# Halon 1211 Stratification/ Localization in Small 4-Seater Aircraft


## Louise Speitel

**Fire Safety Branch**
FAA Wm. J. Hughes Technical Center
Atlantic City International Airport, NJ 08405



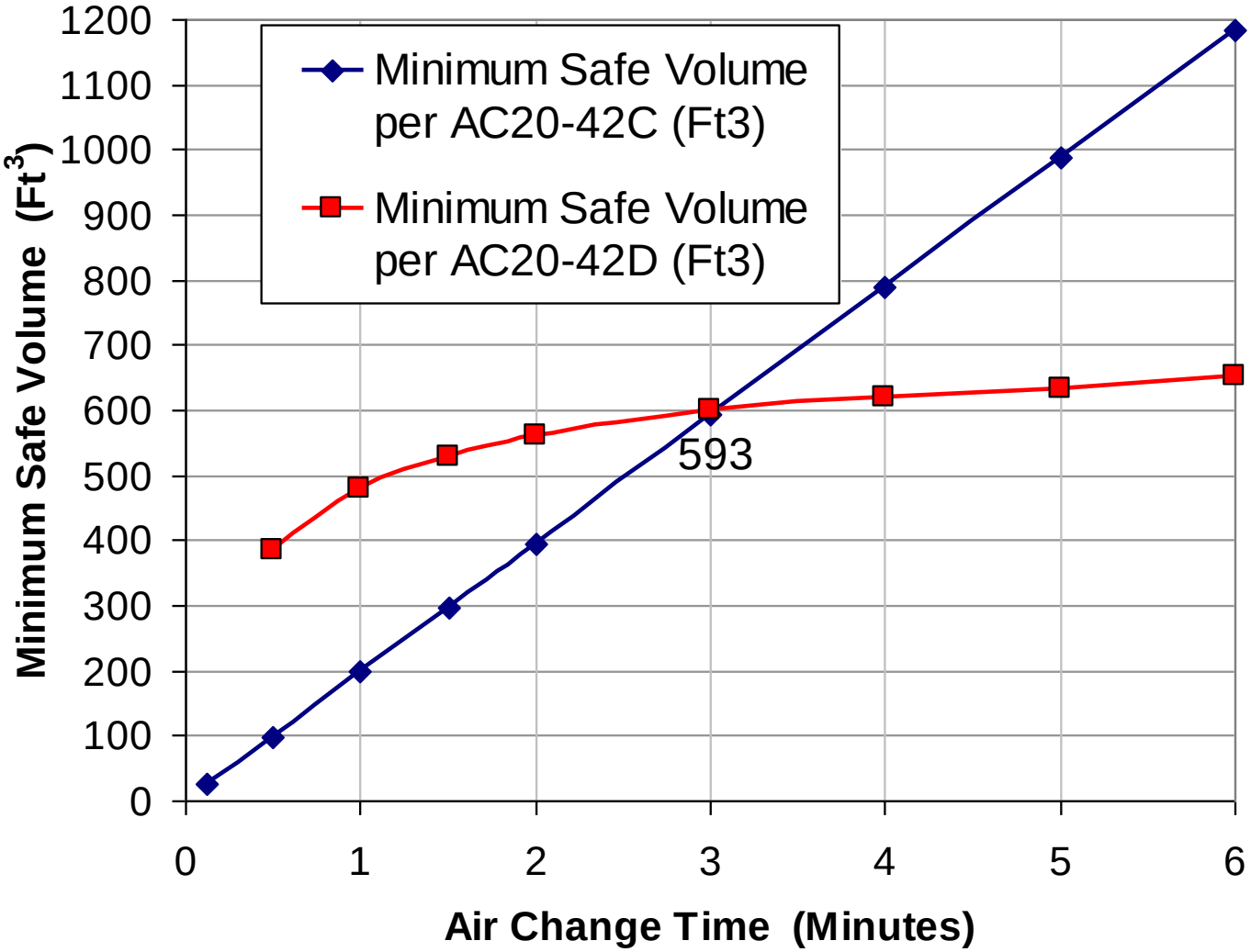
**International Aircraft Systems Fire Protection Nov. 15**, 2012
Seattle, Washington


Federal Aviation Administration

# Background

- Per AC20-42D - Halon 1211, Halotron, and BTP are unsafe for use in 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.
- B-737 flight deck stratification/ localization data for discharges of 2.5 lb Halon 1211 extinguishers was presented at the May 2012 Systems Meeting along with multiplication factors.
  - These test- based multiplication factors ($MF_{Stratification-Localization}$) can be applied to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization: B-737 flight decks and cabin.

# 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 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.***

# 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.*

**Cessna 210C ventilation with overhead vents open: τ = 1.16 min**

# Objective

- **Retrospective study of 1984 FAA stratification/ localization data for Halon 1211 hand extinguishers discharged in a small 4-seater Cessna Model 210C aircraft in a wind tunnel with an airspeed of 120 mph.**

- **Develop test- based multiplication factors ($MF_{Stratification\text{-}Localization}$) for that particular small aircraft to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization.**

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

# Method

- Use concentration histories from existing report:
  - Slusher et al, "Extinguisher Agent Behavior in a Ventilated Small Aircraft", FAA Report DOT/FAA/CT-83/30, January 1984.

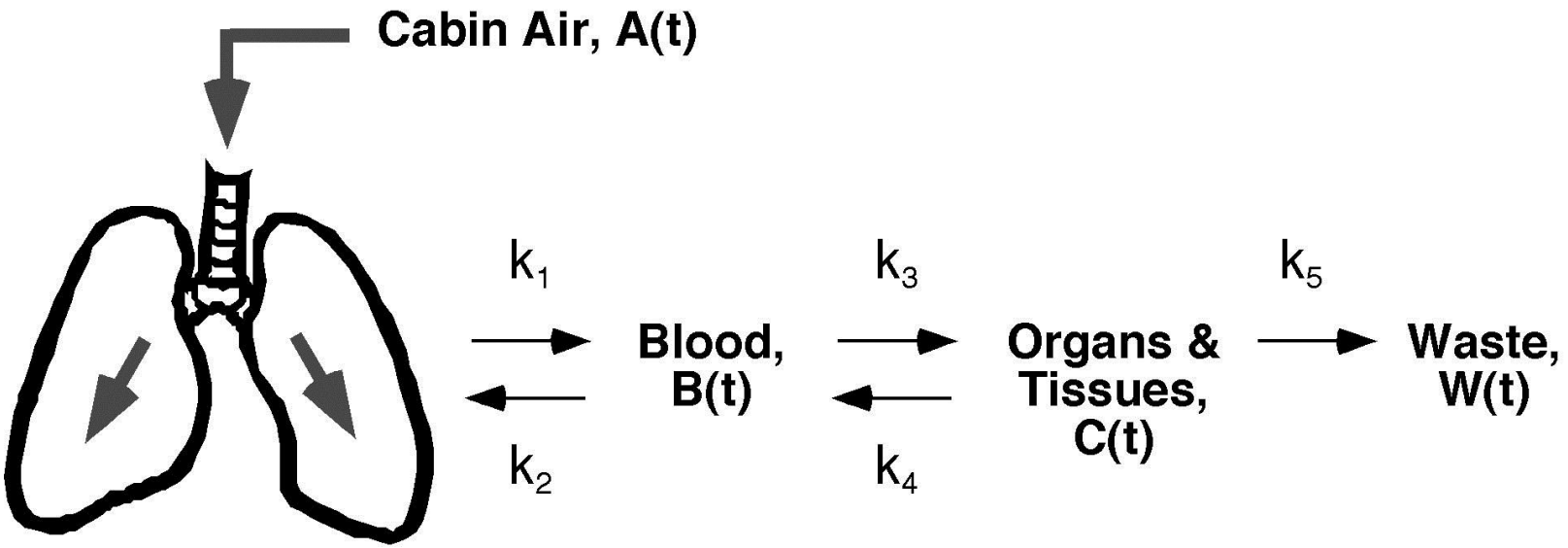
- Compute arterial concentration histories **using FAA's Simplified Kinetic Model and Halon 1301 kinetics.**

- Stratification/localization 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.

# Simplified Kinetic Model




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

# Arterial Blood Concentration, B(t)

**General equation for changing Halocarbon Concentrations:**

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

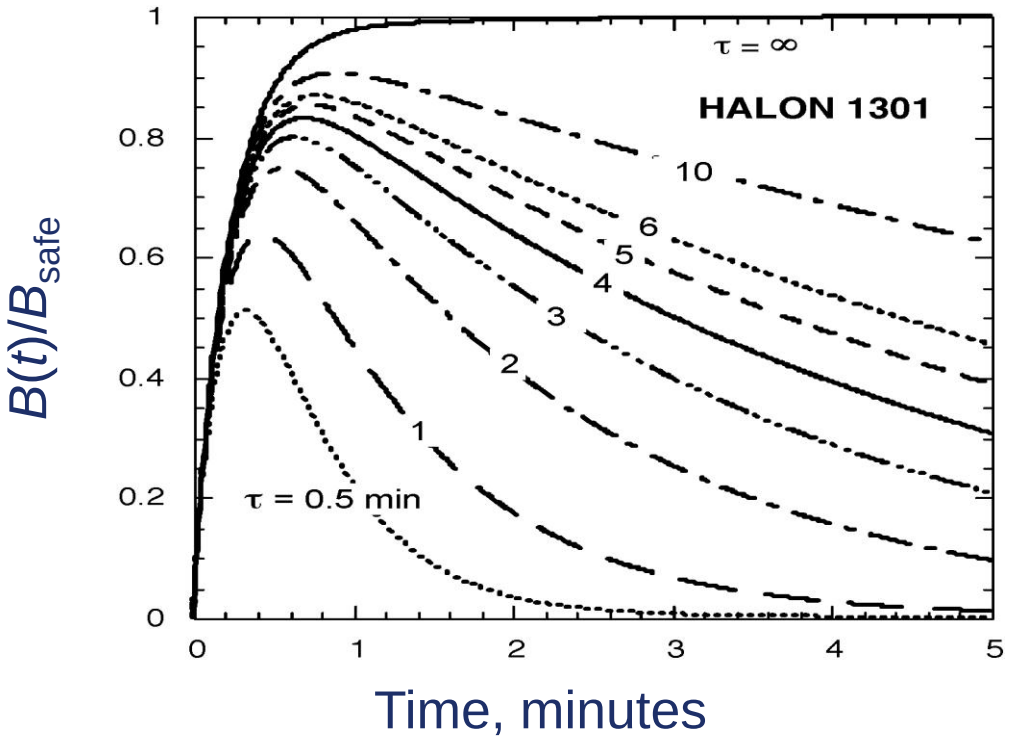
$$k_3 k_4 P_{BA} \int_0^t \left( \int_0^t A(x) e^{-k_4(t-x)} dx \right) e^{-k_{23}(t-y)} dy$$

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 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**

# Tests

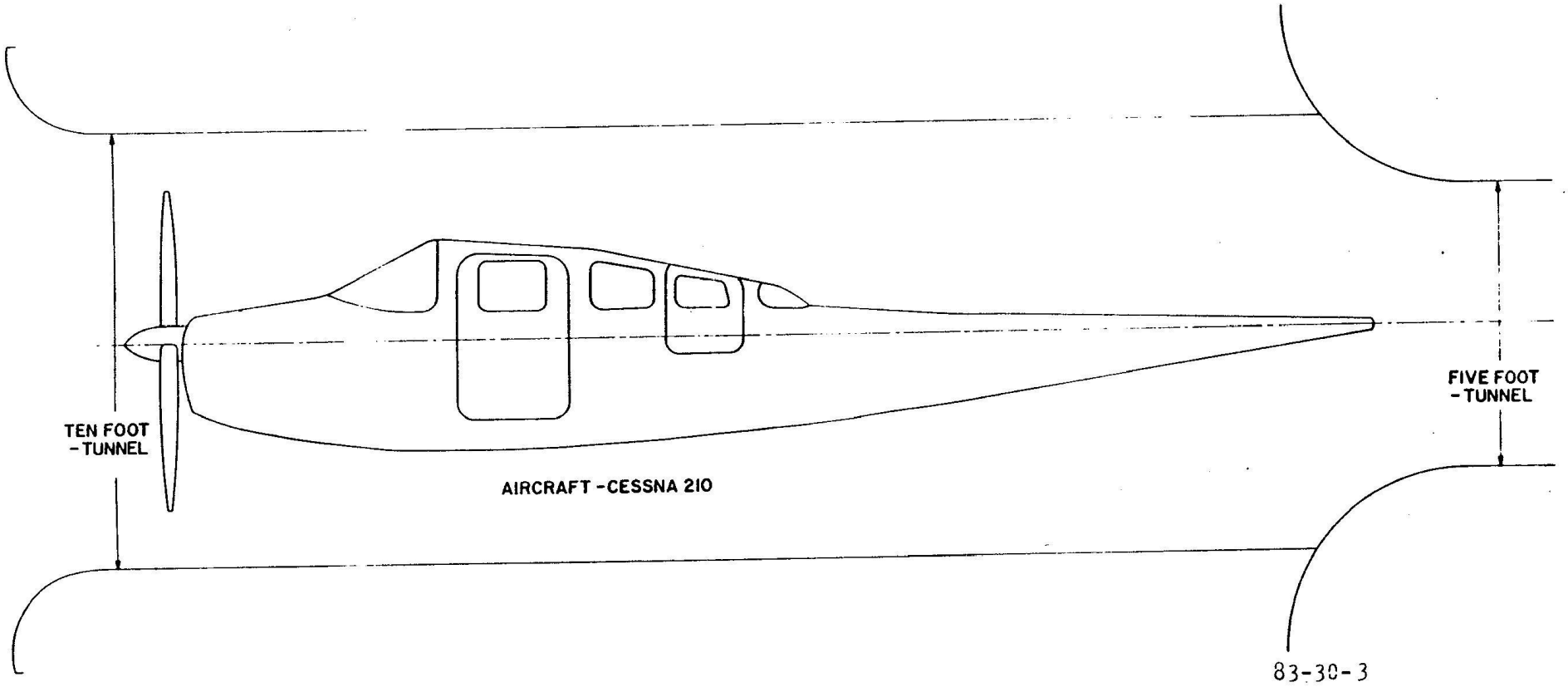
- 2 Discharge locations: Under instrument panel & at copilot's seat
- Discharge 1 circa 2.5 lb Halon 1211 hand extinguisher at selected targets in each compartment.
- 3 ventilation conditions at 120 mph air speed
  - Overhead vents open, Air change time, $\tau$ = 1.16 minutes
  - All vents open
  - All vents closed
- Gases measured at pilot's nose level and at target position

# Determination of Stratification Multiplication Factors: Arterial Blood Concentrations

**Perform following steps based on Halon 1301 kinetics and 2.50 lb. Halon 1211 extinguisher charge weight.**

- Correct Halon 1211 concentration histories to a 2.5 lb. Halon 1211 discharge basis weight. (2.55 to 3.15 lb. actual)
- Calculate arterial concentration histories for the theoretical and actual discharge assuming Halon 1301 kinetics (& 2.5 lb. basis weight).
- The ratio of the theoretical peak arterial concentration to the peak experimental concentration is the multiplication factor.
- Multiplication factor can be applied to the AC 20-42D ventilation-corrected minimum safe volumes or safe-use W/V concentrations.

# Wind Tunnel Profile with Cessna 210



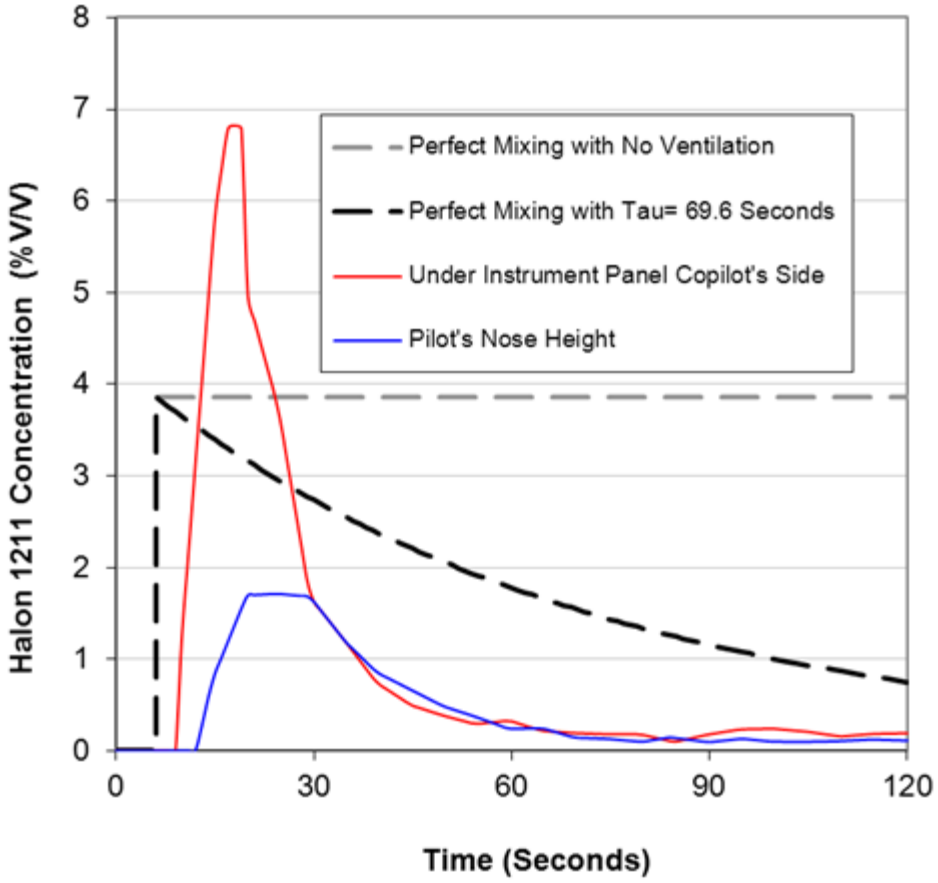

- The aircraft volume is 139.9 $ft^3$
- At 120 mph, the air change time, $\tau$ = 69.6 seconds

# Target: Under Instrument Panel, Copilot's Side

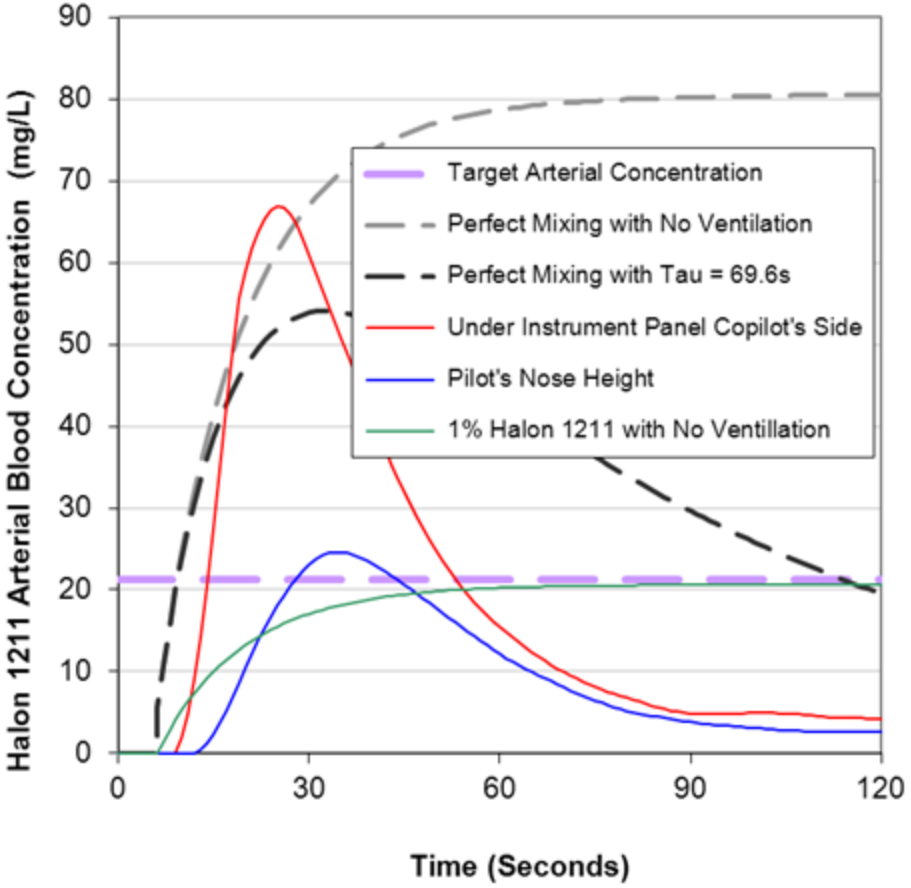
## Overhead Vents Open, $\tau$ = 1.16 min.

MF **Stratification & Localization** = 0.81, 2.2 (Target and Pilot's Nose Height)

*Data from 1984 Report, Fig 6, Test 4*

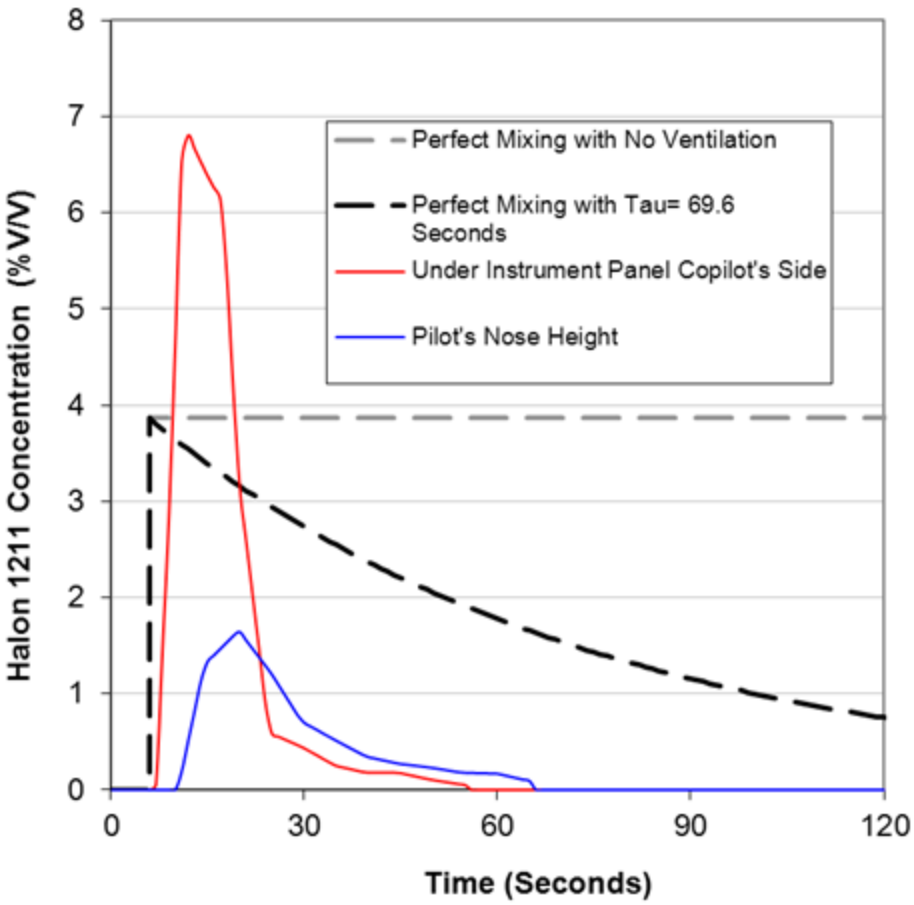



*Based on Halon 1301 Kinetics*

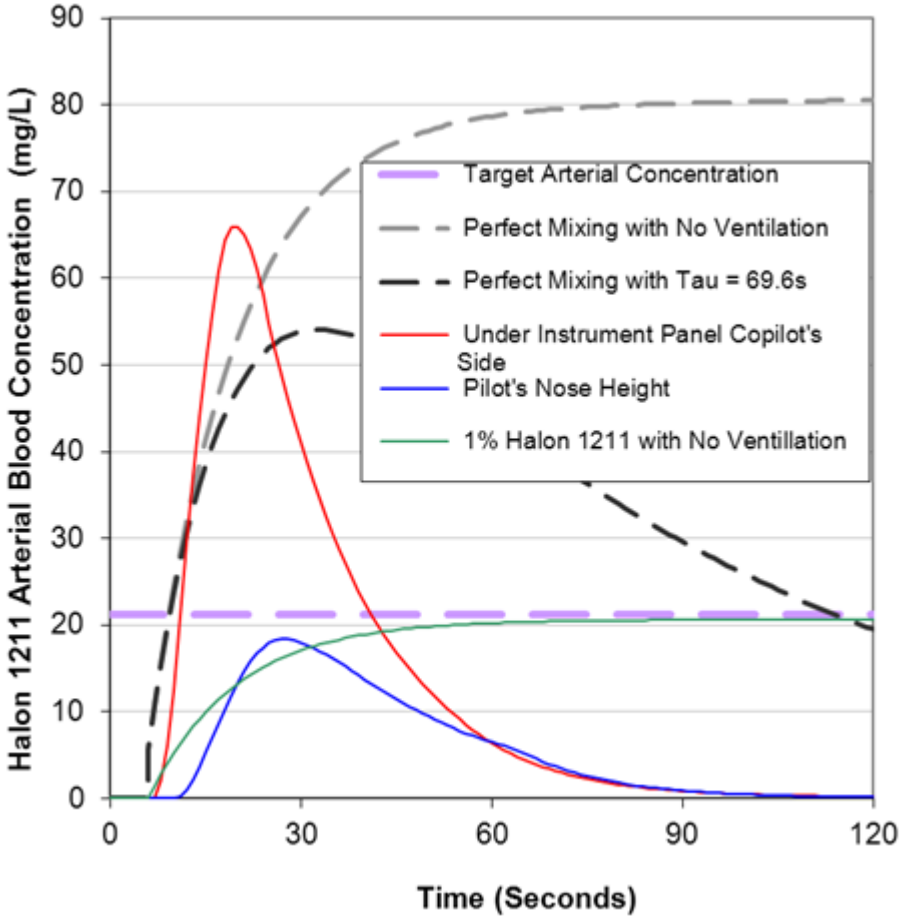


# Target: Under Instrument Panel, Copilot's Side
# All Vents Open

*Data from 1984 Report, Fig 7, Test 7*

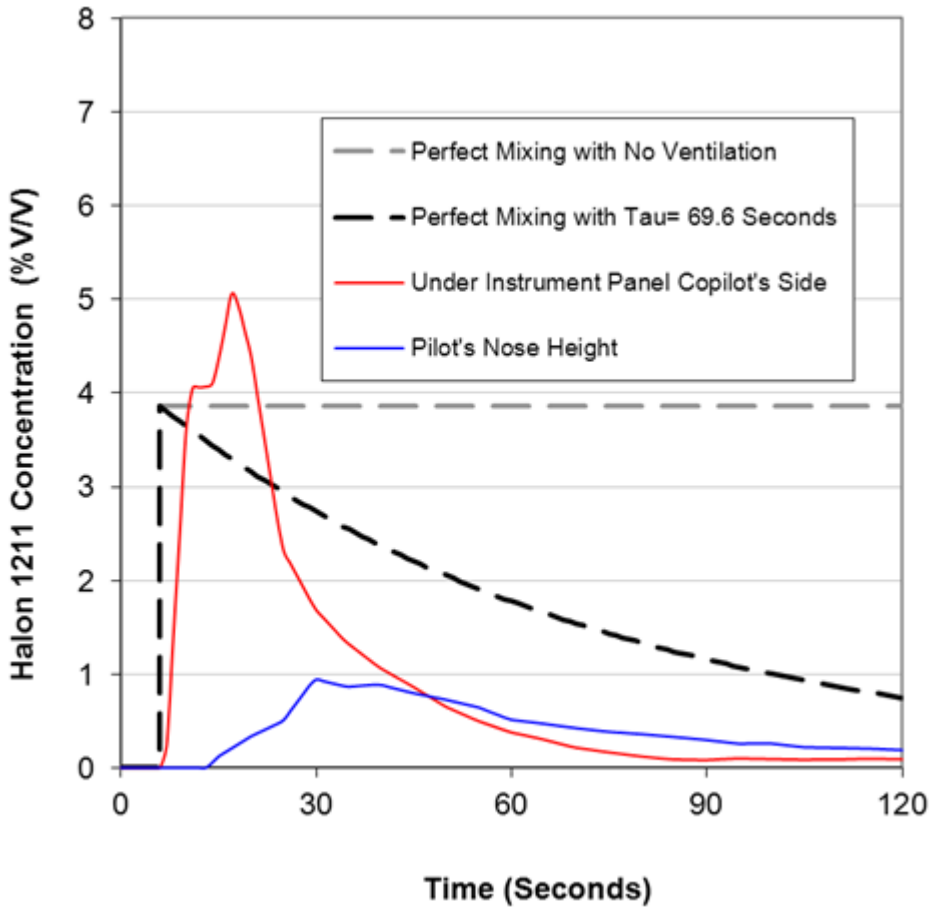



*Based on Halon 1301 Kinetics*

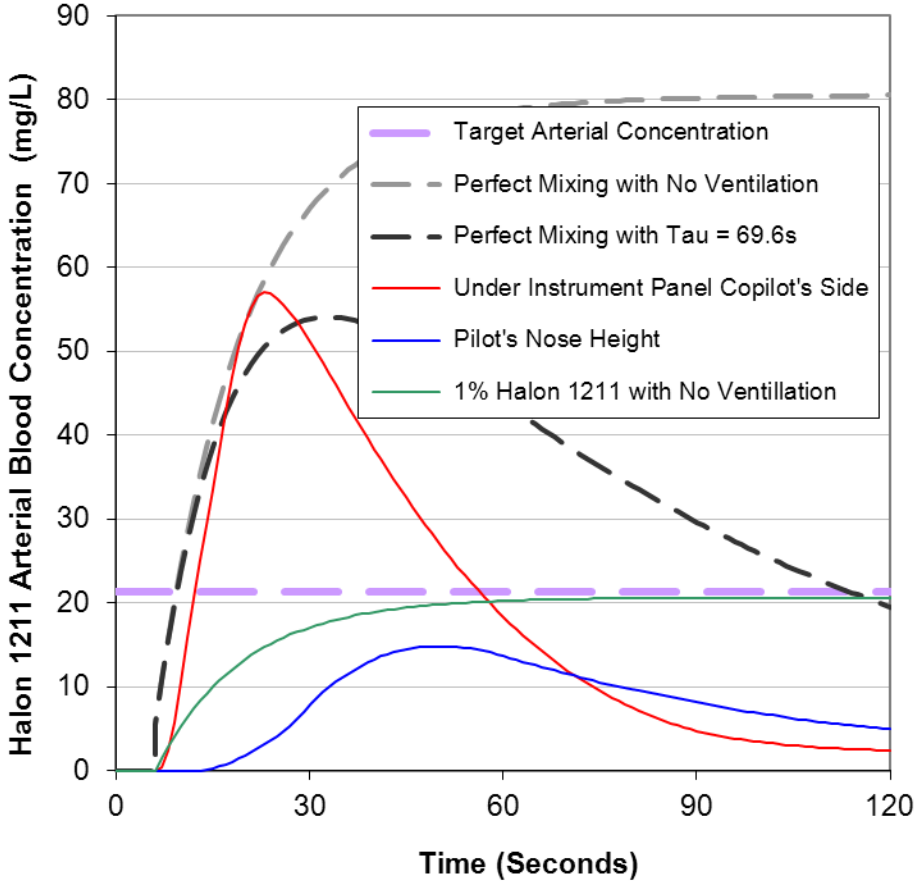


# Target: Under Instrument Panel, Copilot's Side
# All Vents Closed

*Data from 1984 Report, Fig 8, Test 6*




*Based on Halon 1301 Kinetics*

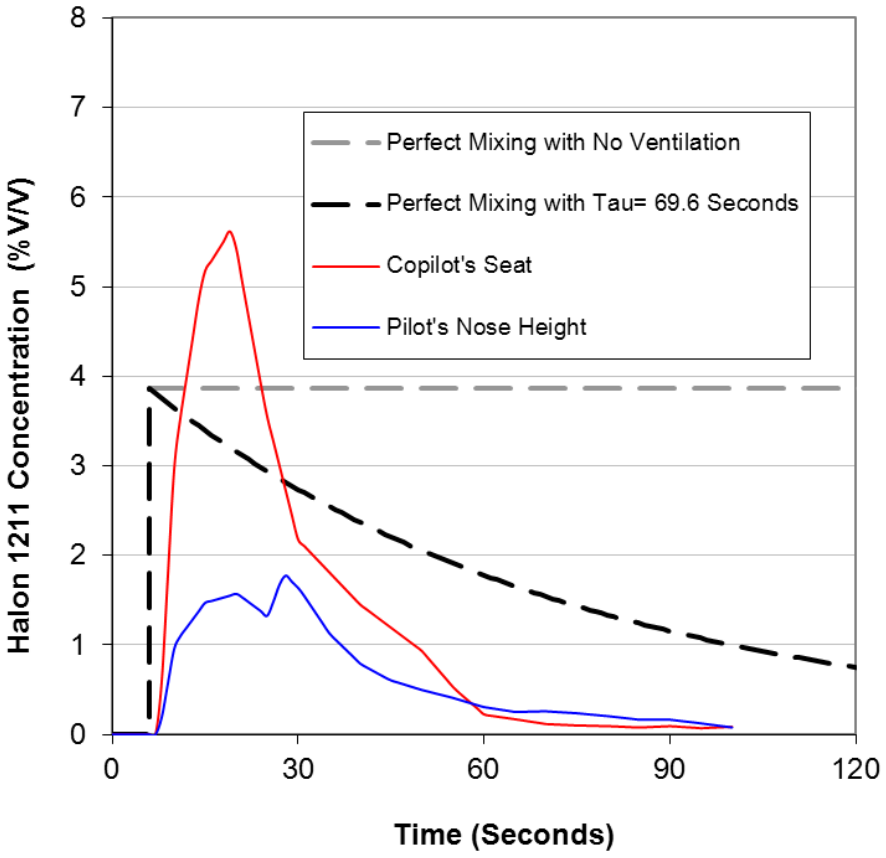


# Target: Copilot's Seat

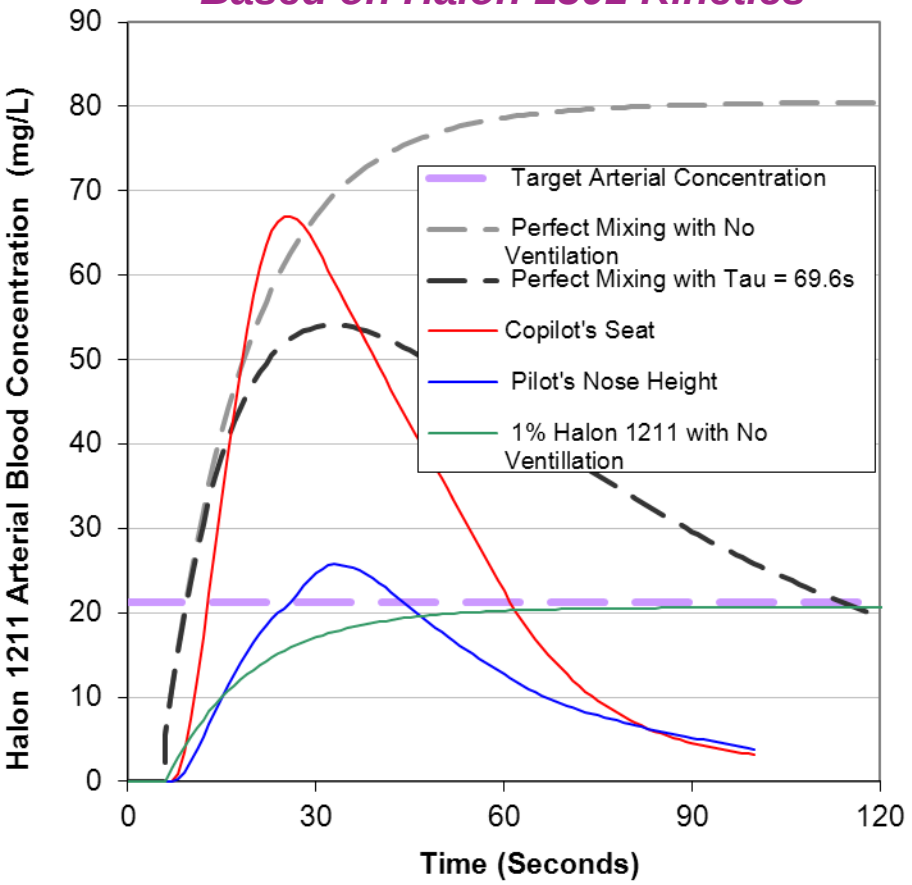
## Overhead Vents Open $\tau$ = 1.16 minutes

$MF_{\text{Stratification \& Localization}}$ = 0.81, 2.1 (Target and Pilot's Nose Height)

*Data from 1984 Report, Fig 17, Test 17*

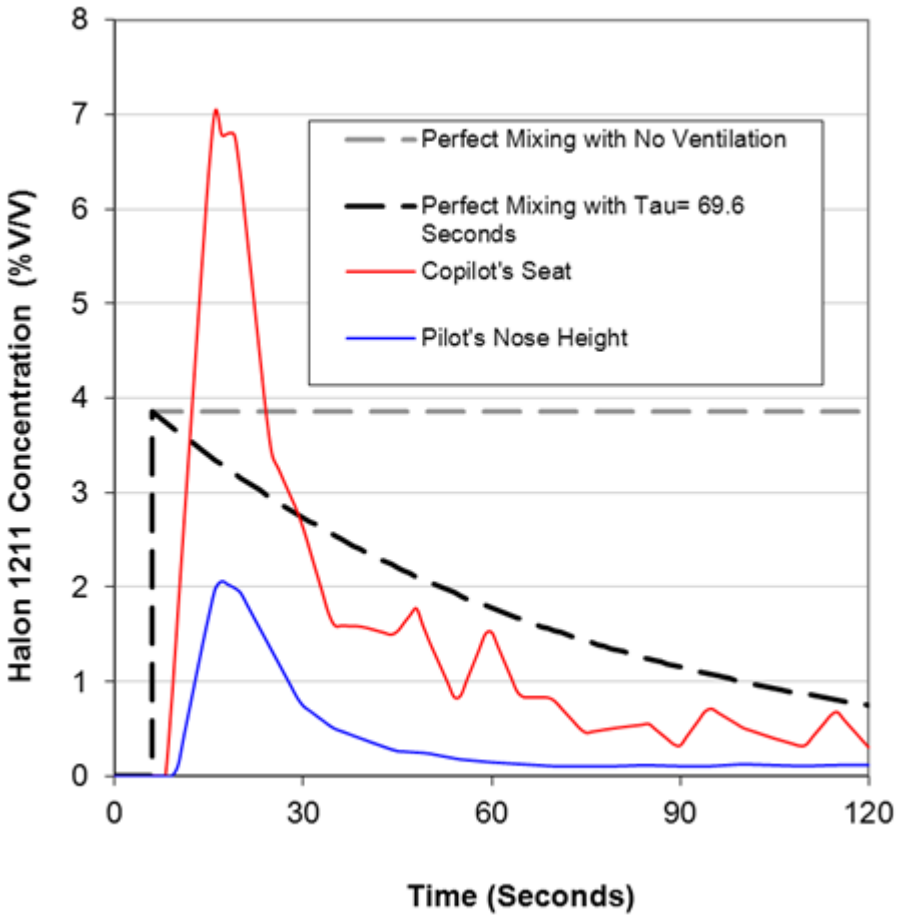



*Based on Halon 1301 Kinetics*

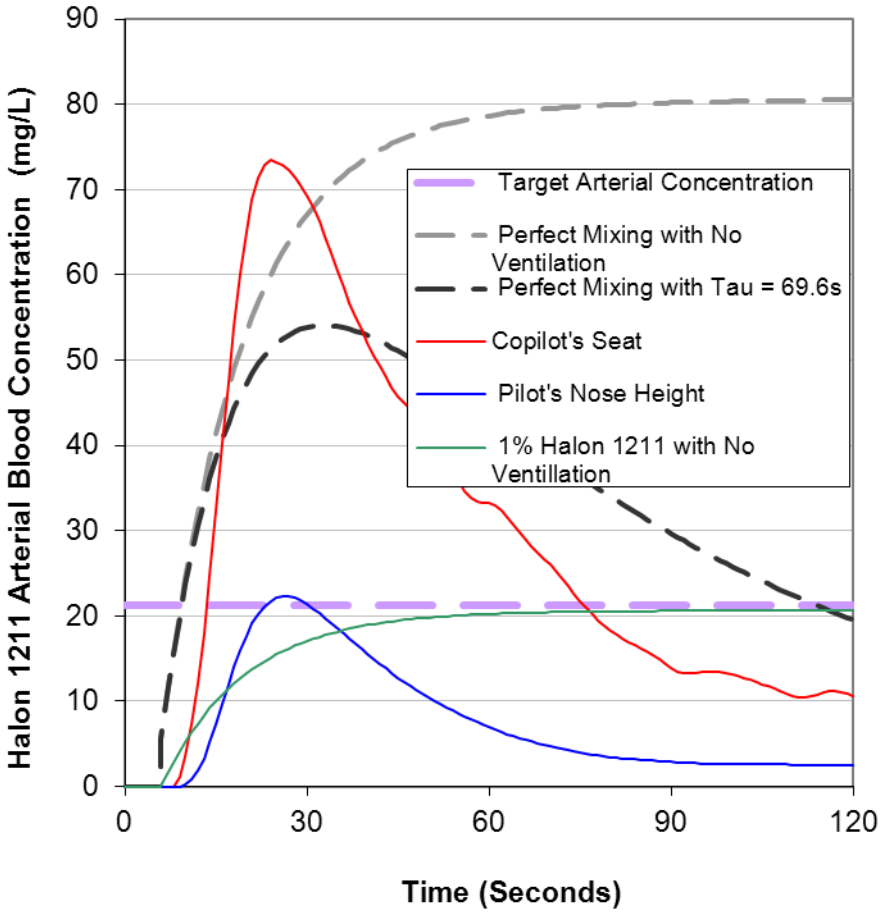


# Target: Copilot's Seat, All Vents Open

*Data from 1984 Report, Fig 19, Test 20*

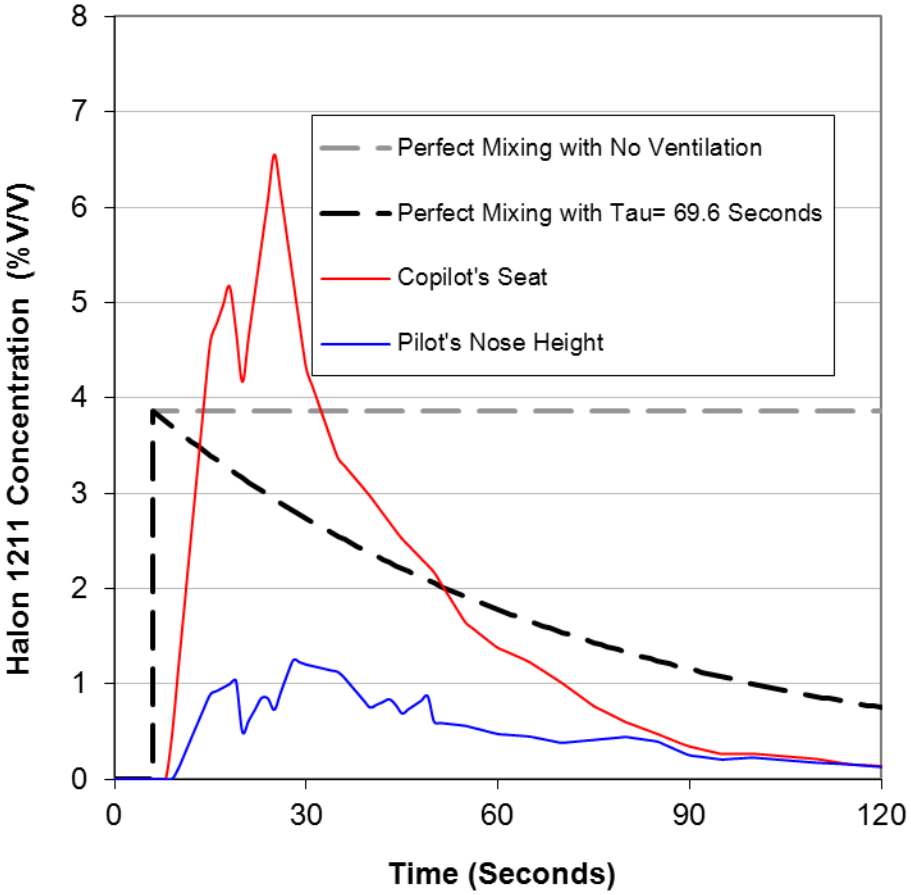



*Based on Halon 1301 Kinetics*

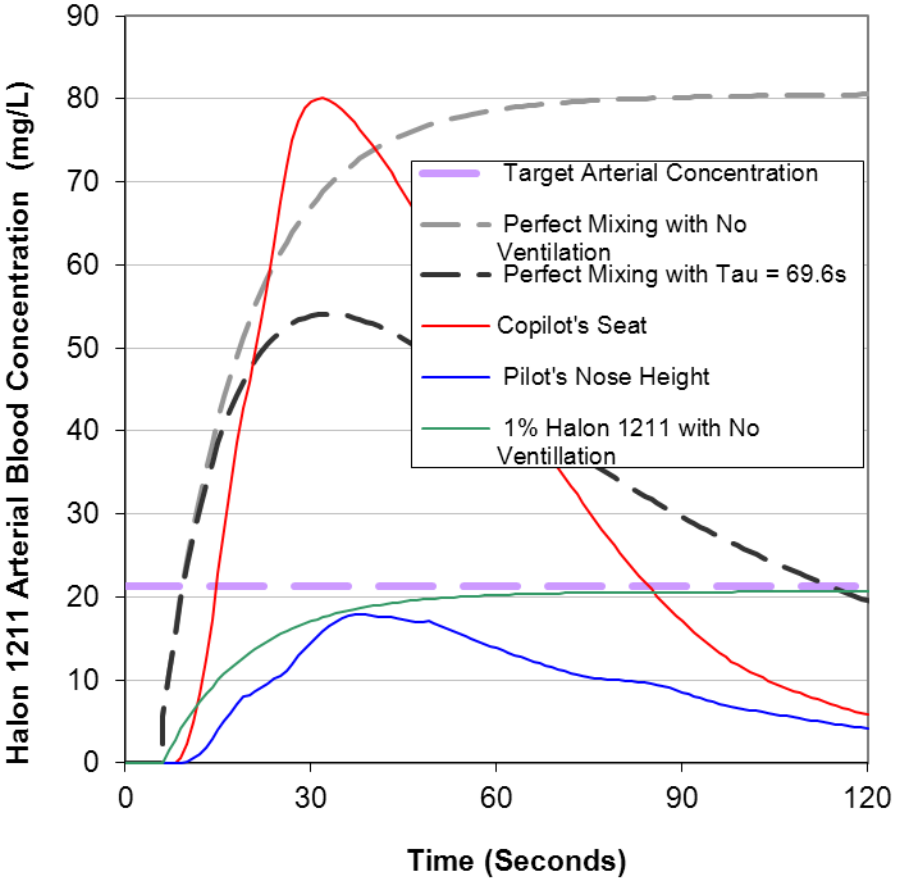


# Target: Copilot's Seat, All Vents Closed

*Data from 1984 Report, Fig 20, Test 19*




*Based on Halon 1301 Kinetics*

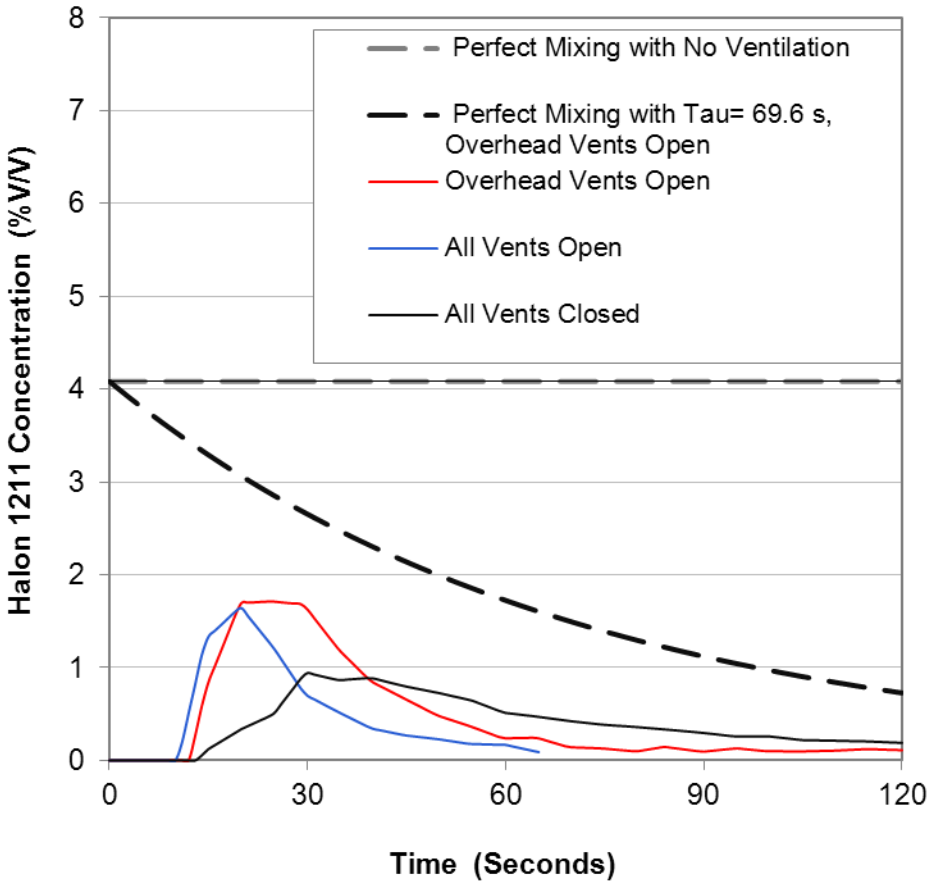


# Target: Under Instrument Panel, Copilot's Side

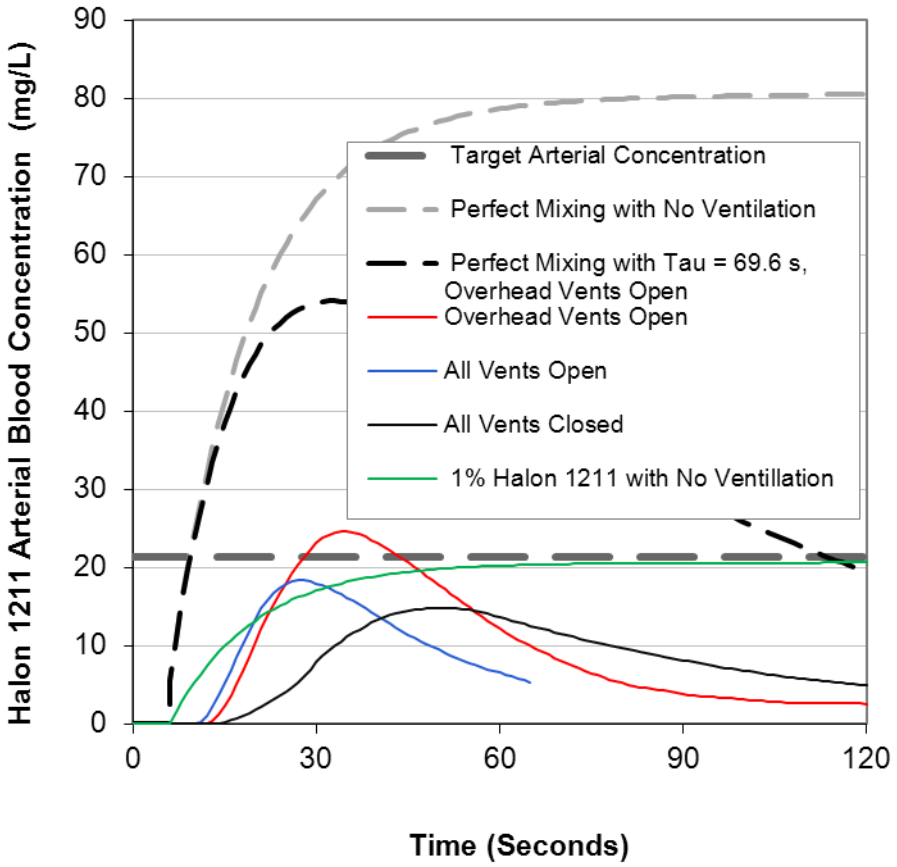
# Comparison of Ventilation Methods

## Halon 1211 at Nose Height

*Data from 1984 Report, Fig 6,7, and 8*




*Based on Halon 1301 Kinetics*

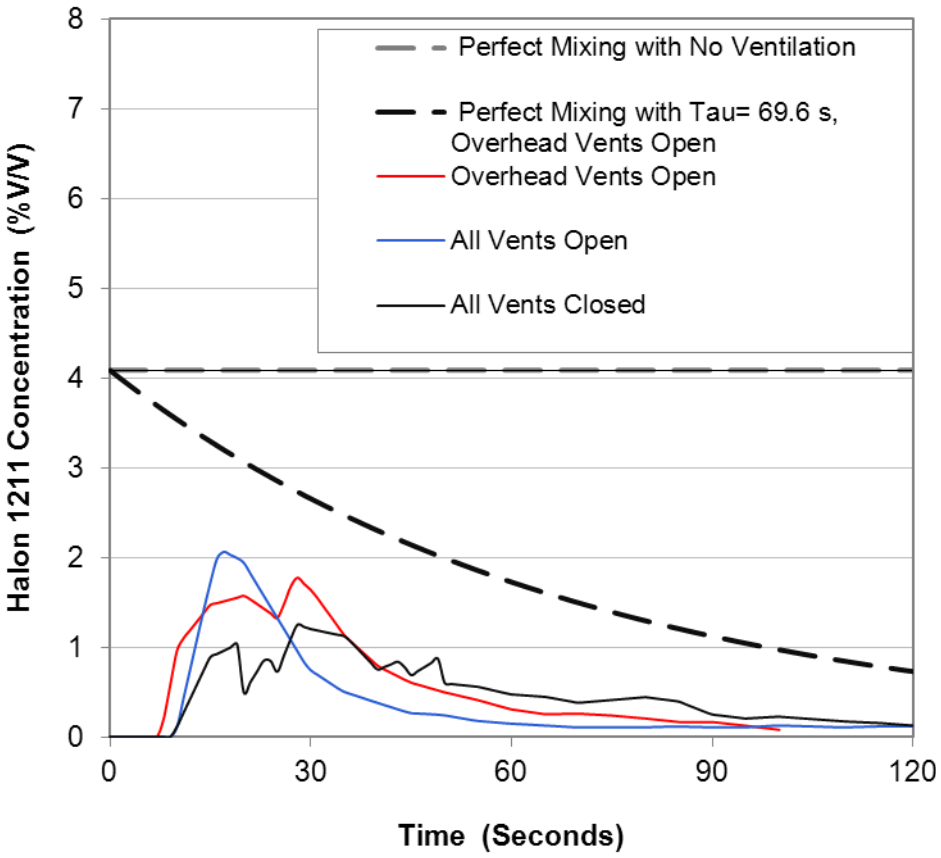


# Target: Copilot's Seat

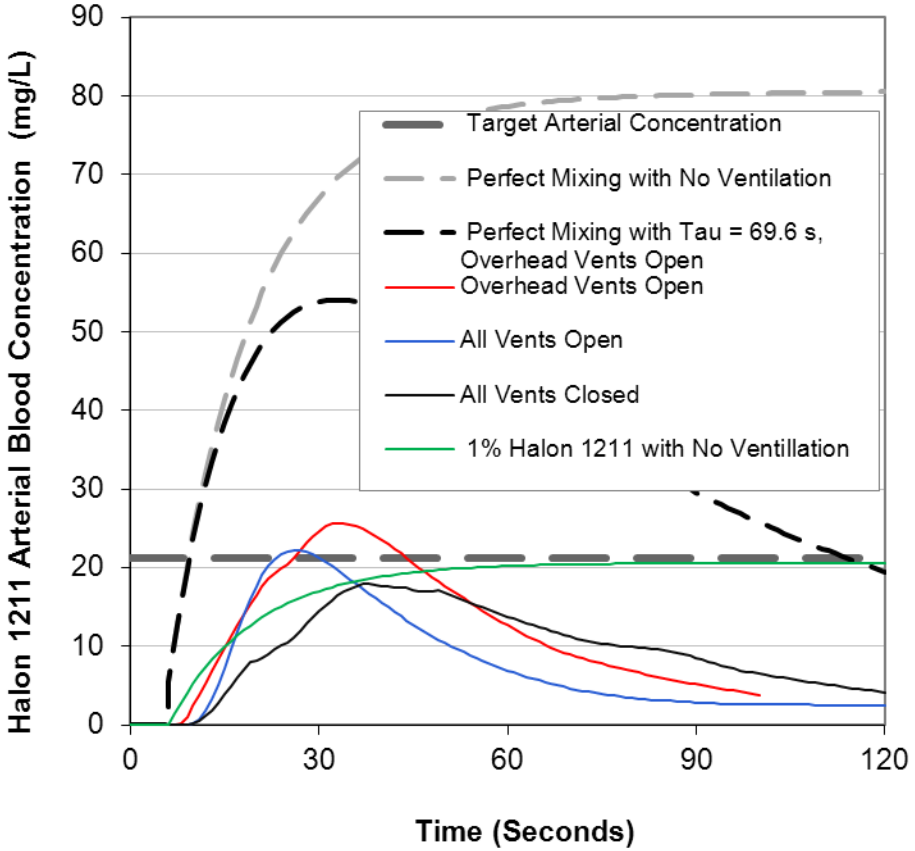
# Comparison of Ventilation Methods

## Halon 1211 at Nose Height

*Data from 1984 Report, Fig 17, 19, and 20*



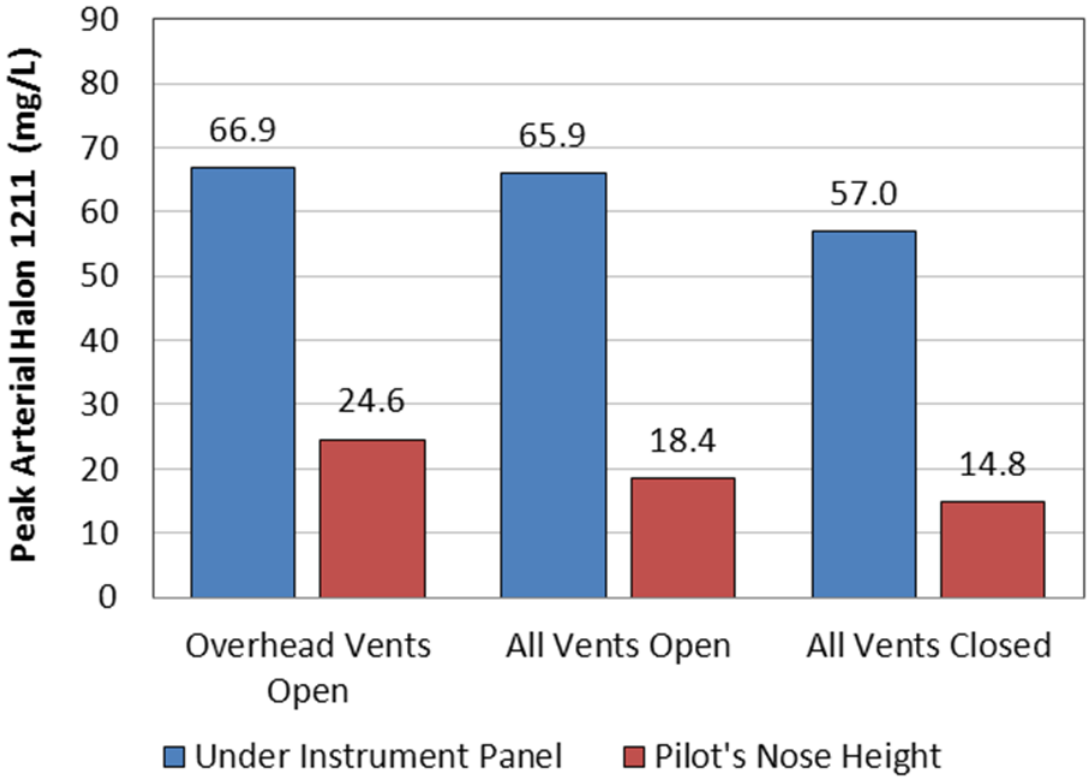

*Based on Halon 1301 Kinetics*



# Target: Under Instrument Panel, Copilot's Side

# Comparison of Ventilation Methods: Peak Arterial Concentrations

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

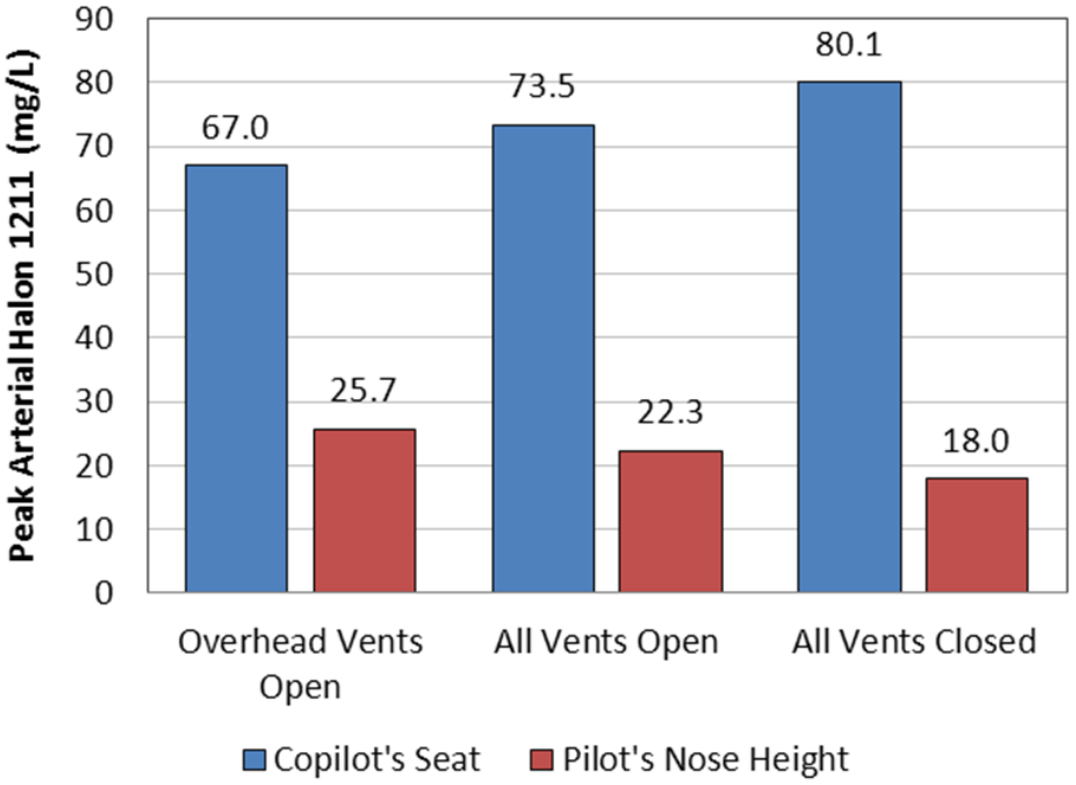



***Based on data from 1984 report, Fig 6, 7, and 8***

# Target: Copilot's Seat

# Comparison of Ventilation Methods
# Peak Arterial Concentrations

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

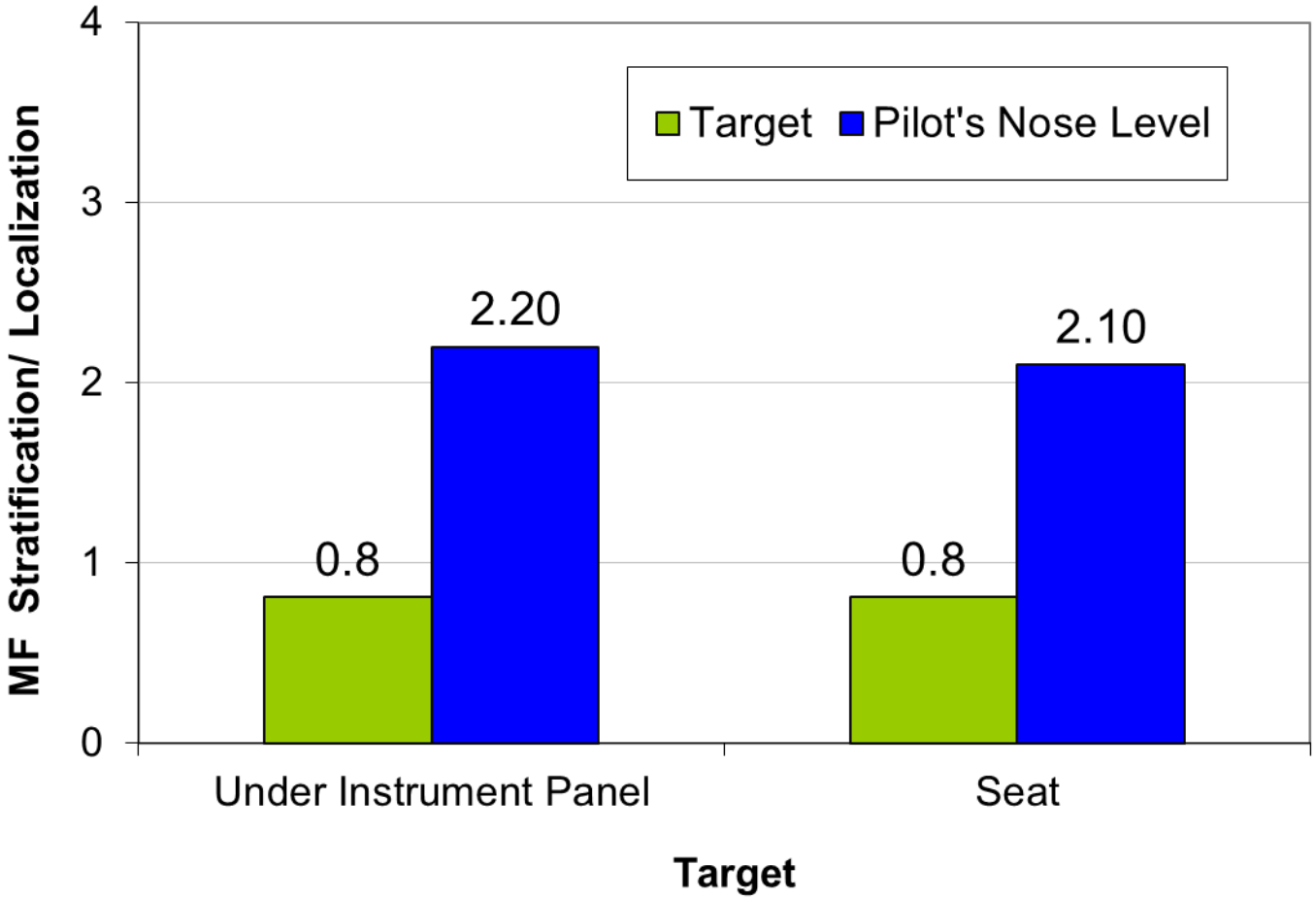



***Based on data from 1984 report, Fig 17, 19, and 20***

# Cabin Tests: Stratification/ Localization MFs

## Pilots Nose Level, Overhead Vents Open, , $\tau$ = 1.16 min.

***Based on Halon 1301 Kinetics***



# Conclusions

- **Stratification is significant for the Cessna 210C, resulting in lower than theoretical perfect mixing Halon 1211 concentrations at the pilot's nose level:**
- **Stratification & Localization MFs greater than one were attained at the pilot's nose level for discharges under the copilot's instrument panel and the copilot's seat: 2.2 and 2.1 respectively.**
- **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.**