Effect of Loading on Halon 1211 Stratification/ Localization in Small 4-Seater Aircraft

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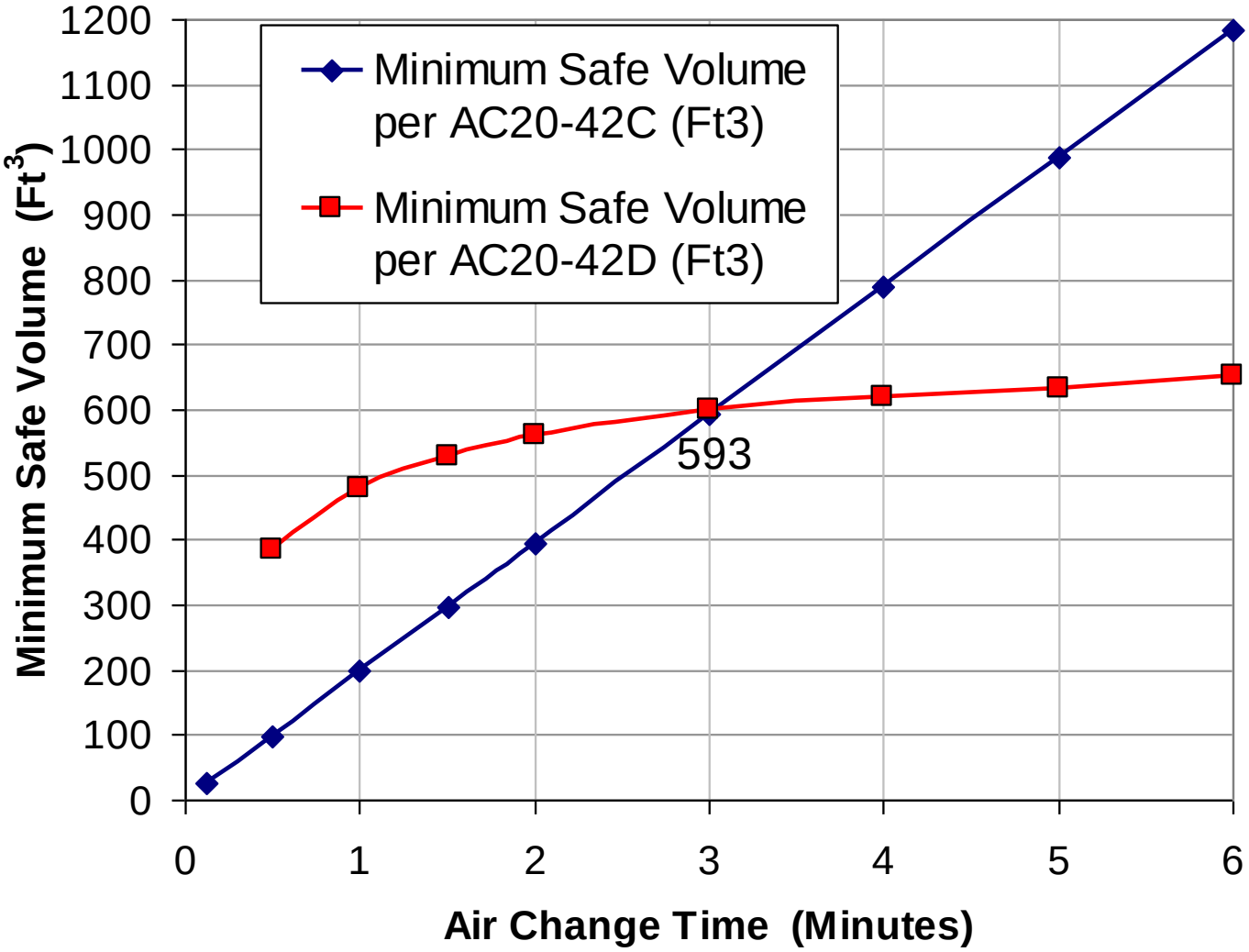
Background

- **Per AC20-42D - Halon 1211, Halotron, and BTP are unsafe for use in flight decks and other small volumes.**
- **Safe use threshold for Halon 1211 gas exposures is based on the peak human arterial blood concentration not exceeding 21.3 mg/L. A large safety factor was used in establishing this value.**
- **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.**
- **Test-based multiplication factors ($MF_{Stratification\text{-}Localization}$) can be applied after $MF_{Ventilated}$ are applied to allow higher concentrations than AC 20-42D guidance provides, accounting for agent stratification and localization.**

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 *$MF_{Ventilated}$ are similar for all non-chlorinated halocarbons.*

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

Objective

- **Evaluate the effect of loading on Halon 1211 stratification in a ventilated 4-seater unpressurized GA aircraft.**

- **Retrospective study of 1984 and 1986 FAA stratification/ localization data for Halon 1211 hand extinguishers discharged in aircraft in a wind tunnel with an airspeed of 120 mph**.
  - 1984 Empty Aircraft
  - 1986 Loaded Aircraft: **4 Seated Mannequins + Luggage**

- **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.**

- ***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 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

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

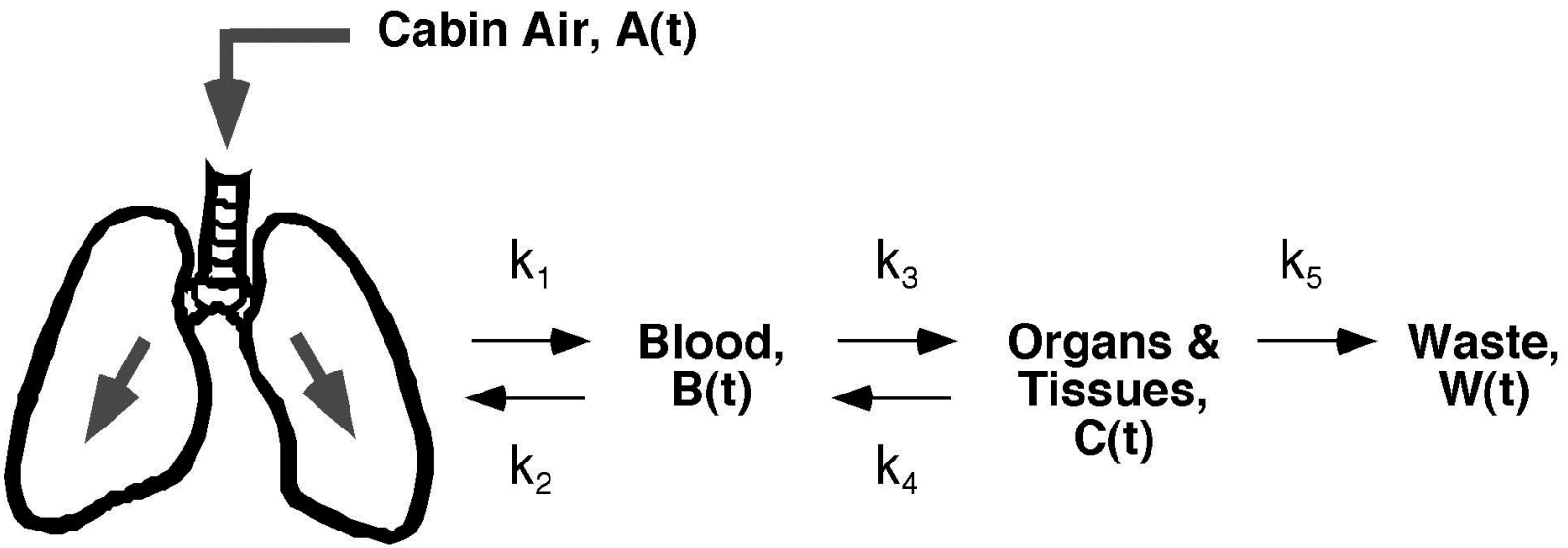
- Compute arterial concentration histories **using FAA's Simplified Kinetic Model and Halon 1301 kinetics**

- 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}.

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

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

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

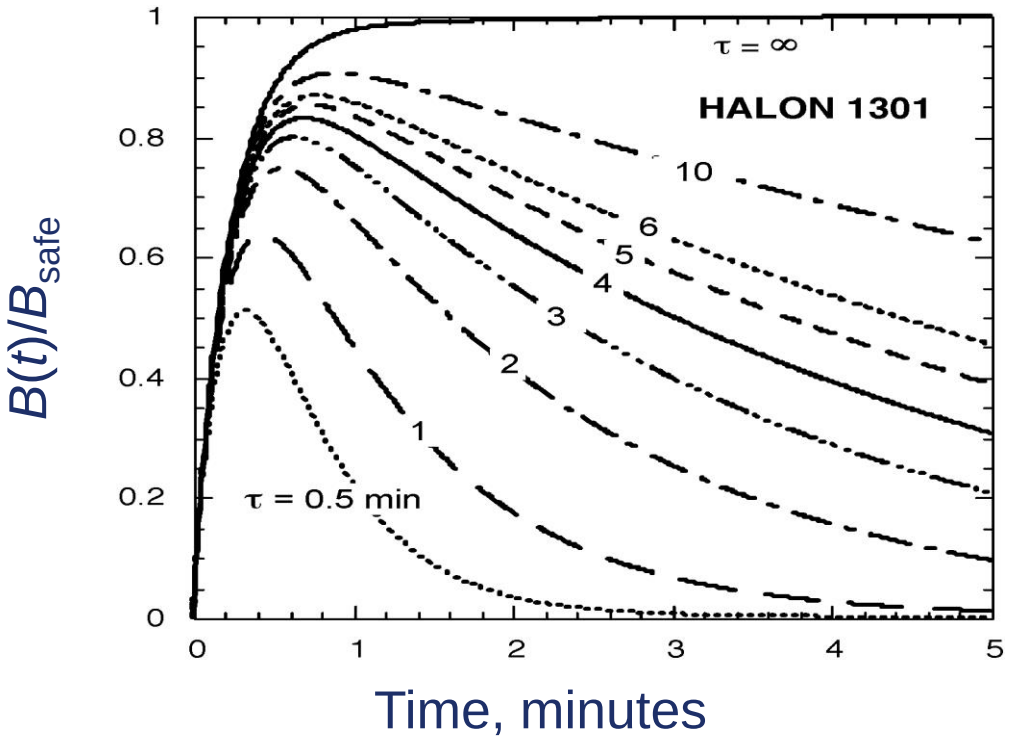
$$k_3 k_4 P_{BA} \int_0^t \left(\int_0^t A(x) e^{-k_4(t-x)} dx \right) e^{-k_{23}(t-y)} dy$$

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.

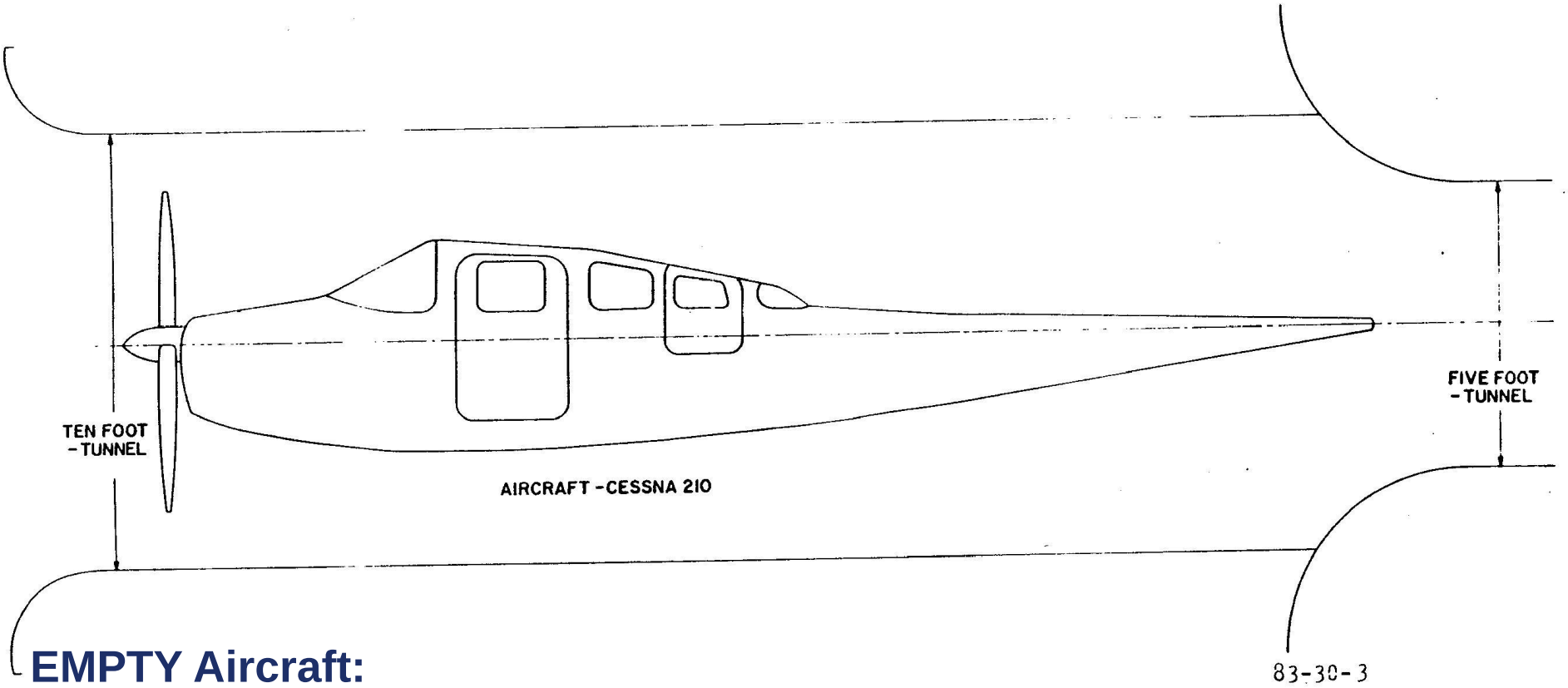
2) Speitel, L.C. and Lyon, R.E, "Guidelines for safe use of gaseous halocarbon extinguishing agents in aircraft", FAA report DOT/FAA/AR-08/3, August 2009, http://www.fire.tc.faa.gov/pdf/08-3.pdf

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

Wind Tunnel Profile with Cessna 210C



EMPTY Aircraft:

- The aircraft volume is 139.9 ft^3
- Four Overhead Vents
- At 120 mph, the air change time, τ = 69.6 seconds, overhead vents open
- Air exits the tailcone area through openings where control cables pass through. Possibility of floor exit vents. Exit openings not documented in reports

Tests

- Discharge location: Under instrument panel:
  - Empty Aircraft: 1984 Report
  - 4 Seated Mannequins with baggage in baggage area: 1986 Report

- **Discharge circa 2.5 lb Halon 1211 hand extinguisher 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 *(measured at OH vents with pitot tubes)*
    - 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.

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.

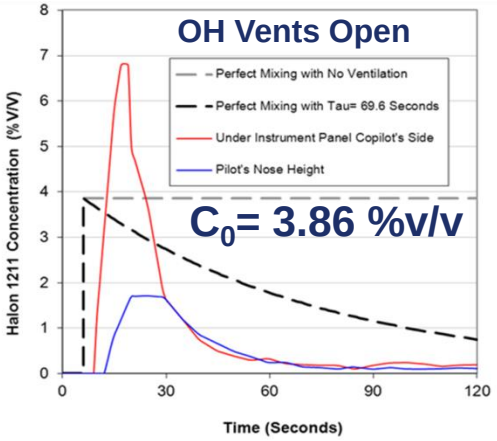
- Correct Halon 1211 gas concentration histories to a 2.5 lb. Halon 1211 discharge basis weight. (2.3 to 2.85 lb. actual)
- Calculate arterial concentration histories for the theoretical and actual discharge assuming Halon 1301 kinetics (& 2.5 lb. basis weight).
- The ratio of the theoretical peak arterial 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.

Air Change Time with Airspeed = 120 mph, Empty Aircraft

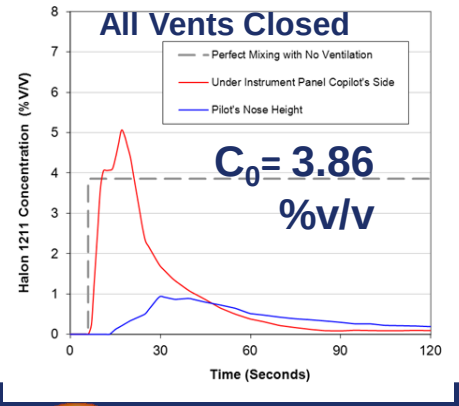
- An accurate air change time and accurate free space volume are needed to determine $MF_{Ventilation}$ and $MF_{Stratification\text{-}Localization}$.
  - Air change times were determined using pitot-static probes at 4 overhead vents in empty aircraft with only overhead vents open, **τ** = 1.16 minute. C_0= 3.86% for 2.50 lb. Halon 1211 discharge. **Concentrations under instrument panel lower than expected at τ = 1.16 min**

- **Overhead Vents Open, τ = 1.16 min**
  - Perfect mixing 3.86% V/V Halon 1211 will decay 36.8% to 1.42% after 1 air change.
  - Actual = 0.2% and 0.1% with OH Vents Open (at 76 s)

- **All Vents Closed, τ = ∞**
  - Perfect mixing 3.86% V/V Halon 1211 should not decay if all vents closed.
  - Actual = 0.2 and 0.4% with OH Vents Closed (at 76 s)



Target: Under Instrument Panel, Copilot's Side

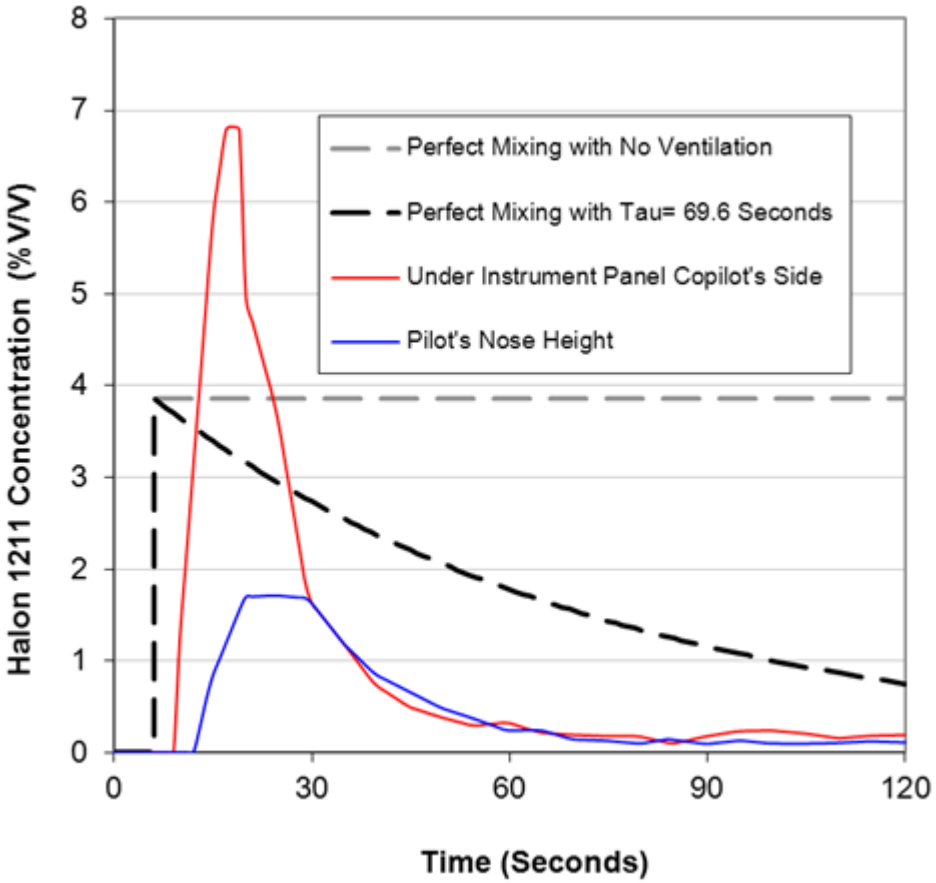


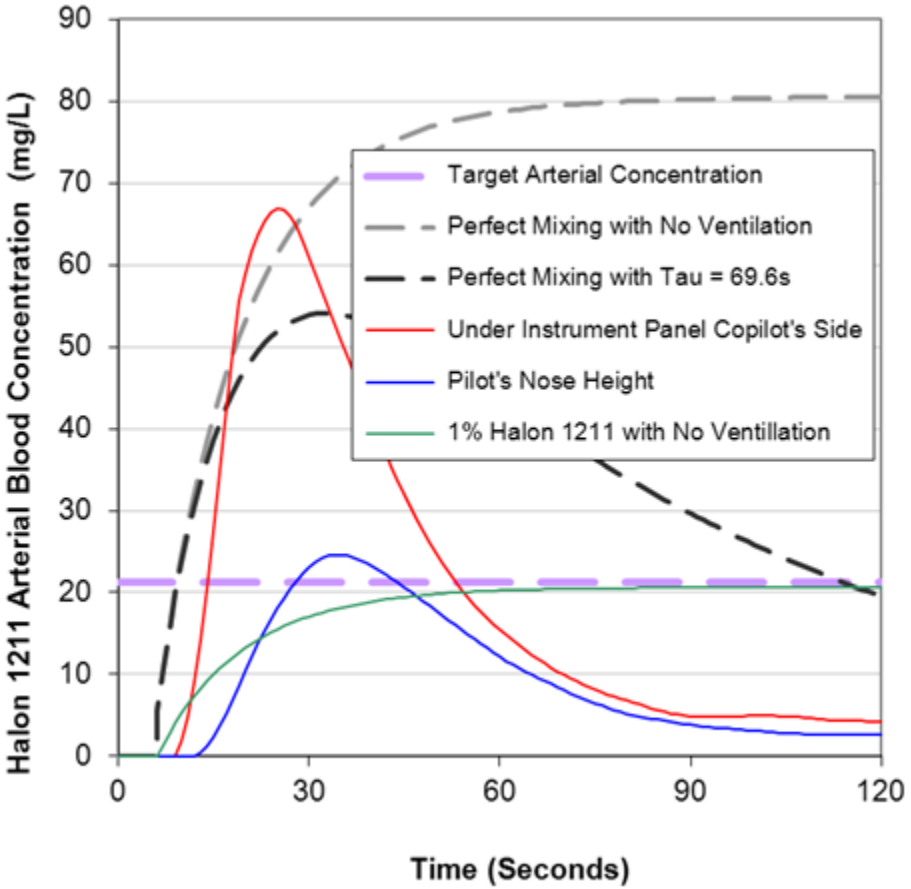
- Authors of 1984 and 1986 reports did not account for possible air infiltration through other openings: **τ** may be much less than 1.16 min
- **OR** Agent may be exiting through openings in the floor **(Need to find and inspect Cessna 210C, 1963 vintage)**

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

Overhead Vents Open, τ = 1.16 min.

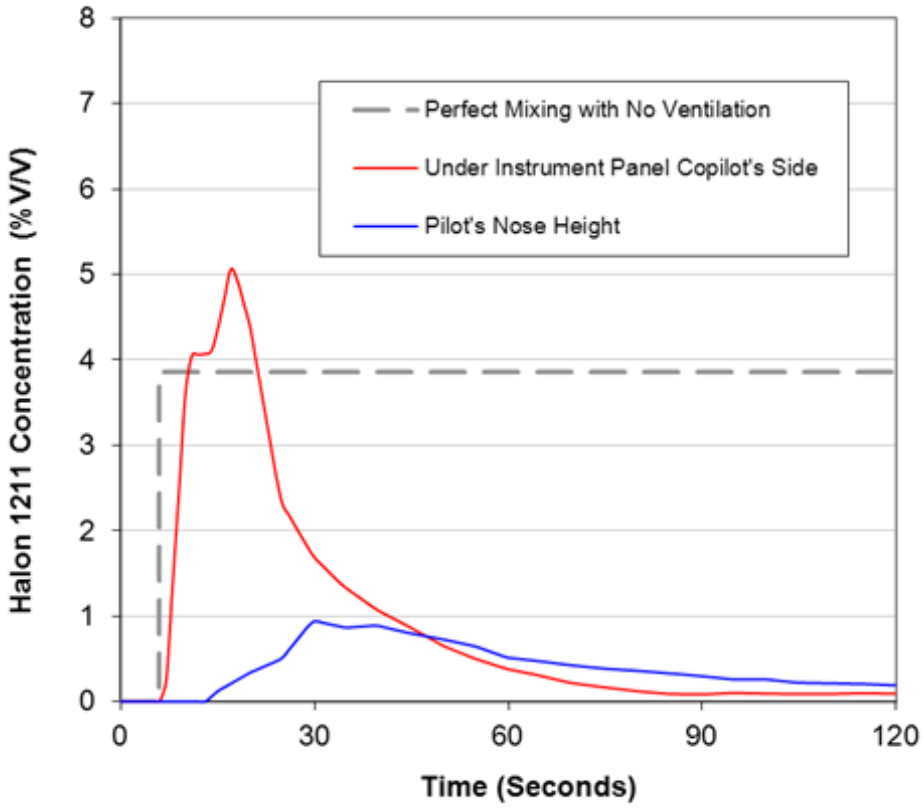
MF $_{\text{Stratification \& Localization}}$ = 0.81, 2.2 (Target and Pilot's Nose Height)

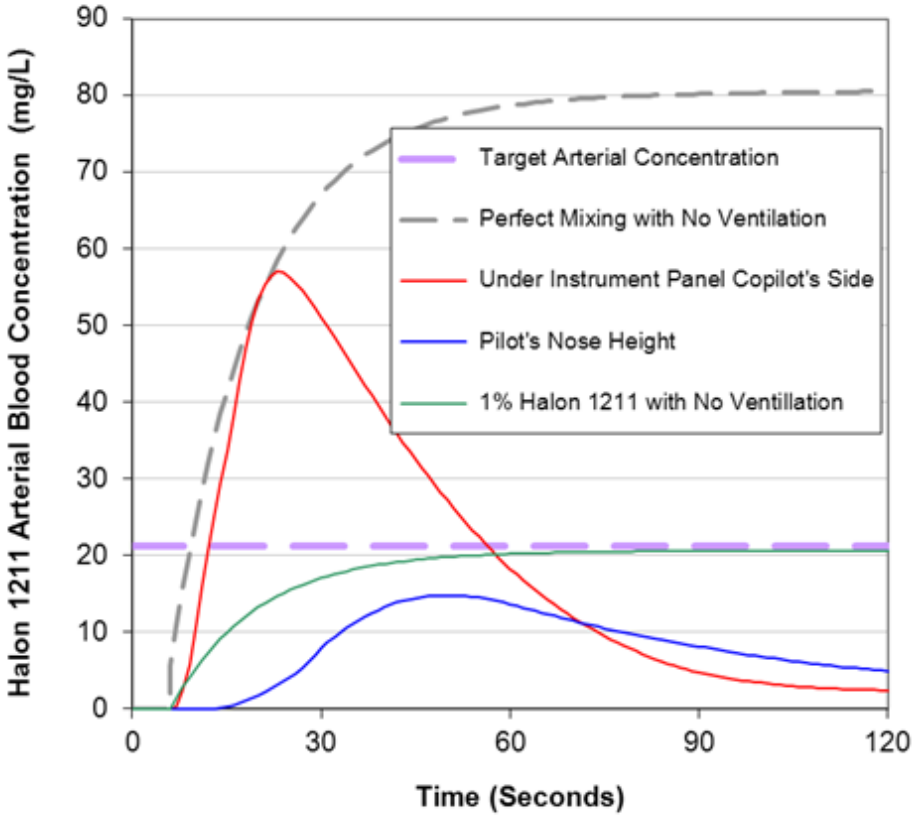




Based on data from 1984 Report, Fig 6, Test 4

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



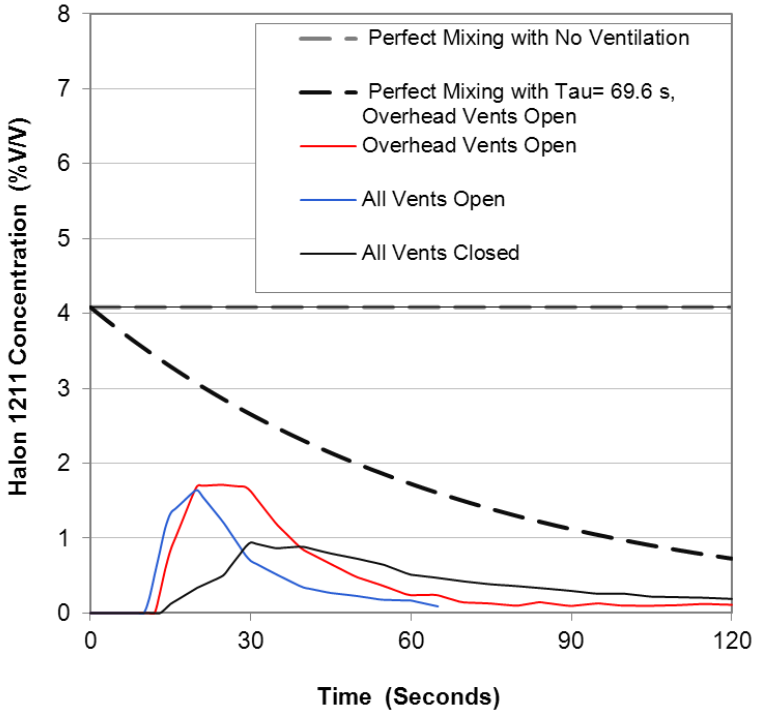


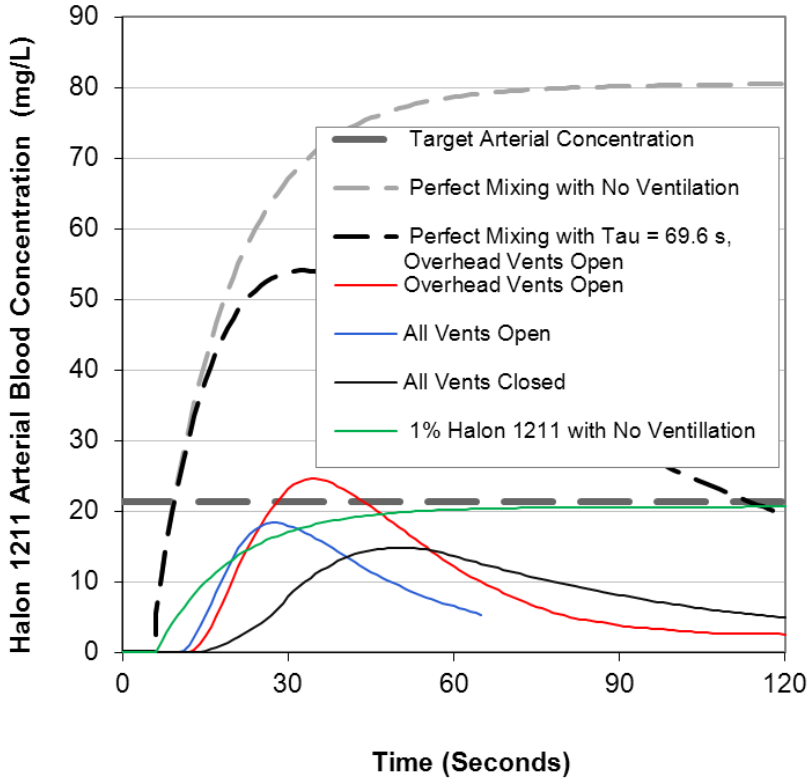
Based on data from 1984 Report, Fig 8, Test 6

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

Comparison of Ventilation Methods

Halon 1211 at Nose Height

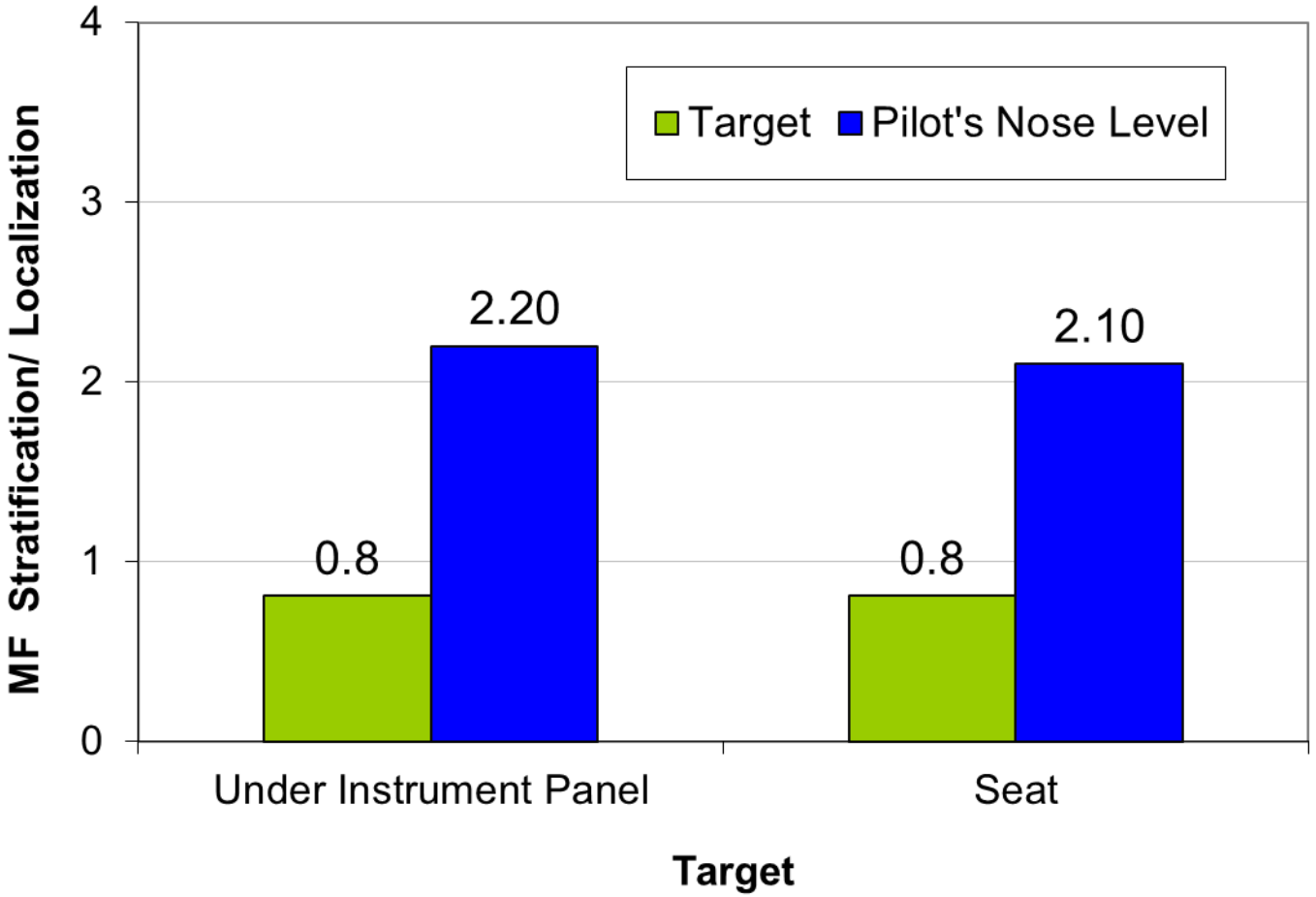




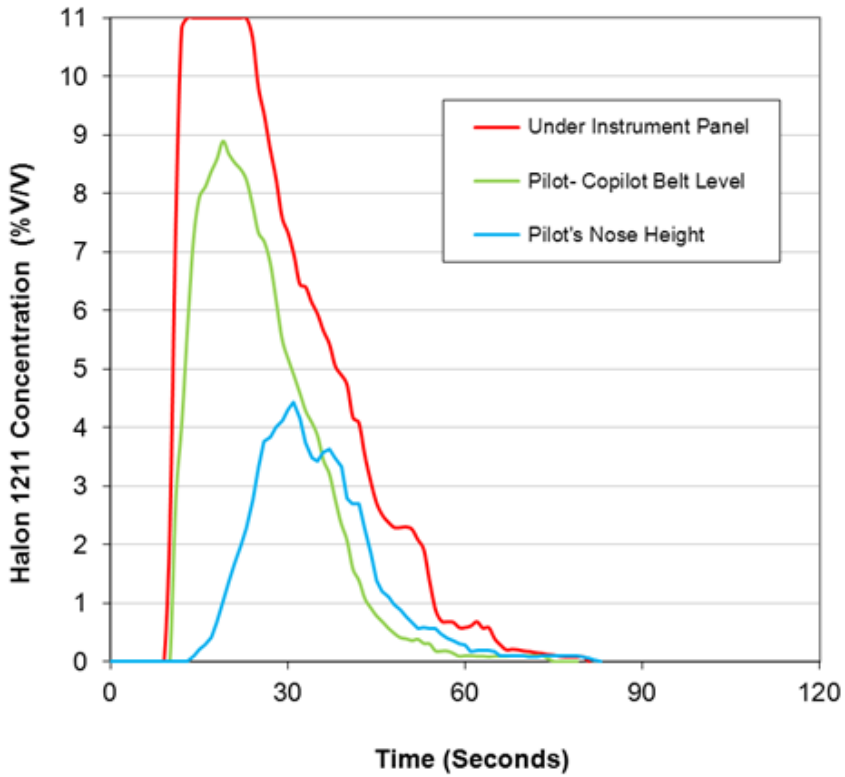
- *Perfect mixing Halon 1211 gas and arterial concentrations are shown for overhead vent open and all vents closed. The air change time is unknown for all vents open.*

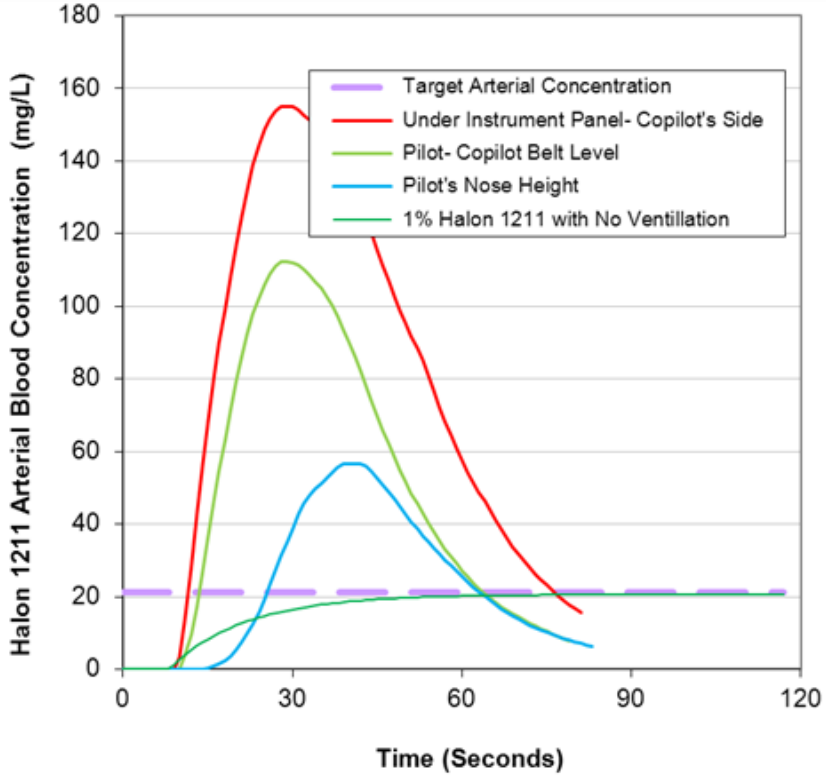
Based on data from 1984 Report, Fig 6,7, and 8

Empty… Cabin Tests: Stratification/ Localization MFs Pilots Nose Level, Overhead Vents Open, , τ = 1.16 min.



Loaded… Target: Under Instrument Panel, Copilot's Side
Overhead Vents Open

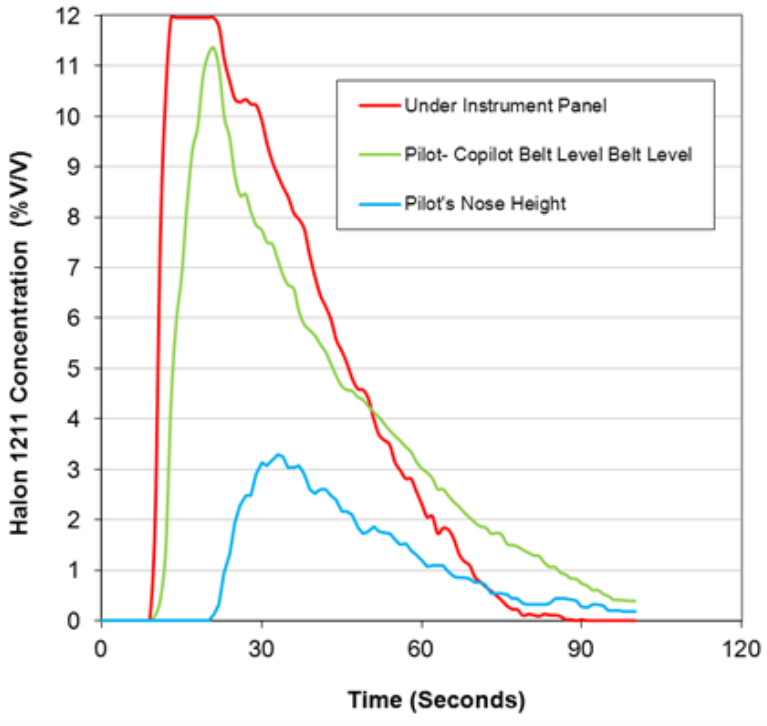


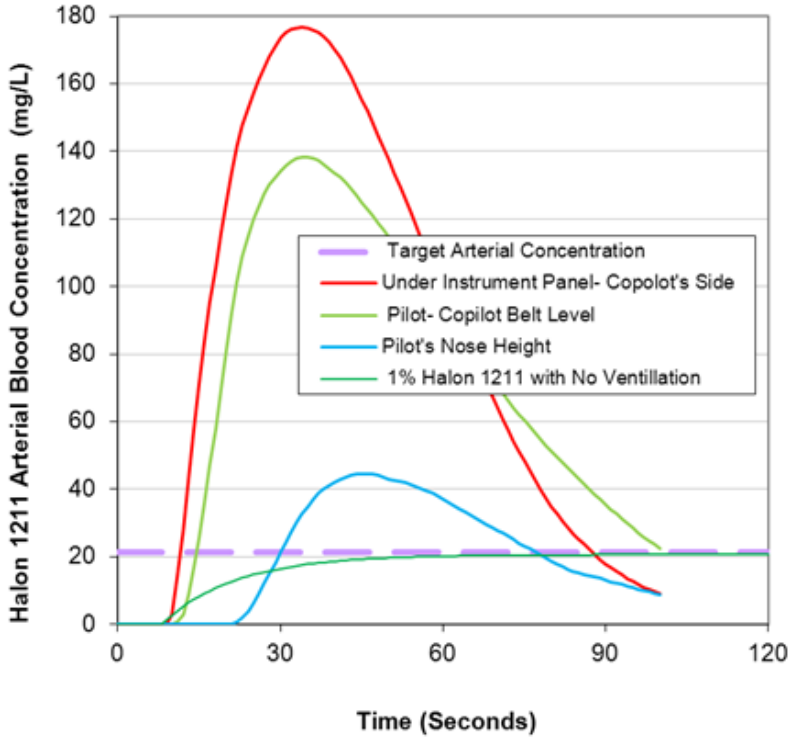


- *Halon 1211 arterial blood concentrations for under the instrument panel are underestimated for the loaded aircraft, as the gaseous concentrations were off-scale.*
- *Perfect mixing Halon 1211 gas and arterial concentrations are not shown for the loaded aircraft: Free space volume and air change time are unknown*

Based on data from 1986 Report, Fig 7, Test 48

Loaded… Target: Under Instrument Panel, Copilot's Side
Overhead Vents Closed

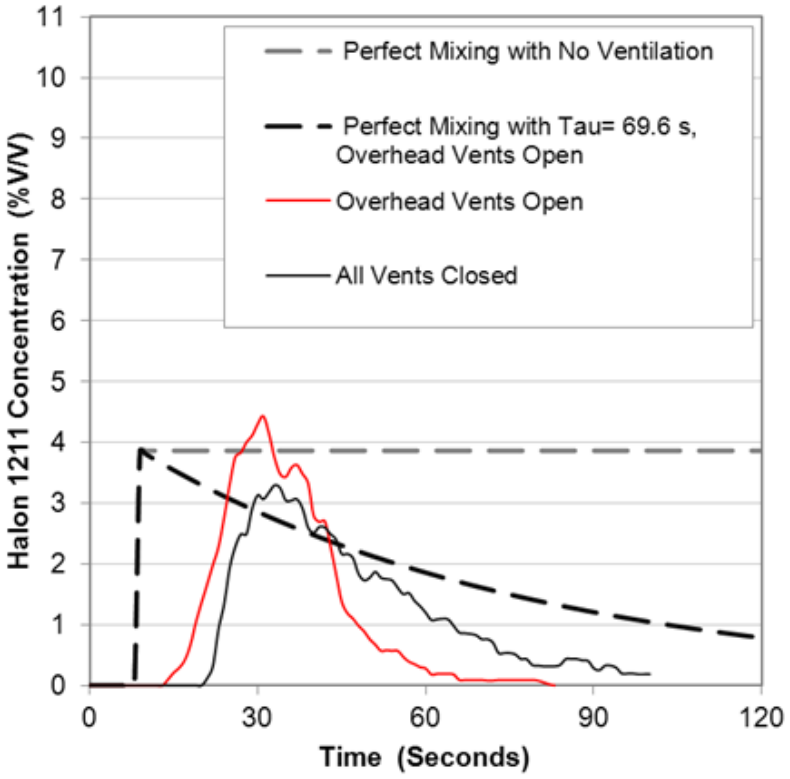


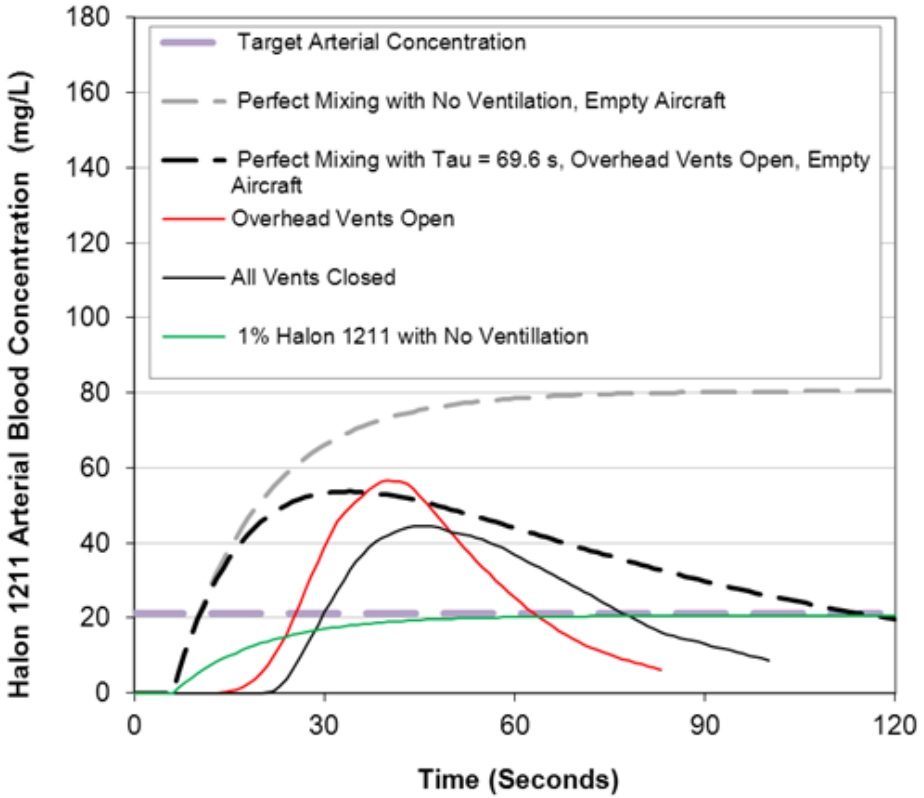


- *Halon 1211 arterial blood concentrations for under the instrument panel are underestimated for the loaded aircraft, as the gaseous concentrations were off-scale.*
- *Perfect mixing Halon 1211 gas and arterial concentrations are not shown for the loaded aircraft: Free space volume and air change time are unknown*

Based on data from 1986 Report, Fig 8, Test 47

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





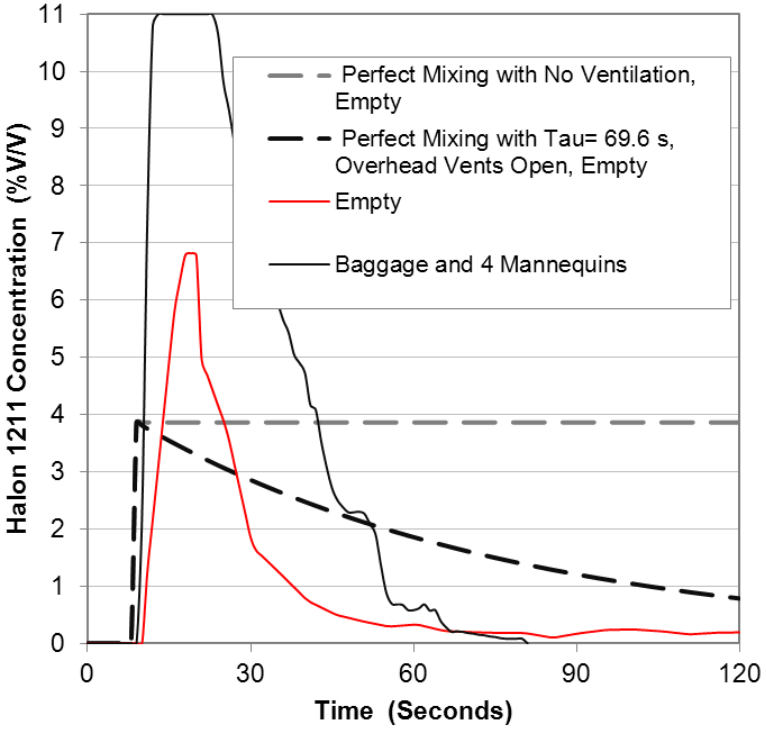
- *Halon 1211 perfect mixing gas and arterial blood concentrations are underestimated for the loaded aircraft, as the free space volume and air change time are unknown.*

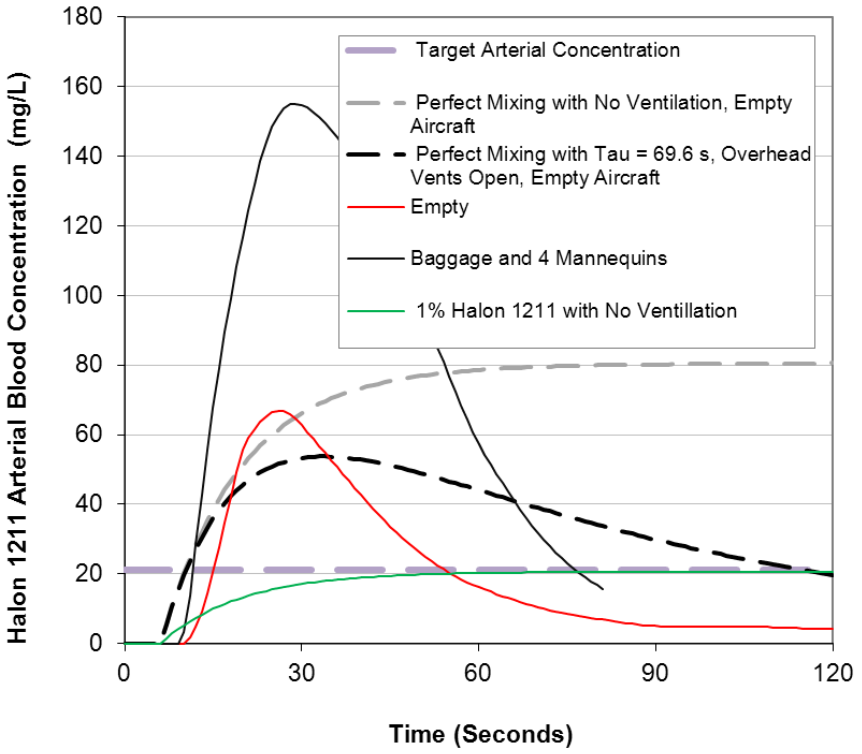
Based on data from 1986 Report, Fig 7 and 8

Halon 1211 Discharged Under Instrument Panel, Copilot's Side

Empty and Loaded, Overhead Vents Open: Under Instrument Panel

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





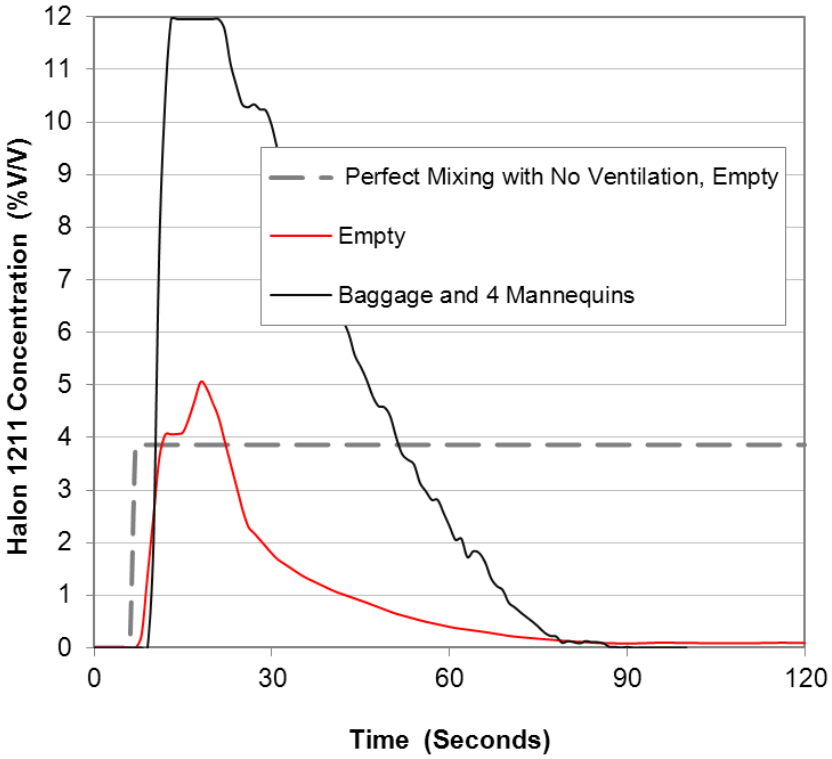
- *Halon 1211 arterial blood concentrations for under the instrument panel are underestimated for the loaded aircraft, as the gaseous concentrations were off-scale.*
- *Perfect mixing Halon 1211 gas and arterial concentrations are underestimated for the loaded aircraft: Free space volume and air change time are unknown*

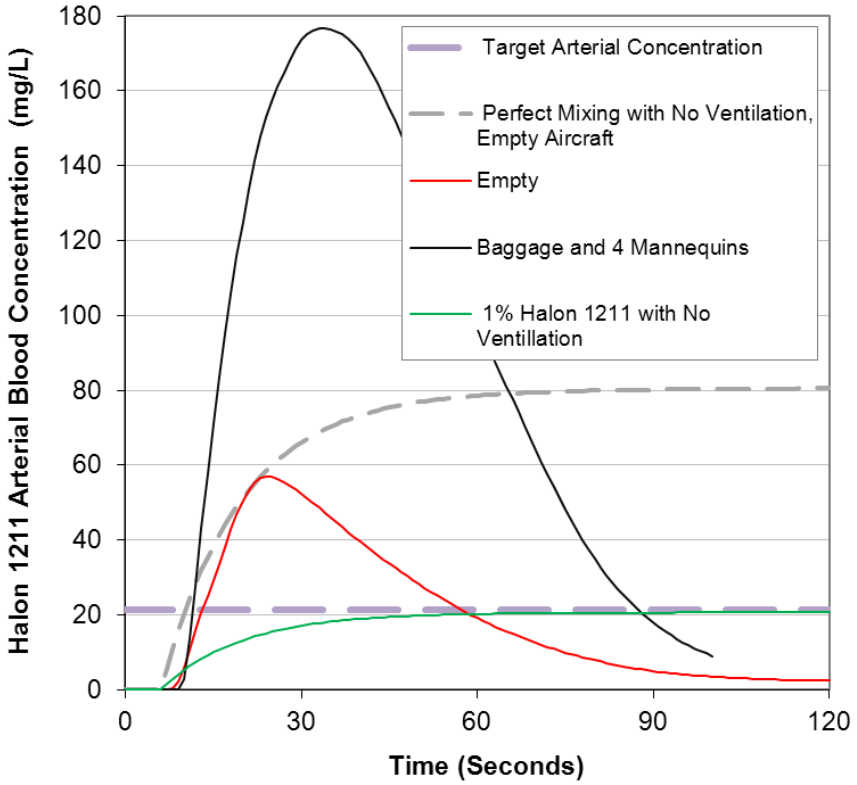
Based on data from 1984 report, Fig 6 and 1986 report, Fig 7

Halon 1211 Discharged Under Instrument Panel, Copilot's Side

Empty and Loaded, All Vents Closed: Under Instrument Panel

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





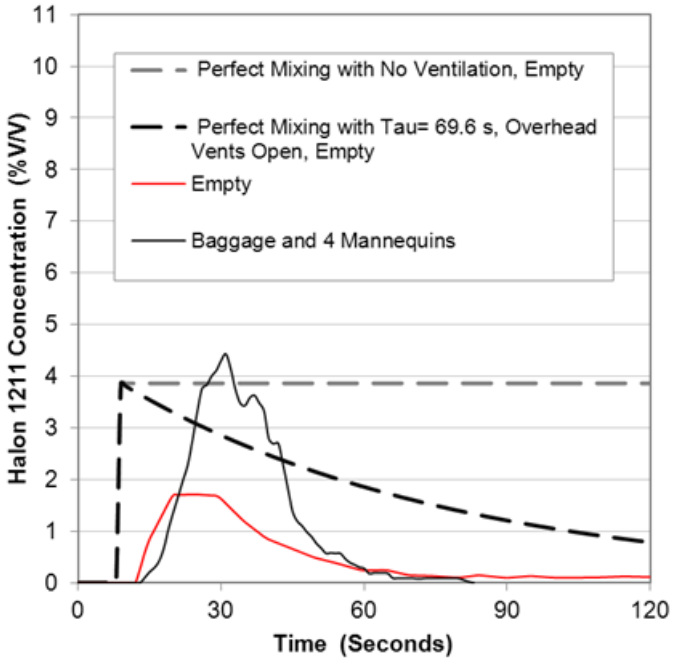
- *Perfect mixing Halon 1211 gas and arterial concentrations are underestimated for the loaded aircraft: Free space volume and air change time are unknown*

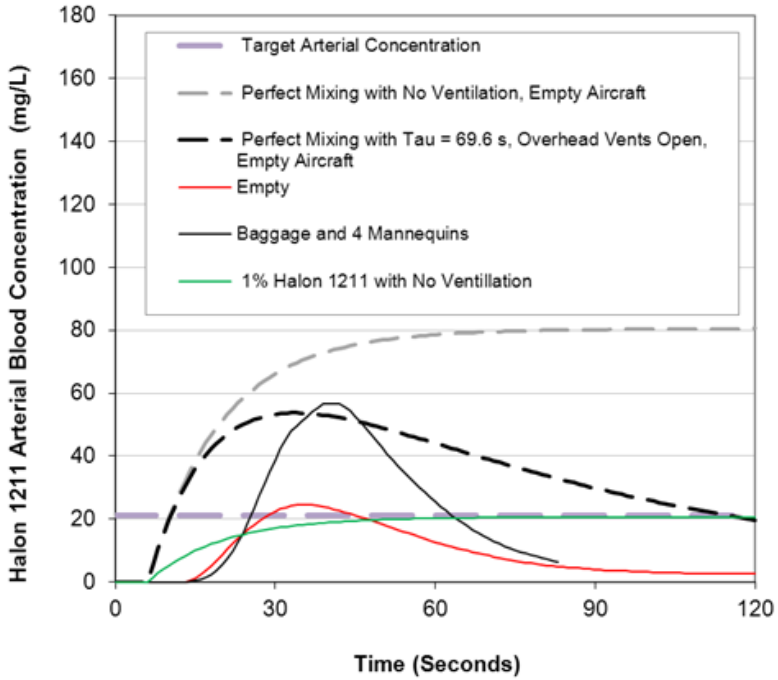
Based on data from 1984 report, Fig 8 and 1986 report, Fig 8

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





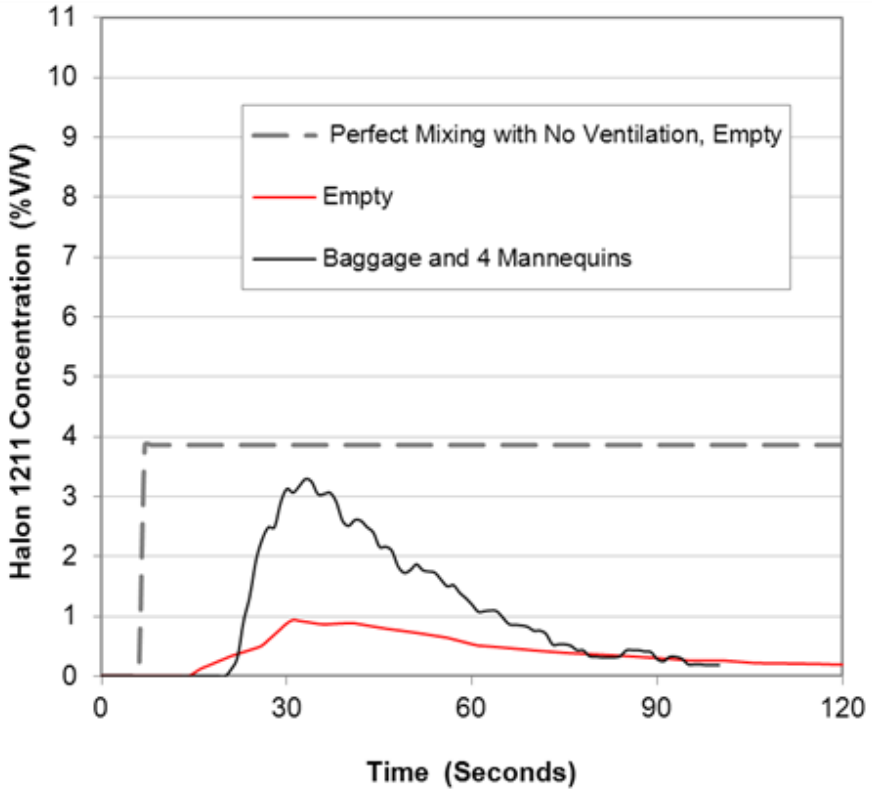
- *Perfect mixing Halon 1211 gas and arterial concentrations are underestimated for the loaded aircraft: Free space volume and air change time are unknown*

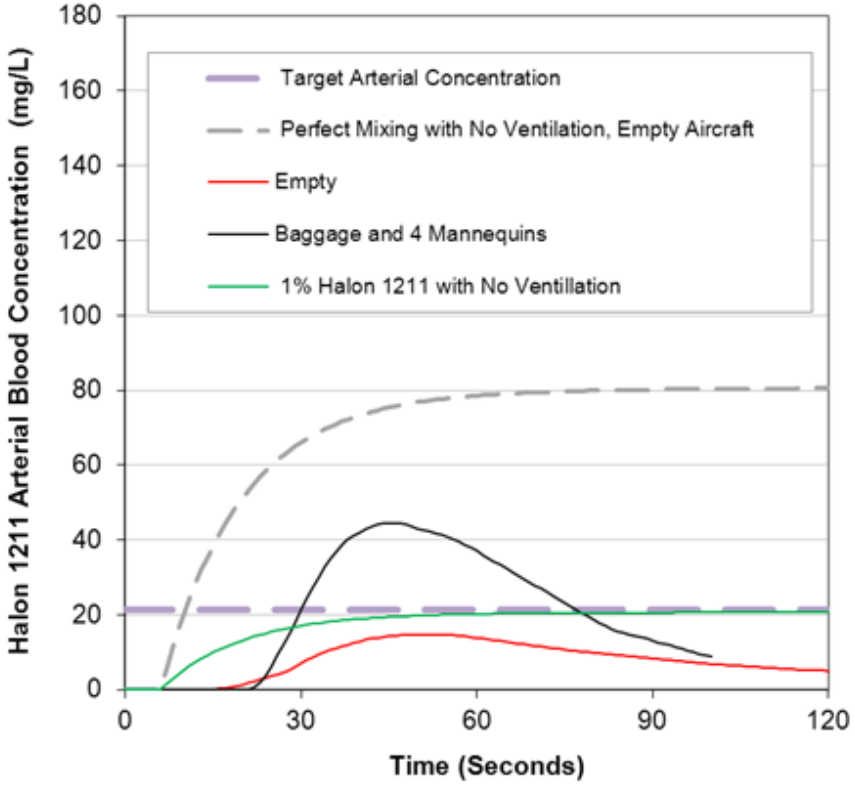
Based on data from 1984 report, Fig 6 and 1986 report, Fig 7

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





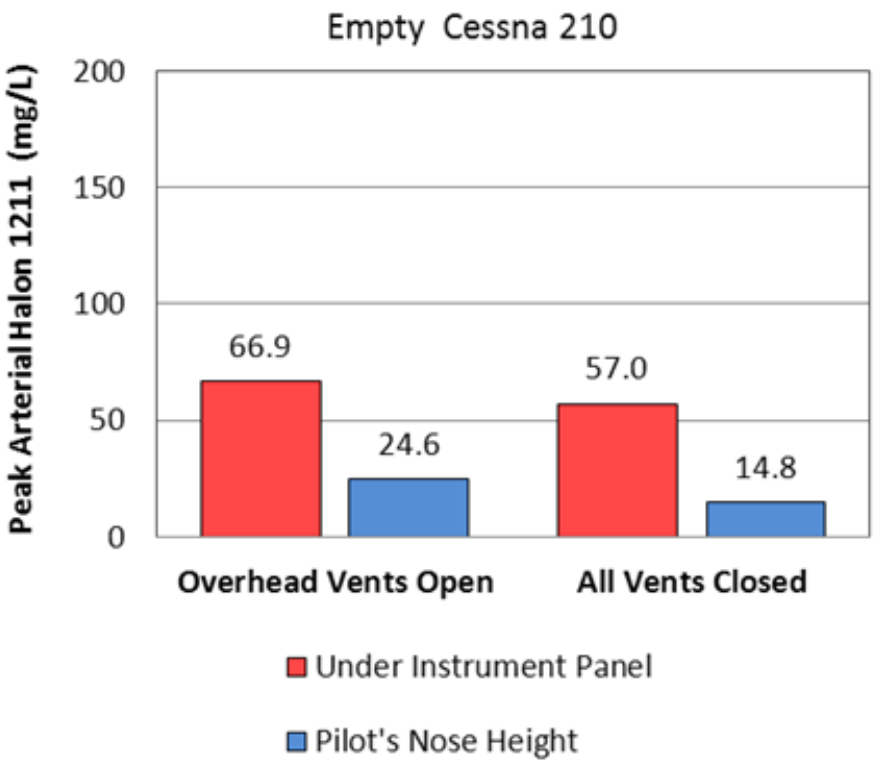
- *Perfect mixing Halon 1211 gas and arterial concentrations are underestimated for the loaded aircraft: Free space volume and air change time are unknown*

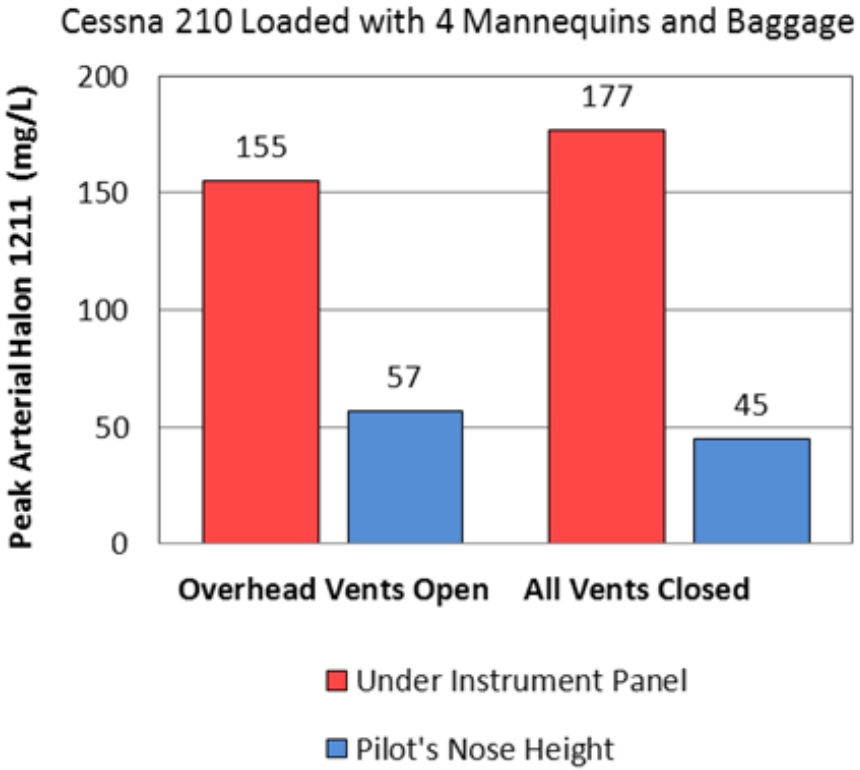
Based on data from 1984 report, Fig 8 and 1986 report, Fig 8

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

Conclusions

- **Stratification is significant for the empty and loaded 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 with overhead vents open. Multiplication factor 2.2 is based on air change time determined from airflow at overhead vents with overhead vents open. Measured air change time does not account for air infiltration from leaks through other openings.**
- **Much higher concentrations were measured in the loaded Cessna 210C than the empty aircraft.**
- **The free space volume and true air change time are necessary to determine ventilation multiplication factors and stratification/localization multiplication factors.**
- **Multiplication factors can not be determined for loaded aircraft, since the free space volume is not available.**

Work Remaining

- **Locate Cessna 210C 1963 vintage and characterize openings.**
- **This author suspects there may have been exit vents in the floor that were not mentioned in the 1984 and 1986 reports.**