sitting higher in seat.
- Moving away from the area of discharge.

Recirculation System Guidance

- **Cabin**
  - On wide and narrow body planes, the volumes are so large that recirculation would have no negative impact. This is due to the extra volumes encountered after the agent has exited the cabin. For example, the area above the B-737 cabin ceiling is about 4 feet high and is part of the mixing volume.
  - Aircraft with less than 30 seats with recirculation systems on, localized airborne concentrations may match or exceed perfect mixing concentratuins, so a stratification benefit should not be applied.
- **Flight Deck**
  - Recirculation Systems are generally not used in flight decks, so a stratification benefit may be applied.

Guidance for Other Agents

- **Halon 1211 stratification/localization Guidance can be applied to agents that have higher boiling points that are greater than or equal to that of Halon 1211.**
  - **HCFC Blend B**: primary component:HCFC-123 = 82.0° F (27.8°C)
  - **HFC-236fa** = 29.5°F (-1.4°C)
  - **Halon 1211** = 26.0°F (-3.4°C)
  - **2-BTP**= 93°F (33.9°C) (not yet approved for use on aircraft)

- **Halon 1211 stratification/localization guidance should not be applied to agents that have lower boiling points than Halon 1211.**
  - **HFC-227ea** = 1.9°F (-16.4°C)
  - **Halon 1301** = -72.0°F (-57. 8°C)

Caveats

- **Tests were done at atmospheric pressure. Stratification is expected to be lower at altitude. Halon 1211 discharge tests or modeling may be used to assess the effect of pressure altitude on stratification of Halon 1211.**

- **The pitot tube method of determining air change time (used for Cessna Tests) may not be sufficiently accurate.**