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EVALUATION OF VENTILATION INSIDE ARMORED VEHICLES

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The ventilation systems in the M1/M1A1 battle tank, M60 battle tank, and the M2A2-M2A3 fighting vehicle were evaluated to determine their effectiveness as compared to ventilatory requirements stated in MIL-STD-1472C. Available ventilation test data was also collected and reviewed. Theoretical and actual ventilatory rates for the M1/M1A1, M60, and M2A2-M2A3, are listed. Projected combustion product concentration build-up and purge rates have been determined under conditions of the several differing modes of ventilation capable by the battle tanks and fighting vehicles. Ventilatory requirements are recommended for the vehicles in accordance with ASHRAE Standard 62-1989.

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INTRODUCTION

The objective of this study has been to evaluate criteria for ventilation in military armored vehicles in terms of the suitability of these criteria to provide a hazard-free breathing environment and adequate evacuation of combustion by-products and weapons exhaust. The approach has been to acquire vehicle specifications for the M1 and M1A1 Abrams tanks, the M60 tank and the Bradley Fighting Vehicle, review appropriate vehicle test data, interview armored vehicle test personnel, and conduct a hands-on survey of the vehicles.

According to MIL-STD-1472C (2 May 1981), "Outside fresh air shall be supplied at a minimum rate of 0.57 m^3/min/person or alternately 20 ft^3/min/person" (CFM/person). Air flow rates for hot-climate operation (temperatures above 32^{o}C, 90^{o}F) shall be maintained between 4.2 and 5.7 m^3 (150 and 200 CFM/person)." For a vehicle with a crew complement of four, this would correspond to minimum vehicular ventilation rates of 80 and 600 CFM.

VENTILATION IN THE M1 AND M1A1 ARMORED VEHICLES

The crew compartment of the M1 (Figure 1) and M1A1 (Figure 2) may be considered to be a cylinder 78 inches in diameter and 64 inches deep (the turret), diminished by a rectangular box approximately 53 inches x 19 inches x 22 inches (the main gun emplacement), and increased by a rectangular box 60 inches x 47 inches x 34 inches (the driver's compartment), for a total volume of about 200 ft^3 (5.66 m^3).[1] (The volume displaced by crew members is not taken into account in this report.)

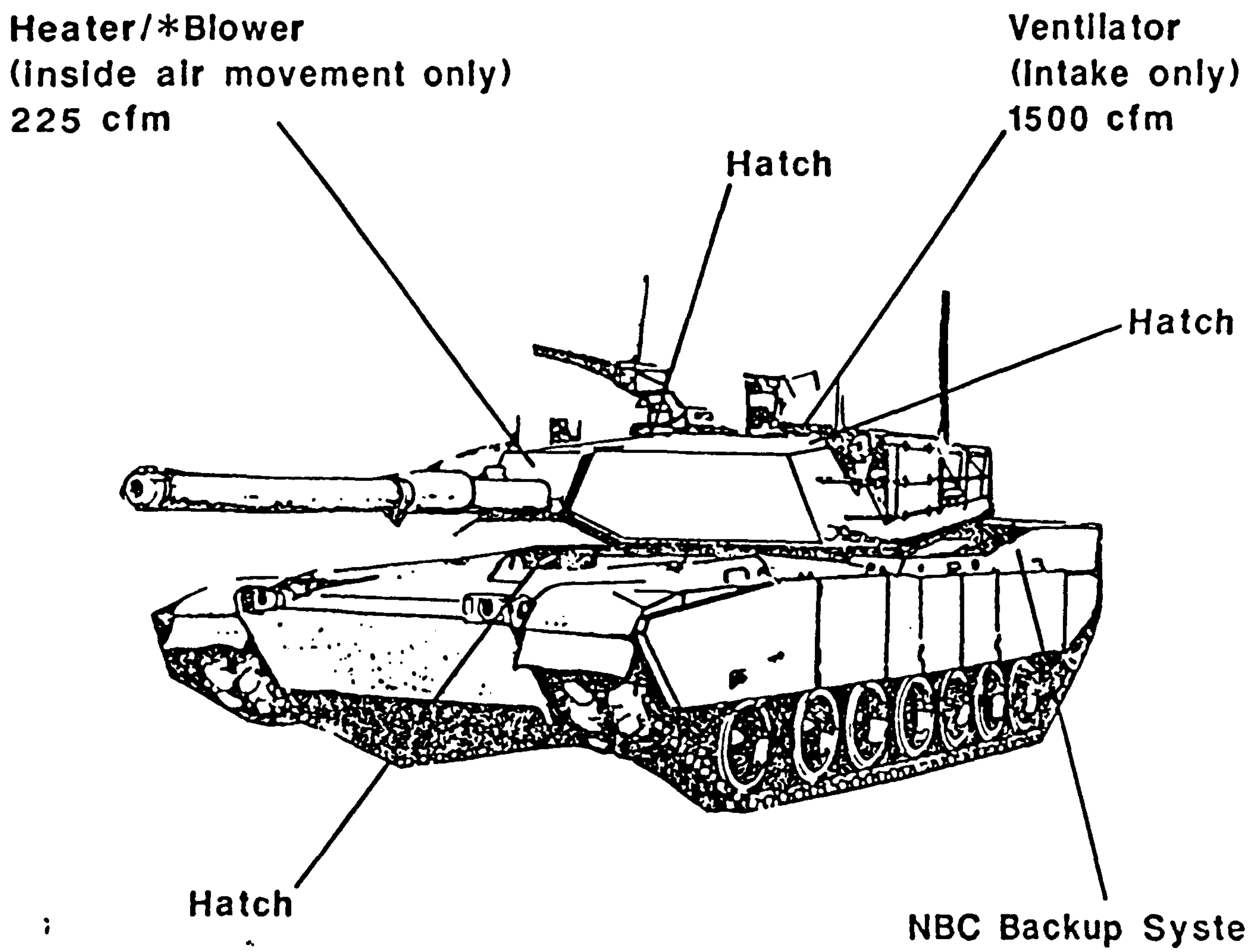
The M1 is provided with a 1500 CFM intake fan, a 20 CFM NBC (Nuclear, Biological and Chemical) system and an interior 225 CFM heater/blower. The 1500 CFM fan is operated intermittently only; its efficiency in extended use would depend on the leakage rate of the vehicle. An early reference stated that vehicle leakage for four XM1 vehicles ranged from 412 to 746 CFM, measured at 1.5 inches water gauge.[2] (Fans are commonly rated at 2.7 inches water gauge.) Target leakage was 200 CFM with the hatches closed.

The primary NBC system of the M1A1 is the only source of fresh air with hatches closed other than the back-up NBC system, with a capacity of 20 CFM. The primary NBC system may be operated in any of several modes: 15 CFM is provided to the cooling vest and 3 CFM to the mask of each crew member; air flow to the vests is adjustable downward, while the flow to the masks is constant whether deployed or not. Alternatively, the bulk dump may be employed, which provides 200 CFM to the vehicle interior.

Ventilation through open hatches is difficult to estimate from available data. According to USACSTA,[3] with hatches closed, the vehicle stopped, and all systems shut down, the air velocity (presumably convective) at the loader's head is 10 ft/min; with hatches open the air flow is 20 ft/min. The loader stands directly below the 23-inch main hatch, and if the difference in air velocity at his head is due to air passing through the main hatch, the ventilation rate is about 29 CFM. With the vehicle in motion at 32 km/hr and the hatches open, the air velocity at the loader's head is 80 ft/min; again,

Figure 1.

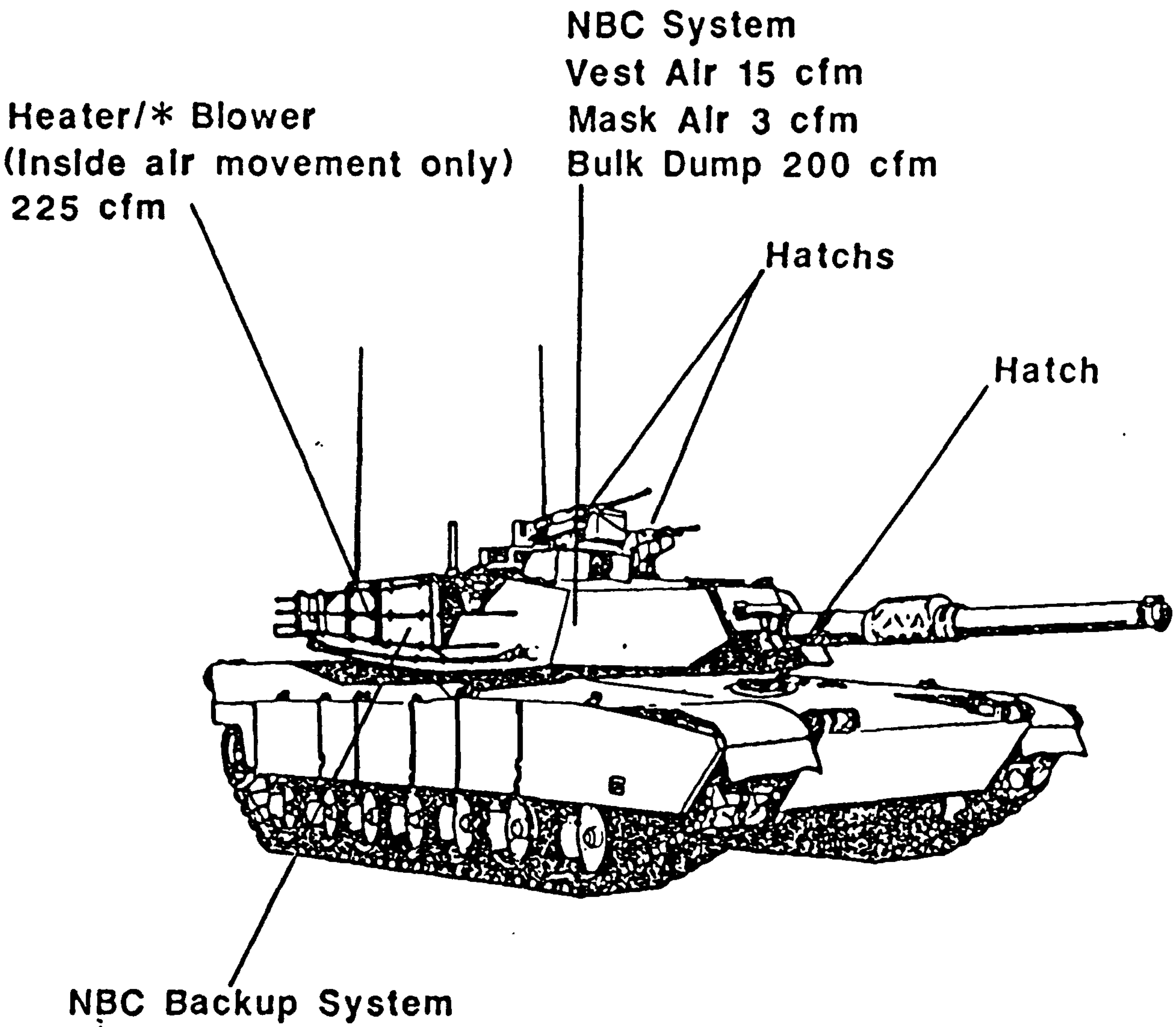
M1 ABRAMS TANK



* Blower may be operated without heater on in order to increase air movement to crew.

Figure 2.

M1A1 ABRAMS TANK



* Blower may be operated without heater on in order to increase air movement to crew.

assuming that the air velocity through the main hatch is 70 ft/min, the ventilation rate is 202 CFM, essentially identical to the bulk dump.

Given these various ventilation conditions, summarized in Table 1, relative contaminant levels can be estimated for three scenarios: (1) single event; (2) continuous input; (3) multiple events. To simplify comparison of the three scenarios, a single event is considered to be equivalent to a 1 minute continuous input in terms of contaminant production. It is assumed that mixing inside the armored vehicle is instantaneous. It is further assumed, for convenience, that a single event will produce 5.66 mg of a contaminant; this would result in a contaminant level of 1 mg/m^3 for the M1 and M1A1. Thus, for the first scenario, a propellant combustion product, having reached the level of 1 mg/m^3 following a single firing event, decays logarithmically, as shown in Figure 3.

TABLE 1. VENTILATORY TURNOVER RATES FOR THE M1 AND M1A1

Condition	Applicability	Air flow m^3/min (ft^3/MIN)	Contam. half-life, min	Turnover rate, min^{-1}
NBC + cooling	M1A1 only	2.04 (72)	1.92	0.36
NBC bulk dump	M1A1 only	5.66 (200)	0.69	1.00
Hatch open, stopped[a]	both	0.82 (29)	4.78	0.14
Hatch open, 32 km/hr[a]	both	5.71 (202)	0.69	1.00
MIL-STD-1472C	both	2.26 (80)	1.73	0.40
MIL-STD-1472C, hot	both	16.98 (600)	0.23	3.00
Vent fan[b]	M1 only	42.45 (1500)	0.13	7.50

a. rough estimate
b. intermittent

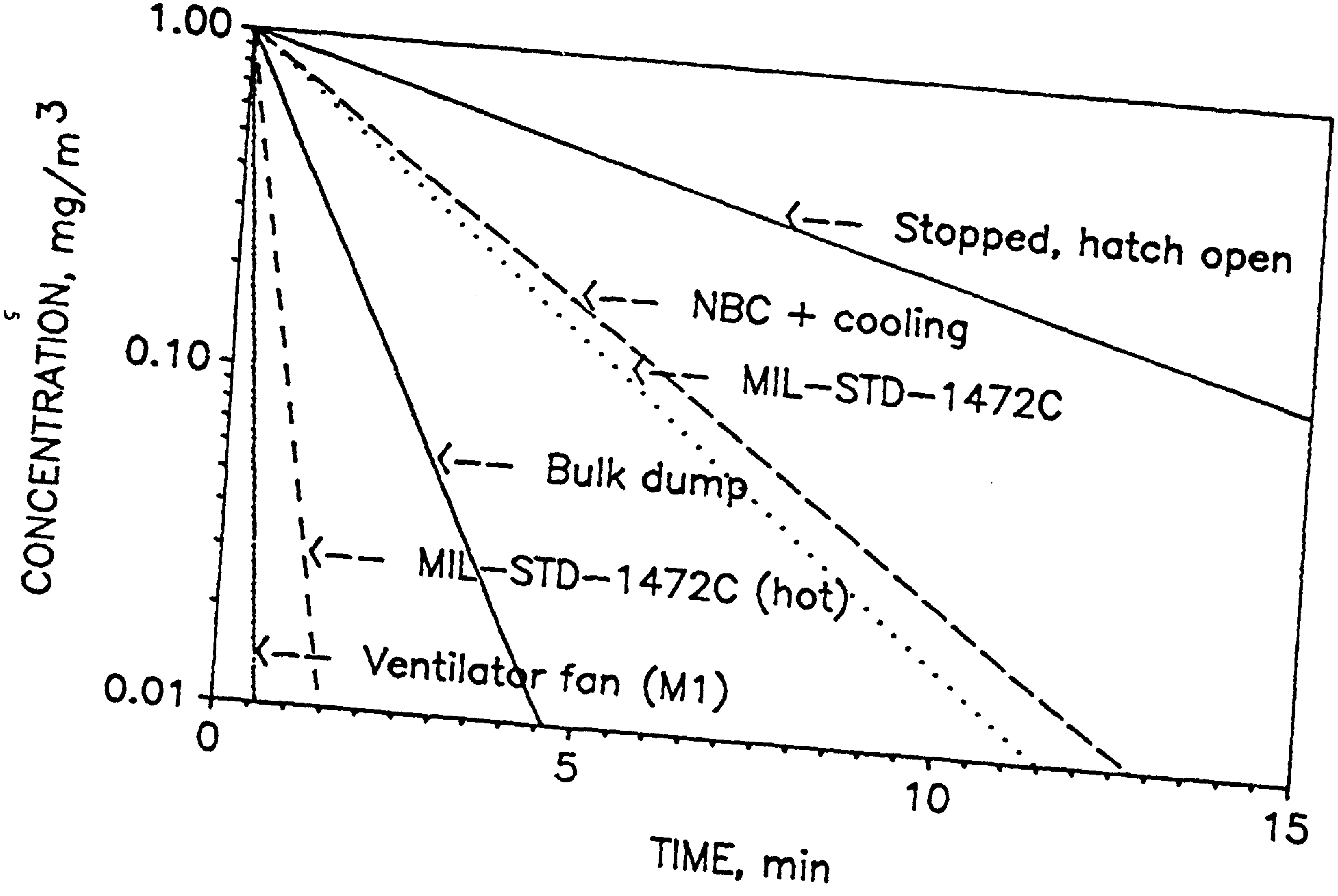
For the case of continuous input:

Let C = level of contaminant in crew compartment
C_0 = 0 at time 0
x = rate of contaminant input (5.66 mg/min)
V = volume of crew compartment = 5.66 m^3
k = air turnover rate (air flow/V) from Table 1
k' = x/V = specific input rate = 1 min^{-1}

Then
$$dC/dt = k' - Ck$$

Integrating:
$$C = (k' - e^{\ln k' - kt})/k \qquad (1)$$

Figure 3. M1/M1A1 Combustion Products, Single Event



Contaminant level:time profiles are presented in Figure 4. It is seen that steady-state contaminant levels are 2.5 times as great as the specific input rate (k', which is equivalent to the initial single-event level, Figure 3) for a vehicle meeting MIL-STD-1472C, equal to that for the M1A1 with the NBC bulk dump operating, and 7* times as great for either vehicle stopped with the hatches open. The steady-state contaminant level is given by k'/k. The time to achieve any fraction of the steady state concentration is a function of turnover rate and is independent of k' (i.e., contaminant input). Contaminant levels at steady state are presented as a function of ventilation rate in Figure 5 for various contaminant input rates. It should be noted that the steady state contaminant concentration for any specific ventilation (flow) rate and contaminant input rate is independent of the volume of the crew compartment; i.e. C(steady state) = x/air flow. Thus, the contaminant level for a large vehicle will ultimately reach the same value as for a small vehicle, but it will take longer.

Multiple events are approximated in Figure 6 for the case of the M1A1 bulk dump, assuming a firing rate of 1/min and instantaneous mixing. After the initial firing (time 0), the concentration of a combustion product, initially 1 mg/m^3, decays logarithmically for 1 minute, then increases by 1 mg/m^3 at the second firing, and again decays until the third firing and so forth. The time to approach steady state and the mean contaminant level at steady state are about the same as for the continuous case, but crew members are briefly exposed to contaminant levels about 0.5 mg/m^3 higher.

VENTILATION IN THE M60 ARMORED VEHICLE

The crew compartment of the M60 (Figure 7) armored vehicle is somewhat larger than that of the M1/M1A1; our best estimate of the volume, with all ammunition tubes filled, is 258 ft^3 (7.30 m^3). There are two independent ventilation systems for the M60; a 1500 CFM exhaust fan and the engine air system, which draws from the crew compartment. The 750 hp engine draws in excess of 1000 CFM, and according to anecdotal accounts, the air flow in the M60 in motion is sufficient to extinguish a cigarette lighter. An internal 225 CFM heater/blower is also provided. Outside air may be drawn from the gun tube. Tests of six different M60A1 vehicles showed leakage rates of 1000 to 1613 standard CF_M at 1.5 inches water gauge;[4] insofar as these vehicles are typical of the M60, overpressure should not be a significant factor in ventilation. Ventilation data for the M60 are summarized in Table 2. We do not have data for induced air velocities in the M60 with hatches open. Steady state contaminant levels for various input rates and ventilation rates can be estimated from Figure 5.

*This is obviously a very rough estimate, which does not take into account wind direction or velocity, air temperature, or state of operations. A vehicle at rest subjected to interior heating from weapons discharge or sun exposure could experience a much higher air turnover rate through the open hatches due to convection.

Figure 4. M1/M1A1 Combustion Product Concentrations, Continuous Input

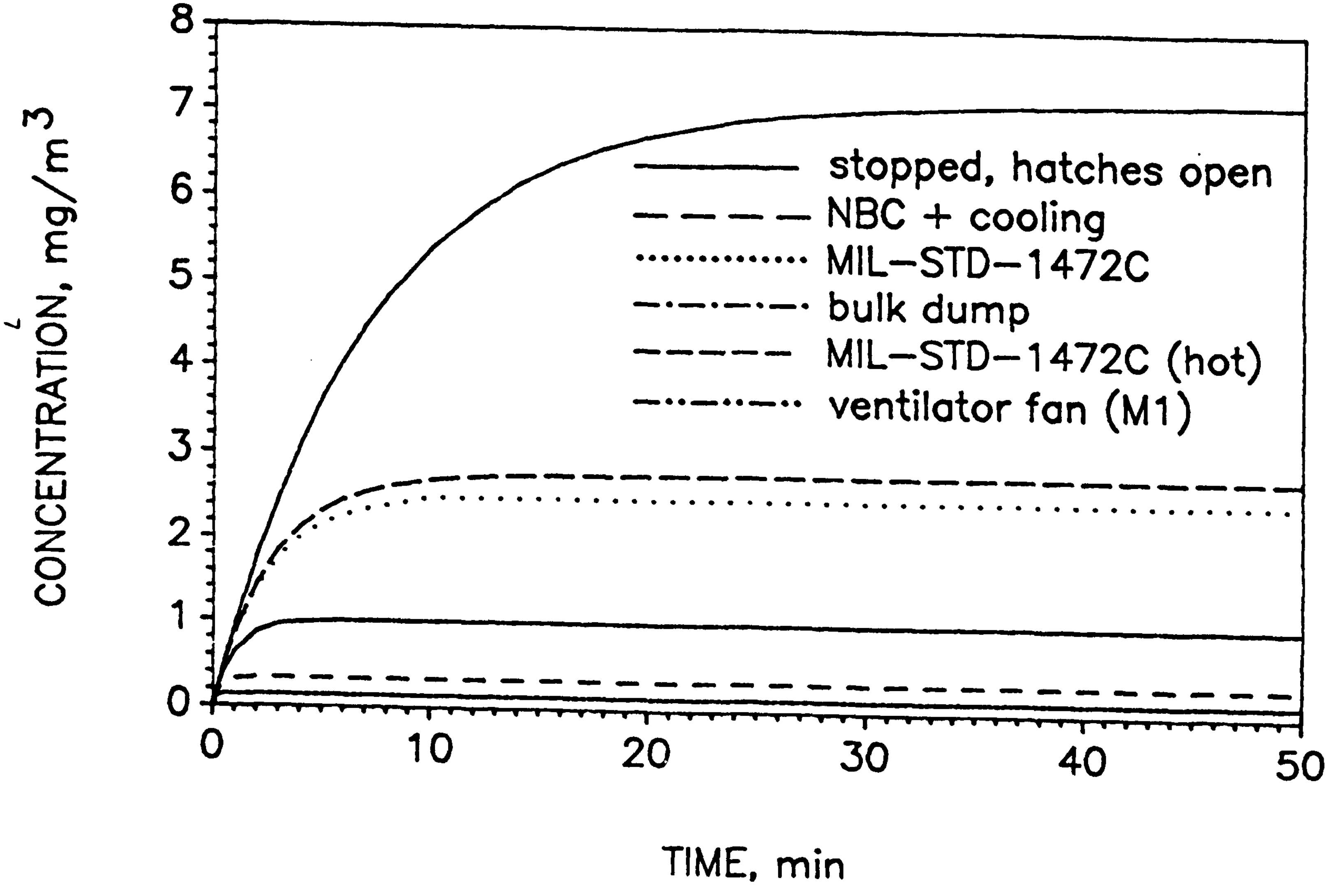


Figure 5. Armored Vehicle Combustion Product Concentrations, Steady State

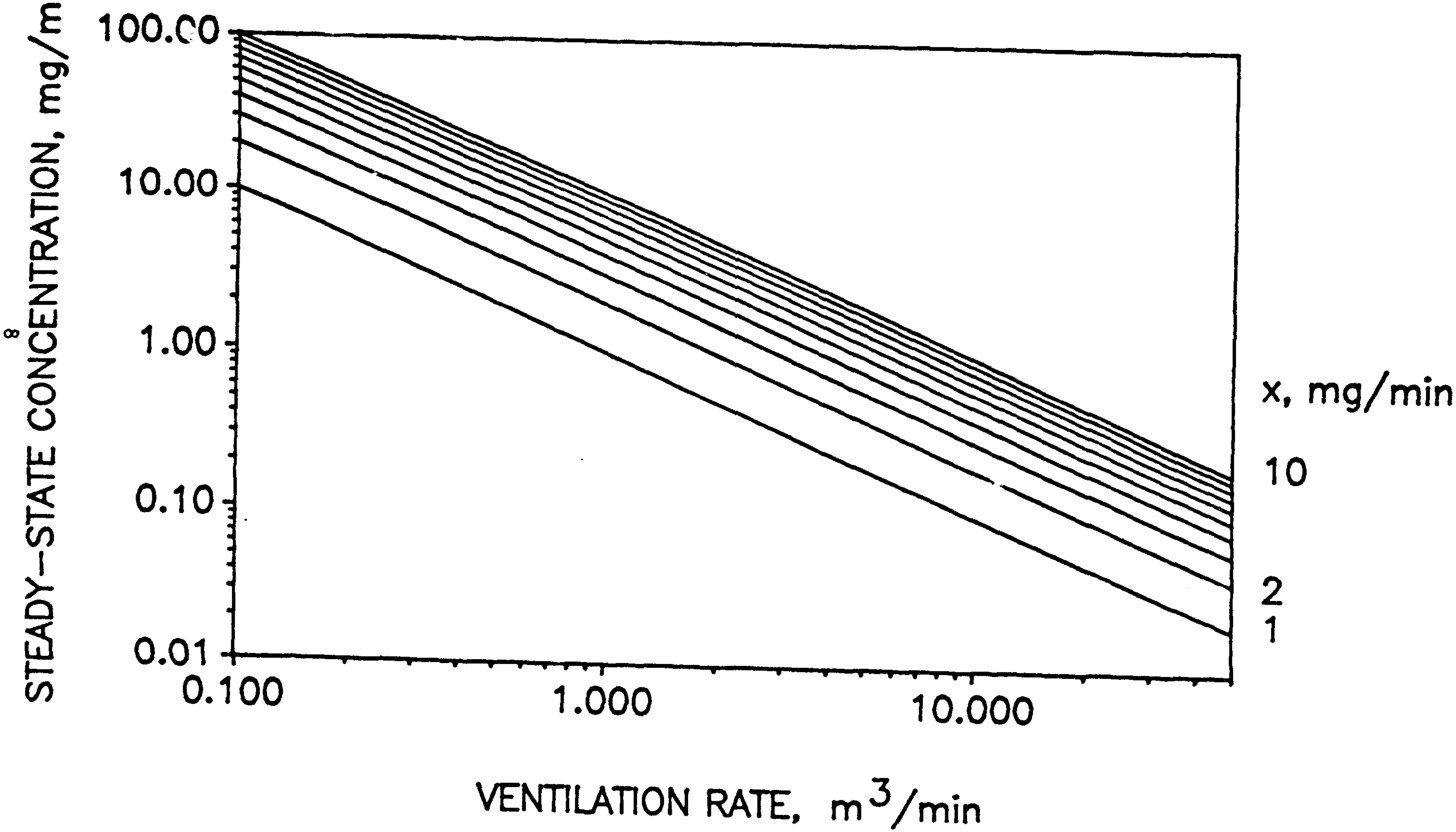


Figure 6. M1A1 Combustion Products, Multiple Inputs (Bulk Dump)

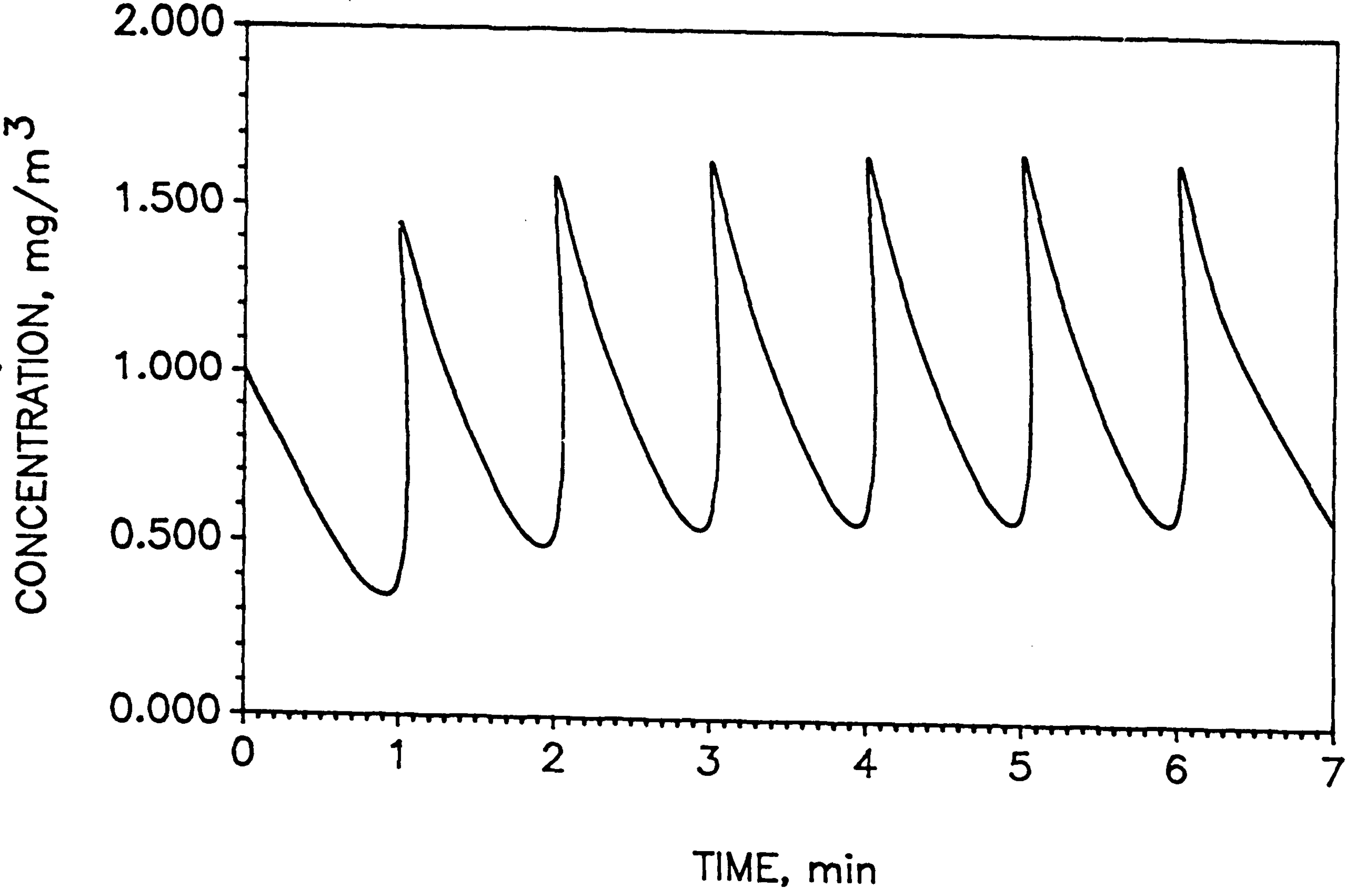


Figure 7.

M-60 BATTLE TANK

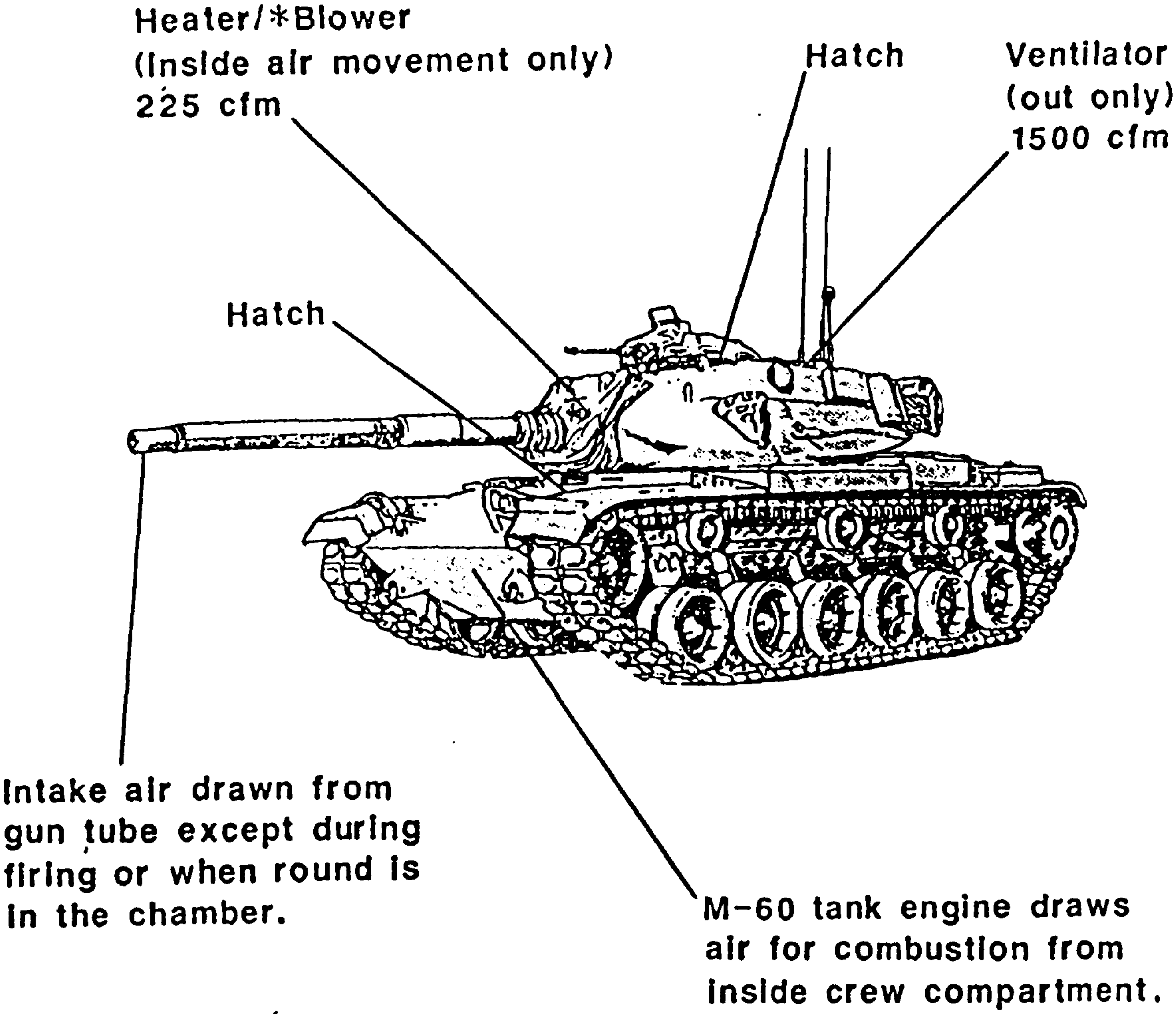


TABLE 2. VENTILATORY TURNOVER RATES FOR THE M60

Condition	Air flow, m^3/min (ft^3/min)	Contam. half-life, min	Turnover rate min^{-1}
Engine only	28.3 (1000)	0.18	3.88
Exhaust fan only	42.4 (1500)	0.12	5.81
MIL-STD-1472C	2.3 (80)	2.24	0.31
MIL-STD-1472C (hot)	17.0 (600)	0.29	2.33

VENTILATION IN THE BRADLEY FIGHTING VEHICLE

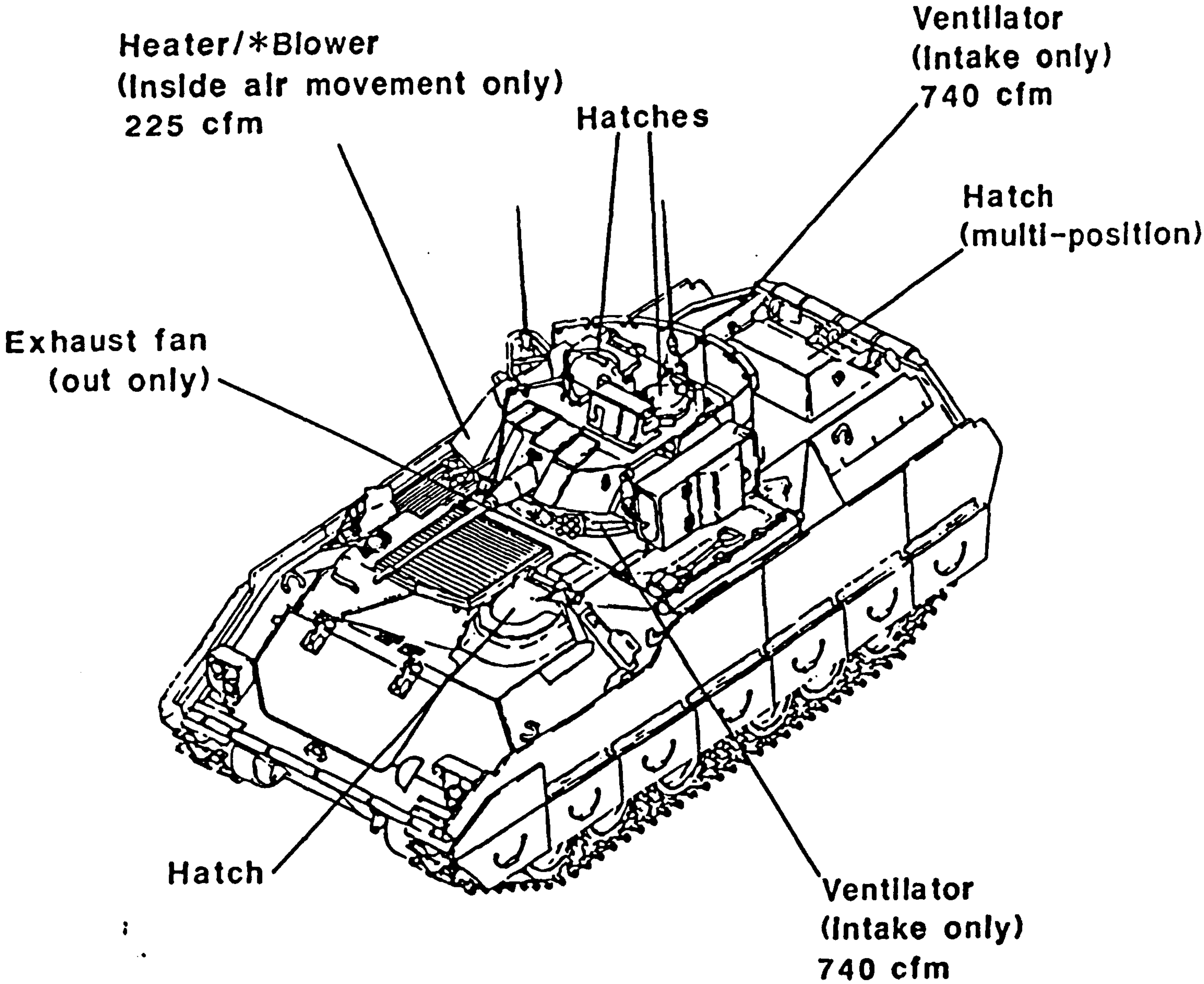
The crew compartment of the Bradley Fighting Vehicle (M2A2-M3A2, Figure 8) displaces 355 ft^3 (10.0 m^3).[1] The M2A2-M3A2 is provided with two 1 hp 740 cfm intake fans (measured at 2.7 inches water gauge at 59^{o}F), one to the turret and one to the driver. In addition, there are a small exhaust fan forward (rating unknown) and a 225 cfm internal heater/blower. The M2A2-M3A2 is not designed to be ventilated by drawing engine air from the crew compartment, but there is some withdrawal from this source, as there is some underpressure whenever the vehicle is running. The M2A2-M3A2 is a relatively open vehicle, and leakage does not significantly restrict ventilation. Ventilation data for the two different crew configurations are summarized in Table 3. Steady state contaminant levels for various input rates and ventilation rates can be estimated from Figure 3.

TABLE 3. VENTILATORY RATES FOR THE BRADLEY FIGHTING VEHICLE

Condition (crew)	Air flow, m^3/min (ft^3/min)	Contam. half-life, min	Turnover rate, min^{-1}
One fan	20.9 (740)	0.33	2.08
Two fans	41.9 (1480)	0.17	4.17
MIL-STD-1472C (5)	2.8 (100)	2.46	0.28
MIL-STD-1472C (hot) (5)	21.2 (750)	0.33	2.11
MIL-STD-1472C (9)	5.1 (180)	1.37	0.51
MIL-STD-1472C (hot) (9)	38.2 (1350)	0.18	3.80

Figure 8.

BRADLEY FIGHTING VEHICLE (M2A2-M3A2)



* Blower may be operated without heater on in order to increase air movement to crew.

RECOMMENDED VENTILATORY REQUIREMENTS

MIL-STD-1472C prescribes that 150-200 CFM of outside fresh air be supplied per person when ambient temperature is above 32°C. For safety purposes it should be assumed that temperatures will approach or exceed that limit in most training environments. This would suggest that all ventilation systems in armored vehicles be designed to meet a supply requirement of 150-200 CFM outside fresh air per person. MIL-STD-1472C is essentially a comfort standard and contaminant based ventilatory requirements should also be considered. ASHRAE Standard 62-1989[5] supplies a simple mass balance equation for outdoor air flow rate needed to maintain the steady-state CO_2 concentration below a given limit. The equation states that:

$$V_0 = N / (C_s - C_0) \qquad (2)$$

where

V_0 = outdoor air flow rate per person

N = CO_2 generation rate per person (l/min)

C_s = % CO_2 concentration in the space

C_0 = % CO_2 concentration in outdoor air

CO_2 does not a pose a substantial risk in armored vehicles and a more appropriate contaminant to base ventilatory requirements on is carbon monoxide (CO). The same equation, modified to provide a ventilation standard for CO, will be used to provide supply air recommendations, where

V_0 = outdoor air flow rate per person

N = CO generation rate inside the crew-compartment per person (l/min)

C_s = % CO concentration in the crew-compartment

C_0 = % CO concentration in outdoor air.

C_s (the maximum allowable CO concentration in the crew-compartment) is equal to the proposed ACGIH 8 Hr threshold limit value[6] of 25 ppm (0.003%), while C_0 (the maximum outdoor air concentration) is equal to the current 8 Hr National Ambient Air Quality Standard[7] for CO of 9 ppm (0.001%).

CO generation rates, in liters per minute per vehicle, were estimated from one minute peak CO[8] averages observed in live fire testing exercises for each vehicle (Table 4). According to equation 2, using estimated CO generation rates, the M1/M1A1 ventilation system should deliver 57 CFM of outside air per person when in combat/training situations and the M60 and M2A2-M3A2 should be capable of delivering 75 CFM per person and 59 CFM per person respectively. CO generation rates per vehicle (l/min), vehicle crew-compartment volume (liters), and supply air requirements per person in CFM as defined by equation 2 are expressed in Table 4.

TABLE 4. RECOMMENDED VENTILATORY REQUIREMENTS FOR THE M1, M1A1, M60 AND M2A2-M3A2

Vehicle	Crew-compartment Volume (liters)	Peak 1 Min CO (ppm)[a]	CO Generation (liters/min/per)[b]	Air Supply (CFM/per)
M1 / M1A1	5660	2300	3.2	57
M60	7300	2300	4.2	75
M2A2-M3A2	10000	1300	3.3	59

[a]Ref 8
[b]Crew of four

CONCLUSIONS

Airborne contaminants, such as propellant combustion products, can build up significantly in armored vehicles operating under the ventilatory requirements of MIL-STD-1472C specified for temperatures of less than 32^{o}C. The steady-state concentration is a function of contaminant input rate and flow rate only, and is independent of the volume of the crew compartment.

The M1A1 ventilation system is only capable of meeting the ventilatory requirements of MIL-STD-1472C specified for ambient temperatures of less than 32^{o}C with the 200 CFM NBC bulk dump employed, or when in motion with the hatches open. The M1A1 ventilation system can not, operating under any ventilation configuration, meet the increased ventilatory requirements of MIL-STD-1472C for applications with temperatures of 32^{o}C or greater. Similarly the M1A1 ventilation system is not capable of meeting the contaminant-based supply air requirements generated by equation 2 (Table 4). The M1 meets both of the ventilatory requirements specified in MIL-STD-1472C when the 1500 CFM intake fan is operating, and can meet the lower requirement solely by vehicle movement with the hatches open. The M1 ventilation system easily meets the ventilatory requirements generated by equation 2 (Table 4). For both vehicles, adequate ventilation may be unachievable or may result in unacceptable overpressure if the leakage rate is reduced to 100 CFM at 1.5 inches water gauge, as proposed.[9]

Supply air requirements of MIL-STD-1472C for normal and elevated temperatures are readily achieved using the ventilation systems of the M60 and the Bradley Fighting Vehicle (M2A2-M3A2) which are capable of supplying 740-1480 CFM outside air to the crew-compartment. Similarly the Bradley ventilation system easily meets the contaminant based ventilatory requirements specified in Table 4. For neither vehicle is overpressure a concern.

REFERENCES

1. Chinn, K.S.K. and D. Malabarba. 1989. Vapor Hazard Evaluation for M1A1 Tank and Bradley Fighting Vehicle Personnel. Technical Report, Technical Analysis and Information Office, U.S. Army Dugway Proving Ground, Dugway, UT

2. Ferriter, J.M., N. Yura and L. Beeson. 1982. Summary of XM1 Tank Leakage Testing. Technical Report ARCSL-TR-81062, Chemical Systems Laboratory, Aberdeen Proving Ground, MD

3. U.S. Army Combat Systems Test Activity, Aberdeen Proving Ground, MD Unpublished data.

4. Ferriter, J.M. and L.J. Beeson. 1979. Summary of M60A1 Tank Leakage Data. Technical Report ARCSL-TR-79041, AD A072160, Chemical Systems Laboratory, Aberdeen Proving Ground, MD

5. ASHRAE 62-1989. Ventilation for acceptable indoor air quality (Appendix D. 1989. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA

6. Threshold limit values for chemical substances and physical agents and biological exposure indices. 1990. American Conference of Governmental Industrial Hygienists. Cincinnati, OH

7. National Ambient Air Quality Standards.

8. Menzies, K.T., M.A. Randel and A.L Quill. January 1989. Evaluation of weapons' combustion products in armored vehicles. Final Report. U.S. Army Medical Research and Development Command, Fort Detrick, Frederick, MD DAMD 17-85-C-6245.

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