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WORKING PAPER

SELECTION CRITERIA FOR HALON EXTINGUISHERS IN VENTILATED AND HABITATED AIRCRAFT COMPARTMENTS

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INTRODUCTION

PURPOSE

The purpose of this work is the development of logical criteria whereby Halon hand-held fire extinguishers can be properly matched to the compartment where they are to be deployed.

BACKGROUND

Extensive work has been done by many investigators to define properties, firefighting cpaabilities, and human exposure limits of Halon extinguishing agents. A review of much of this material is given in reference 1. Of particular interest in civil aviation are Halons 1211 and 1301. From the available data, calculations can easily be made on safe concentrations allowable in nonventilated enclosures or conversely what is the minimum compartment volume in which Halon of a given weight can be discharged. For instance, reference 2 gives the following guidelines for 1211 and 1301, respectively.

"For Halon 1211, the minimum room volume in cubic feed is determined by multiplying the charge weight of Halon 1211 in pounds by 124.7. This calculation is derived from a maximum concentration of 2 percent of Halon 1211 at a temperature of 120°F (48.9°C)."

"For Halon 1301, the minimum room volume in cubic feet is determined by multiplying the charge weight of Halon 1301 in pounds by 52.6. This calculation is derived from a maximum concentration of 5 percent at a temperature of 120°F (48.9°C)."

It should be noted that this standard allows $2\frac{1}{2}$ times the 1301 exposure as 1211 exposure. Nevertheless, it should be recognized that aircraft compartments are generally ventilated, and an analysis should be developed which includes ventilation effects.

THEORETICAL OBJECTIVE

The theroetical objective is the development of criteria whereby, for a given aircraft comaprtment volume and given ventilation rates of that compartment, proper sized Halon extinguishers can be selected.

THEORETICAL ANALYSIS

ASSUMPTIONS

The analysis is based on a number of assumptions and conditions.

1. The working altitude for the analysis is 8,000 feet above sea level. This is the typical cabin pressurization level of a commercial transport.

2. The compartment can be treated as a perfectly stirred reactor as far as concentration versus time profiles are concerned.

3. The integration of concentration over time gives an effective dose that must be maintained within allowable limits.

4. The allowable doses are 4 percent-minute and 10 percent-minute for 1211 and 1301, respectively, and these are in the same ratio (2.5) as the UL standard stated previously.

5. The temperature for the calculation is 72°F.

APPLICATION OF STIRRED REACTOR

The starting point for the development is Avogadro's principle which states that equal volumes of gases contain the same number of molecules. In a given aircraft compartment, assume an instantaneous discharge of A Halon extinguisher so that the compartment is left with A air molecules and H Halon molecules. Ventilation occurs through the addition of a air molecules per minute to the compartment and the loss of an equal number of molecules per minute consisting of m air molecules and n Halon molecules. As this process goes forward in time, the number of air molecules A' will be A plus the integral of a over time minus the integral of m over time or

$$A + \int a\,dt - \int m\,dt = A' \qquad (1)$$

The number of Halon molecules at times after discharge will be given by H'.

$$H - \int n\,dt = H' \qquad (2)$$

The equivalence of inflow and outflow described previously is

$$m + n = a \qquad (3)$$

and the stirred reactor assumption allows setting a ratio for m and n

$$\frac{n}{m} = \frac{H'}{A'} \qquad (4)$$

Equation (3) can be rewritten as

$$H'm + H'm = H'a \qquad (5)$$

and equation (4) can be rewritten as

$$H'm - A'm = 0 \qquad (6)$$

Equations (5) and (6) can be combined and solved to get

$$m = \frac{H'}{A'+H'}\,a \qquad (7)$$

Employing (2), the Halon volume concentration can be defined as

$$\frac{H'}{A'+H'} = \frac{H - \int m\,dt}{A'+H'} \qquad (8)$$

Equation (7) can be inserted into equation (8) to get

$$\frac{H'}{A'+H'} = \frac{H - \int \frac{H'}{A'+H'}\,a\,dt}{A'+H'} \qquad (9)$$

Also, equations (1), (2), and (3) can be combined to yield the following identity

$$A + H = A' + H' \qquad (10)$$

Thus, equation (9) can be written

$$(A+H)\left(\frac{H'}{A'+H'}\right) = H - \int \frac{H'}{A'+H'}\,a\,dt \qquad (11)$$

Taking the derivative of each side of equation (11), the following can be seen

$$(A+H)\frac{d}{dt}\left\{\frac{H'}{A'+H'}\right\} = -\frac{H'}{A'+H'}\,a \qquad (12)$$

Both sides of equation (12) can be divided by $H'/(A'+H')$ to get

$$(A+H)\frac{d}{dt}\ln\left\{\frac{H'}{A'+H'}\right\} = -a \qquad (13)$$

Equation (13) can now be integrated.

To get

$$\frac{H'}{A'+H'} = B\, e^{-at/(A+H)} \qquad (14)$$

Since at $t = 0$

$$\frac{H'}{A'+H'} = \frac{H}{A+H} \qquad (14a)$$

Equation (14) can be written as

$$C = \frac{H'}{A'+H'} = \frac{H}{A+H}\, e^{-at/(A+H)} \qquad (15)$$

Where C is the volumetric Halon concentration at any time after discharge, and $H/(A+H)$ is the concentration immediately after discharge. Since a is the number of air molecules entering perminute and $A+H$ is the total number of molecules in the compartment

$$\frac{a}{A+H} = \frac{1}{\tau} \qquad (16)$$

Where τ is the time for an air change in the compartment. Thus, the weight of the extinguisher charge allows one to compute its volume as it is discharged under the specified compartment conditions, and the decay in concentration is an exponential function controlled by the time for air change

$$C = C_o\, e^{-t/\tau} \qquad (17)$$

Where C_o is the initial volume concentration. Specifying 8,000 feet altitude and 72°F, the following two equations give the initial concentrations for Halon 1211 and 1301, respectively

$$C_o\Big|_{1211} = \frac{(\text{weight of 1211 in lbs})\ (3.160)}{(\text{compartment volume})} \qquad (18)$$

$$C_o\Big|_{1301} = \frac{(\text{weight of 1301 in lbs})\ (3.5093)}{(\text{compartment volume})} \qquad (19)$$

Where compartment volumes are in cubic feet.

VERIFICATION OF STIRRED REACTOR ASSUMPTION

Reference 3 provides data on Halon concentrations for discharges under ventilated conditions within specified volumes. Table 1 lists the predicted concentrations from equation (17) based on the discharge weights documented in reference 3. Figures 1 through 4 show the data for Halon 1211 from figure 1 against the actual measurements. Given the simple nature of the stirred reactor assumption, the agreement of the theory with the data is good.

DEVELOPMENT OF SELECTION CRITERIA

Using assumption (4), the following equations can be written

$$\left[\int_0^\infty C\,dt \right]_{1211} \leq .04 \text{ minute} \qquad (20)$$

$$\left[\int_0^\infty C\,dt \right]_{1301} \leq .10 \text{ minute} \qquad (21)$$

Equation (17) can be integrated to give

$$\int_0^\infty C\,dt = \int_0^\infty C_0 e^{-t/\tau} = \tau C_0 \qquad (22)$$

Equation (22) states that the total dose is simply the initial volumetric concentration times the time for an air change. Thus, equations (20) and (21) become

$$\tau C_0 \Big|_{1211} \leq .04 \text{ minute} \qquad (23)$$

$$\tau C_0 \Big|_{1301} \leq .10 \text{ minute} \qquad (24)$$

Using equation (18) with equation (23) and equation (19) with equation (24), the plots on figure 5 can be generated. An example of the use of figure 5 would be a compartment of 1,000 cubic feet volume with a fixed time for air change of 5 minutes. In that case 4 lbs. of 1211 would be too much but 4 lbs. of 1301 would be safe.

CONCLUSIONS

A conservative set of plots has been generated for safe deployment of Halon 1211 and 1301 hand-held fire extinguishers in ventilated aircraft compartments. For a given compartment volume and available ventilation rates, the plots indicate maximum extinguishing charge weights to prevent nausea, dizziness, or impaired judgment caused by neat agent discharge.

It should be noted that the charts are conservative in that they are based on uniform mixing of the agent within the compartment. In reality, the Halons are dense and ordinarily will tend to concentrate near the floor. Thus, actual human exposure would in most cases be less than predicted by the stirred reactor theory.

It should also be noted that the maximum extinguishing agent weight in a compartment could be raised in two specific situations; first, when air or oxygen breathing apparatus are available to use during high agent concentration periods; second, when short temporary judgment impairment, nausea, or dizziness of the occupants is tolerable in the face of a major fire threat.

REFERENCES

(1) Krasner, 1982.

(2) UL 1093

(3) Bristol, 1978

t(min)	$\exp\left(\frac{-at}{A}\right)$	3.5 lbs $\left.\frac{1211}{261}\right\rvert_{A1}$	3.1 lbs $\left.\frac{1301}{261}\right\rvert_{A1}$	16.7 lbs $\left.\frac{1211}{261}\right\rvert_{A3}$	15.63 lbs $\left.\frac{1301}{261}\right\rvert_{A3}$	3.44 lbs $\left.\frac{1211}{814}\right\rvert_{A4}$	3.11 lbs $\left.\frac{1301}{814}\right\rvert_{A4}$	15.81 lbs $\left.\frac{1211}{814}\right\rvert_{A5}$	15.75 lbs $\frac{1301}{814}$
0	1	.0315	.0310	.1457	.1561	.0099	.0102	.0456	.0500
1	.3679	.0116	.1140	.0536	.0574	.0036	.0038	.0168	.018[illegible]
2	.1353	.0043	.0419	.0197	.0211	.0013	.0014	.0062	.0068
3	.0498	.0016	.0015	.0073	.0078	.0005	.0005	.0023	.0025
4	.0183	.0006	.0006	.0027	.0029	.0002	.0002	.0008	.000[illegible]
5	.0067	.0002	.0002	.0010	.0010	.0001	.0001	.0003	.0003

TABLE I

TEST DATA

FIG. 1

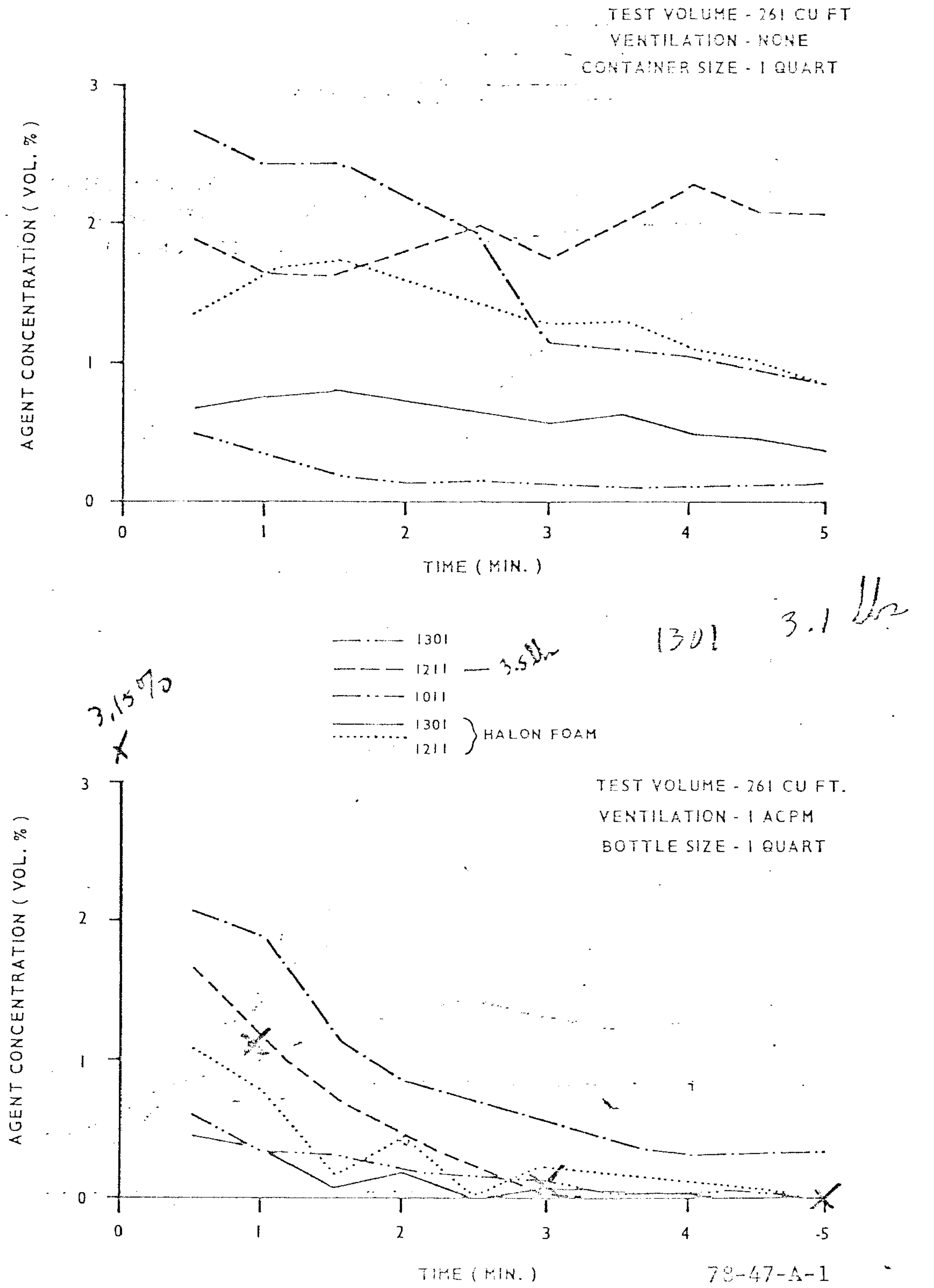


FIGURE A-1. AGENT CONCENTRATION IN SMALL VOLUME USING 1-QUART EXTINGUISHERS

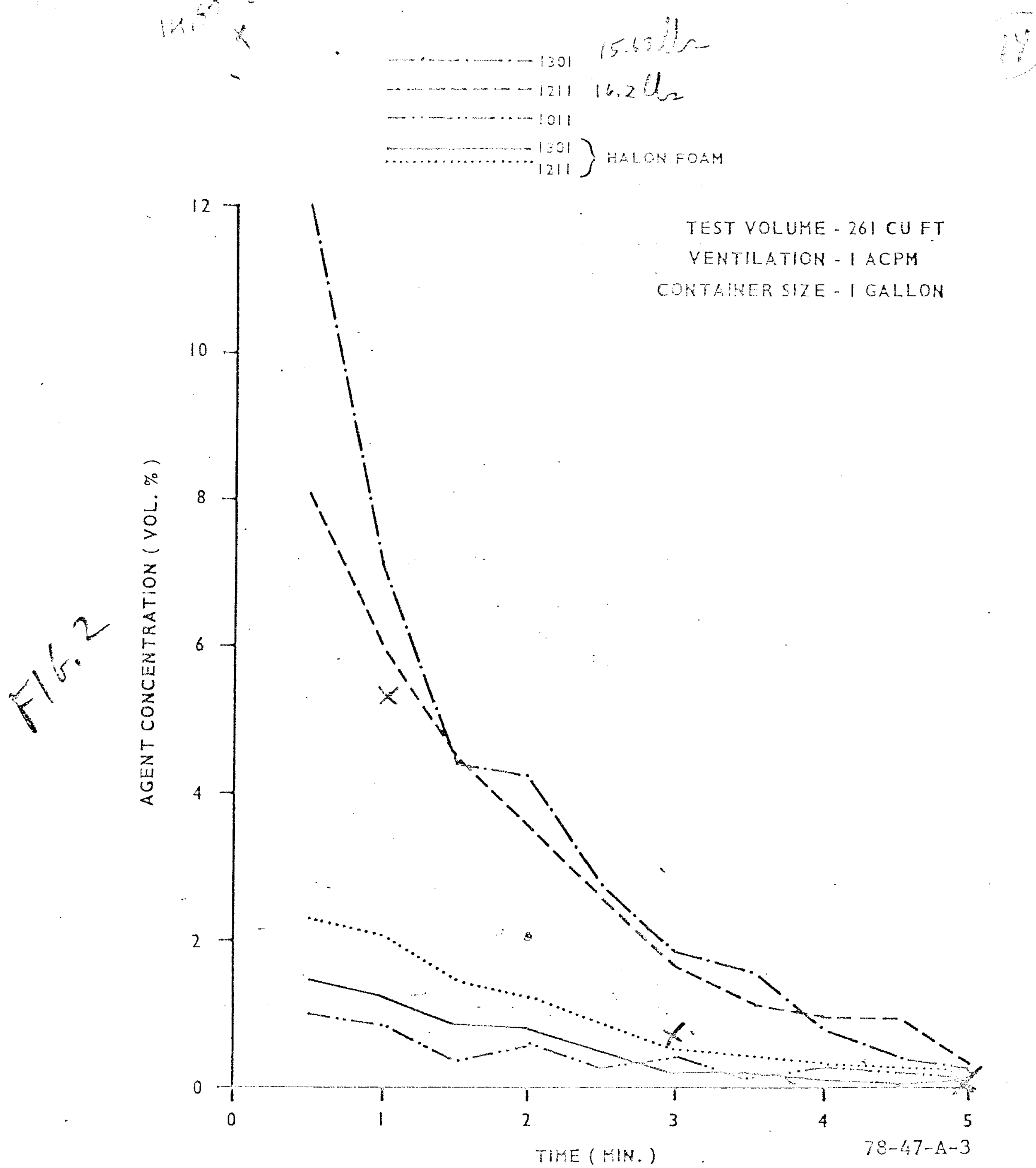
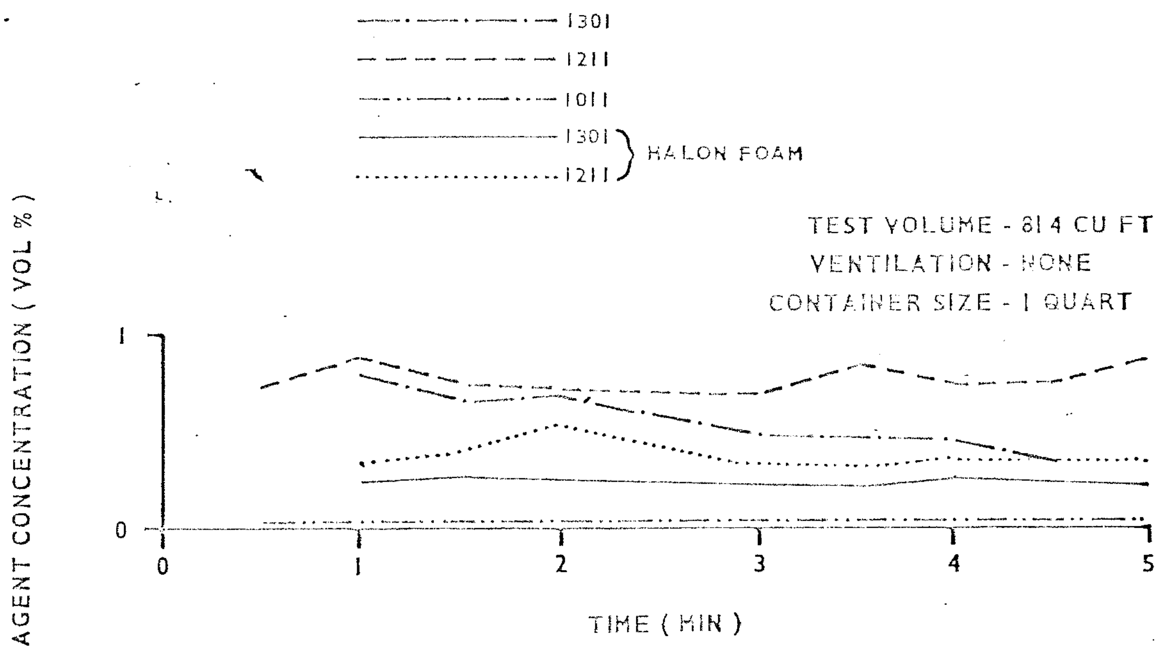


FIGURE A-3. AGENT CONCENTRATION IN SMALL VENTILATED VOLUME USING 1-GALLON EXTINGUISHERS



170
X
1211 3.49 lbs
1301 3.19 lbs

FIG. 3

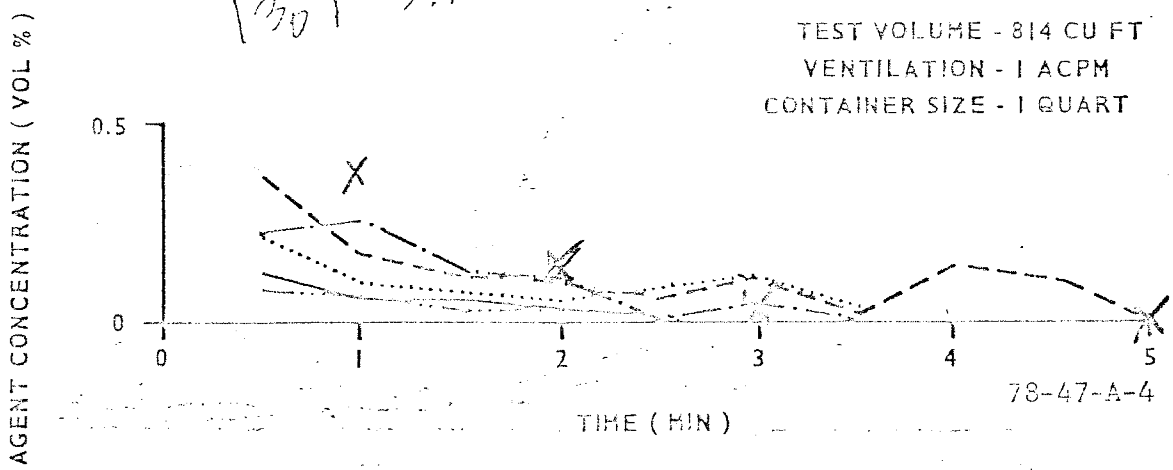


FIGURE A-4. AGENT CONCENTRATION IN LARGE VOLUME USING 1-QUART EXTINGUISHERS

FIG. 9

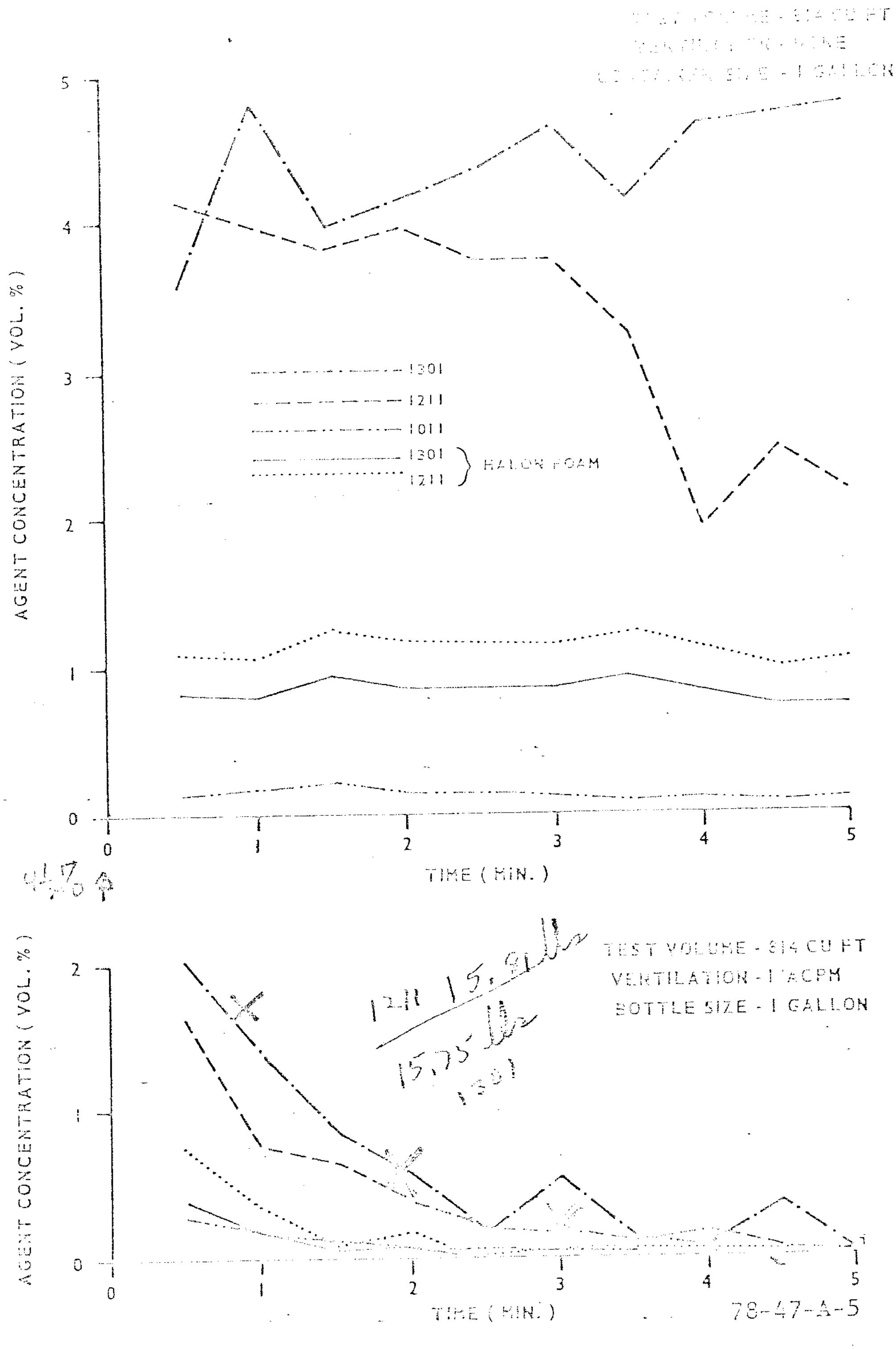


FIGURE A-5. AGENT CONCENTRATION IN LARGE VOLUME USING 1-GALLON EXTINGUISHERS