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A STUDY OF THREE BLAST SUPPRESSANTS FOR PERSONNEL PROTECTION

R.J. Hancox and A.V. Pleckauskas

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A study has been made of three materials as blast suppressants. Two materials, vermiculite and aqueous foam, have been shown to reduce pressure levels significantly. From the results it is possible to estimate the amount of suppressant necessary to reduce the pressure to a specified level.

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1. INTRODUCTION

In 1964 the US Committee on Hearing, Bioacoustics and Biomechanics of the National Research Council (CHABA) proposed a set of damage-risk criteria (DRC) for intermittent and continuous steady-state noise [1].

These criteria were based on the assumption that the permanent hearing loss produced by many years of exposure to noise is approximately equal to the auditory fatigue (temporary threshold shift, or TTS) shown by the normal ear after a single day's exposure [2]. These criteria, also known as CHABA curves (Fig. 1), set tolerance limits for exposure to steady state noise. Impulsive noise is characterised by a high energy, short duration impulse which typically follows an exponential decay with time. Many countries, including Australia, have adopted or recommended that the CHABA curves (or a slightly modified version) be accepted as the standard for impulse noise.

One way to reduce noise levels is to use suppressants. A diverse range of suppressant materials has been reported, usually for specific applications. Examples include vermiculite [3], aqueous foam [4 and 5], spherical shields [6] and liquid nitrogen [7]. In each of these samples the suppressant has been used to contain the environmental effects of noise and blast, e.g. in residential areas, or to protect firing tunnels or chambers from the damaging effects of blast.

Blast suppressants offer considerable potential as a means of protection of personnel situated close to a blast. It is anticipated that from the results reported here and future studies in this field, charts (or nomograms) will be constructed relating blast overpressure, frequency of exposure and suppression indices. Such information should then be included in the appropriate training manuals of the Australian Army.

2. EXPERIMENTAL PROCEDURE

2.1 *Criteria for Military Use of a Blast Suppressant*

We considered that for a suppressant to be effective for personnel protection it should meet the following criteria:-

(a) Produce a many-fold reduction in blast pressure.

(b) Not require an excessive time for assembly and/or dispersal.

(c) Produce no undesirable effects, e.g. noxious gases, fires, fragments.

2.2 *Suppressant Materials*

This investigation was limited to three materials known to exhibit blast suppressant effects. These materials were assessed against the above criteria:-

(a) Vermiculite (also known as exfoliated mica) is a heat-treated form of mica and is commonly used in packaging and acoustic applications.

(b) Aqueous fire fighting foam - dispensed from a foam fire extinguisher. Protein foams of this type are stable for several hours.

(c) Carpet shampoo - produces a rigid foam after being dispensed from a pressure-pack container.

Some physical characteristics of these materials are listed in Table 1.

2.3 *Experimental Technique*

Firings were conducted in a 300 mm thick reinforced concrete firing chamber, the interior dimensions of which were 5.3 m in length, 2.9 m in width and 2.5 m in height.

Peak overpressure was measured using a Kistler 202A pressure transducer, placed in the optimum position to ensure that the signal received contained only minimal reflections from the walls and roof of the chamber.

The foam concentrate (800 ml) was added to the fire extinguisher containing water to the stipulated level (9 litres) and the extinguisher pressurised to about 700 kPa. A stiffened polythene cylindrical container (.5 mm wall thickness), in which the diameter was equal to the height, was filled with the suppressant and placed on a caneite stand. The explosive charge, PE4, was lowered into the foam-filled container and positioned at its midpoint. In the case of vermiculite it was necessary, to position the explosive charge before adding the suppressant. The Kistler 202A pressure transducer was situated 1.6 m from the explosive charge in the same horizontal plane. A sketch of the experimental array is shown in Fig. 2.

2.4 Experimental Program

Explosive charge weights used ranged between 20 and 200 g. Cylindrical sticks of PE4 (90% RDX) were used in all firings except for one in which a sheet explosive, SX-2, (88% RDX) was used. The volume of suppressant was controlled by the polythene cylinder dimensions.

Details of charge weights, suppressant content and type are listed in Table 2.

3. EXPERIMENTAL RESULTS

3.1 Pressure-Time History

A pressure-time history (or impulse curve) was recorded for each firing. A typical example is shown in Fig. 3.

3.2 Significant Features of an Impulse Curve

There are a number of characteristics of an impulse curve which are considered as significant and which are detailed in Fig. 3.

(a) Peak Pressure Level (or peak overpressure) is the maximum pressure level achieved (point B). Point B is derived by eliminating the instrument overshoot (fig. 3) through calibration across the pressure range of interest. The peak overpressure for each firing is listed in Table 2.

(b) Rise Time is the time taken for the initial positive pressure fluctuation to rise from 10% above ambient to 90% of the peak overpressure value, i.e. in Fig. 3, the time represented by AD. The values of the rise time are listed in Table 2.

(c) Pressure-Wave Duration (Duration-A) is the time required for the pressure wave to rise to the peak overpressure and return to within 10% of ambient i.e. AE Duration-A values are listed in Table 2.

(d) Impulse is the area under the pressure-time curve, i.e. the area bounded by the limits, ABC. The areas under the curves were computed using a Calcomp digitiser and normalised to the unsuppressed pressure curve. These ratios are listed in Table 2.

(e) Pressure-Envelope Duration (Duration B) is the total elapsed time for the envelope of pressure fluctuations (positive and negative) to be reduced to less than 10% of the peak overpressure. This time would normally be the sum of the incident and reflected pressure envelope durations.

4. DISCUSSION

4.1 *Experimental Considerations*

The firing chamber was not typical of sites where blast suppression might be used. Therefore we have eliminated where possible the contribution to the pressure wave from reflections from the walls, floor and ceiling of the firing chamber. In order to reduce this effect the Kistler pressure transducer was positioned such that minimal reflections were observed. Fig. 3 is a pressure-time curve of an unsuppressed charge.

4.2 *Experimental Results*

4.2.1 *Effect of Suppression on Overpressure*

The relative effects of increasing thicknesses of suppressant on the peak overpressure are shown for two materials, aqueous foam (Fig. 4) and vermiculite (Fig. 5).

In Fig. 6, the relative effect on the pressure-time curve of different charge weights, for the same diameter of aqueous foam suppressant, can be seen.

In Fig. 7, the three suppressants are compared. The results indicate that for the same diameter, vermiculite of particle size as listed in Table 2 is a better suppressant than aqueous foam (AFFF) of expansion ratio 10 and both materials appear to be considerably better than carpet shampoo of expansion ratio about 38. It is possible from the results in Fig. 7, to also measure the gradients for each suppressant. This value is known as the suppression index and is a measure of the noise level loss per unit of suppressant (Table 3). It is thus possible to estimate the amount of suppressant necessary to reduce the noise level to the DRC limit. For a 100 g charge (PE4) and ground range of 1.6 m this value has been estimated and included in Table 3.

It is assumed that once a minimum thickness of suppressant is obtained the suppression index should remain constant irrespective of the charge weight over the limited high explosive mass range which has so far been examined. This is verified in Fig. 8 where the relationship between charge weight and overpressure for AFFF foam is shown (8).

4.2.2 Directional Effects

Where a cylindrical charge has been suspended vertically, it is reasonable to expect that provided the suppressant is uniform in particle or bubble size and equally distributed around the charge, the pressure front should be uniform in the azimuth direction.

In one experiment sheet explosive SX-2 (88% RDX) was used instead of the PE4 cylindrical sticks. The SX-2 was folded over sandwich-style, and initiated in a similar manner to the PE4 charges.

As expected, the pressure front is subject to local irregularities i.e. shock waves emanating from each side of the sheet are essentially planar, non-divergent waves and decay less rapidly than the divergent waves coming off the edges.

Sheet explosive is commonly used for such operations as demolition and pressure front irregularities like those reported here could cause dangerous overpressures in certain directions. It means that attention must be given to the positioning of personnel during such operations.

4.2.3 Impulse

The above discussion has assumed that operators have only been subjected to peak overpressures of short duration. Previous studies [9,10] have indicated that numbers and durations of pressure pulses are important and this has been considered in the damage risk criteria [1], where an adjustment is made to the permitted noise level depending on the number of impulses (Fig. 9).

4.3 Exposure Limit Levels

4.3.1 Stipulation of an exposure limit level above which physiological damage may occur is a complex problem. This is further complicated by the fact that such a value is dependent on:

(a) the duration of the exposure

(b) the number of exposures over a twenty-four hour period

(c) proximity and positioning of personnel.

There is currently no international standard for noise level but many countries, including Australia, have recommended that the CHABA levels be accepted as a damage-risk criteria (DRC). These DRC are;

(a) Limit the temporary threshold shift (TTS) (measured two minutes after exposure) produced in the exposed population except for the most susceptible 5% of individuals, to the CHABA limits of TTS.

(b) Represent tolerance limits for 100 impulses distributed over a period of four minutes to several hours on a single day.

(c) Assume that the pulses reach the ear at normal incidence.

The value of the DRC (or the preferred limit of exposure) is as follows:

(a) The maximum peak pressure level permitted is 164 dB without ear protection for the shortest pulse of any practical interest (25 μs).

(b) As the duration increases the permitted peak pressure level decreases steadily at the rate of 2 dB for each doubling of the duration (Fig. 1).

(c) For A-duration considerations, a terminal level of 125 dB is reached after 1.5 ms.

Two allowance factors can be applied.

(a) If the pressure pulse reaches the ear at a grazing rather than normal incidence, the limit should be raised 5 dB.

(b) If the number of pulses in a single day is greater than or less than 100, an adjustment can be made according to the gradient in Fig. 8.

The greatest risk of hearing damage is likely to occur during training exercises when there are repeated firings. The nature of such exercises eg. demolition would not normally allow more than 10 firings a day. Using the above criteria a working level of 152 dB plus a 5 dB allowance for only 10 firings/day, i.e. 157 dB can be derived.

4.4 Estimation of Suppressant from Data

In Table 2 the effect of varying thicknesses of foam on the peak overpressure for a range of charge weights (20 to 200 g) can be seen.

It is thus possible, for instance, to estimate the amount of foam suppressant needed to reduce the pressure level of a PE4 charge of 150 g with a ground range of 3.2 m to the DRC limit of 157 dB.

If we assume that the mechanism of suppression is the same irrespective of charge weight (up to 200 g) and thickness of foam then from Fig. 8 a charge weight of 150 g will give a peak pressure of 184.5 dB for a ground range of 1.6 m and 0.2 m of AFFF foam suppressant.

For relatively low charge weights and relatively small ground ranges, pressure levels decay with distance from the charge according to the relationship [8],

$$P \propto \frac{1}{r^2} \qquad (\ldots 1)$$

Using the conversion relationship,

$$1 \text{ dB} = 20 \log_{10} \frac{P(\text{in kPa})}{2 \times 10^{-5}} \qquad (\ldots 2)$$

the pressure level of 184.5 dB is equivalent to 33.6 kPa.

From: (eq 1)

$$P_1 r_1^2 = P_2 r_2^2 \qquad (\ldots 3)$$

where P_1 and P_2 are the pressure levels and r_1 and r_2 are the respective ground ranges.

If the ground range is moved to 3.2 m the pressure level at that distance would reduce to 8.4 kPa, (or from eq (2), 172.5 dB). From Fig. 7, the suppression gradient can be estimated at 0.85 dB/cm of foam suppressant.

Thus to reduce the pressure level from 172.5 to 157 dB, the DRC limit would require about 15 cm of foam, i.e. 15 cm of foam in addition to the 20 cm suppressant already specified in Fig. 8, giving a total of 35 cm of foam.

5. CONCLUSIONS

5.1 A limited study has been made of three materials as blast suppressants. For charge masses up to 200 g that vermiculite was a marginally more efficient suppressant than aqueous foam while carpet shampoo was clearly less efficient than the other two.

5.2 From the results published in Tables 2 and 3 and Figs. 7 and 8 it is possible to estimate the amount of suppressant needed to reduce the pressure level to the DRC limit.

5.3 These results should only be considered as a guide since the contribution made by ground reflections has been ignored. Furthermore only aqueous foam and vermiculite have been investigated and it is likely that other types of foam and vermiculites of different sizes could behave differently as suppressants.

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TABLE 1

PHYSICAL CHARACTERISTICS OF SUPPRESSANTS

Physical Characteristic	Suppressant		
	Vermiculite	Aqueous Foam	Carpet Shampoo
1. Specific gravity (bulk) Mg/m^3	.11	.11	.05
2. Expansion Ratio	N/A	approx 10	approx 38
3. Drainage time (ref. 5)	N/A	Low	Negligible
4. Particle size (by sieve analysis)	2.5 mm (mean particle diameter)	N/A	N/A

TABLE 2

Event No.	Explosive wt (g)	Suppressant Type	Suppressant Radius (m)	Peak Overpressure (POP)			Rise Time (ms)	Duration-A (ms)	Normalised Impulse
				psi	kPa	db*			
1	100 (PE4)	unsuppressed	0	10.4	71.6	191	.025	.8	1.0
2	100 (PE4)	aqueous foam	.1	7.2	49.6	188	.04	.9	.70
3	100 (PE4)	"	.2	2.4	16.3	178	.025	1.2	.49
4	100 (PE4)	"	.25	1.4	9.5	173	.025	1.4	.25
5	100 (PE4)	"	.35	.8	5.4	168	.03	2.0	.23
6	100 (PE4)	"	.5	.4	2.6	162	.8	2.6	.06
7	20 (PE4)	"	.2	.3	1.8	159	.11	1.4	
8	50 (PE4)	"	.2	.6	4.3	167	.025	1.45	
9	100 (PE4)	"	.2	3.3	22.9	181	.025	2.0	.87
10	200 (PE4)	"	.2	9.1	62.5	190	.03	.8	
11	44 (SX2)	"	.2	1.4	9.4	173	.03	.8	
12	100 (PE4)	vermiculite	.1	6.4	44.3	186	.02	1.0	.83
13	100 (PE4)	"	.2	2.1	14.4	177	.025	1.4	.46
14	100 (PE4)	"	.3	.6	4.3	167	.03	3.0	.11
15	100 (PE4)	carpet shampoo	.2	4.4	30.3	184	.04	1.0	.37

* relative to 20 μPa

TABLE 3

	Suppression Index Change wt 100 g PE4 Ground range 1.6 m	Thickness (radius) of Suppressant to Reduce POP (m) DRC Limit (157 dB)
Aqueous Foam	.85 dB/cm	.40 m
Vermiculite	1 dB/cm	.34 m
Carpet Shampoo	.5 dB/cm	.7 m

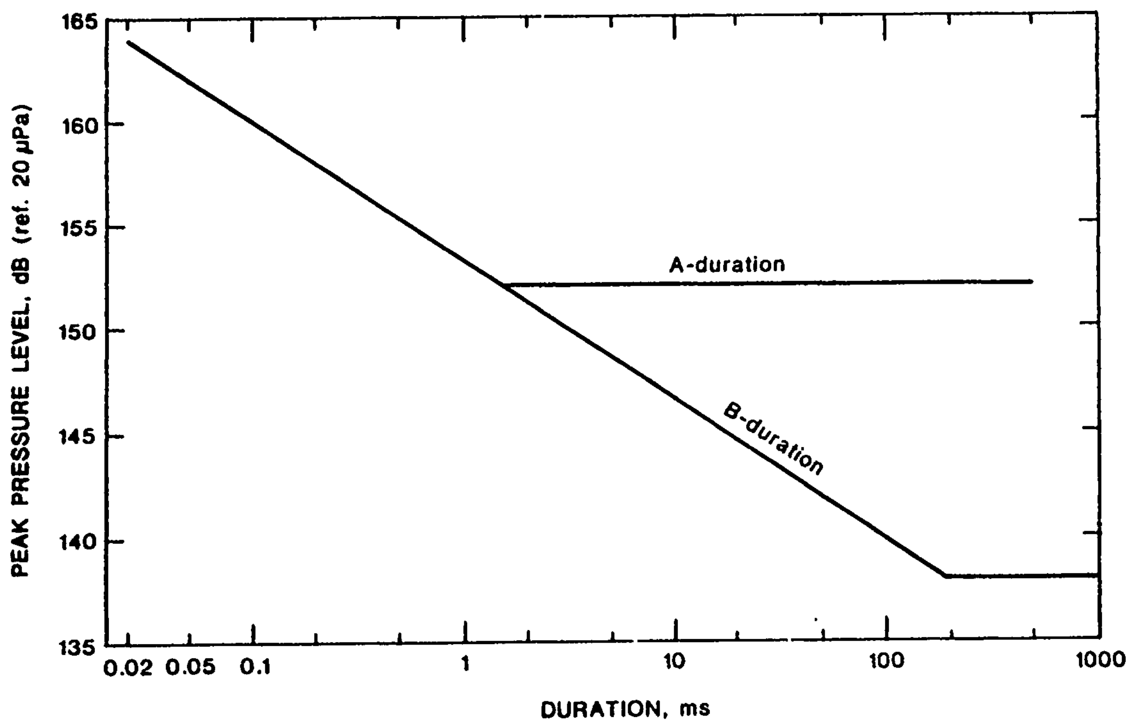

FIG. 1 Damage Risk Criteria Limits of Temporary Threshold Shift.

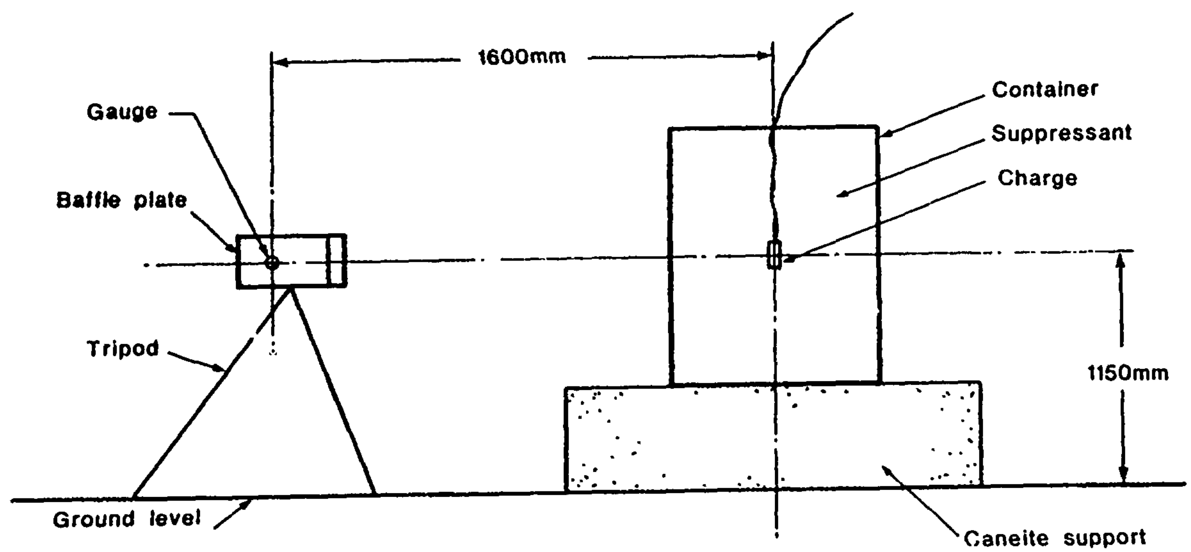

FIG. 2 Experimental Layout for Blast Suppression Measurement

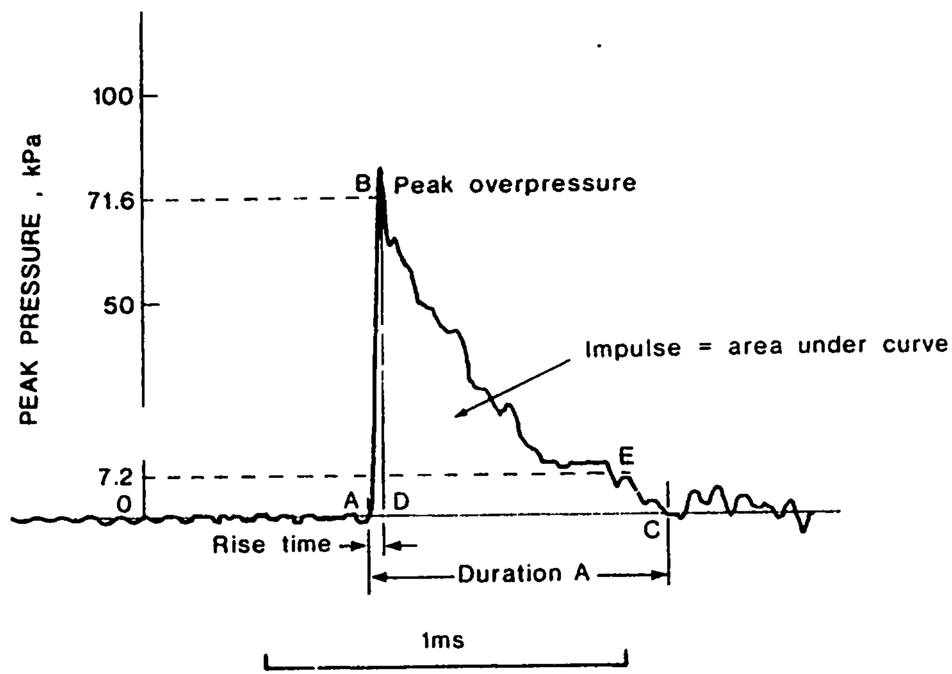

FIG. 3 Typical Pressure-Time Curve

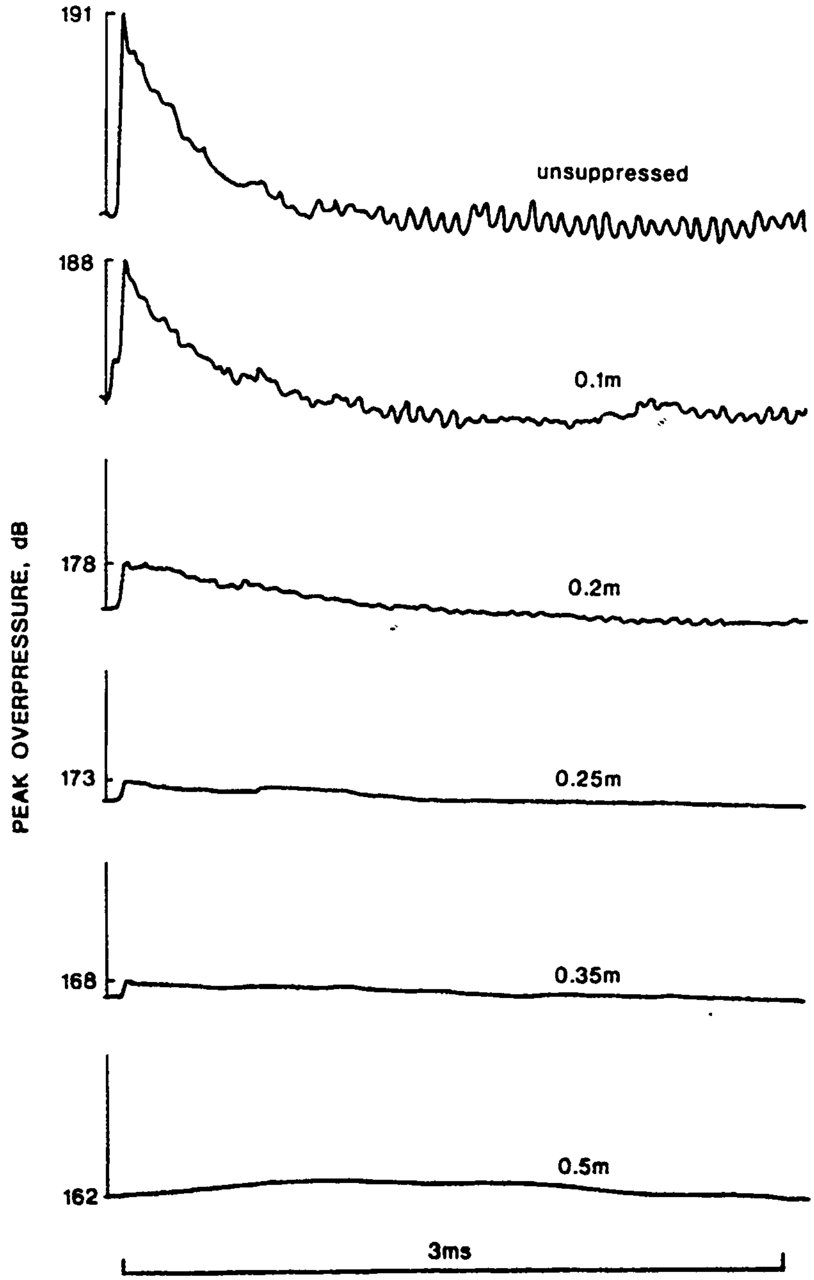

FIG. 4 Suppression effect of varying radii (m) of AFFF foam (charge wt 100 g PE4, ground range 1.6 m)

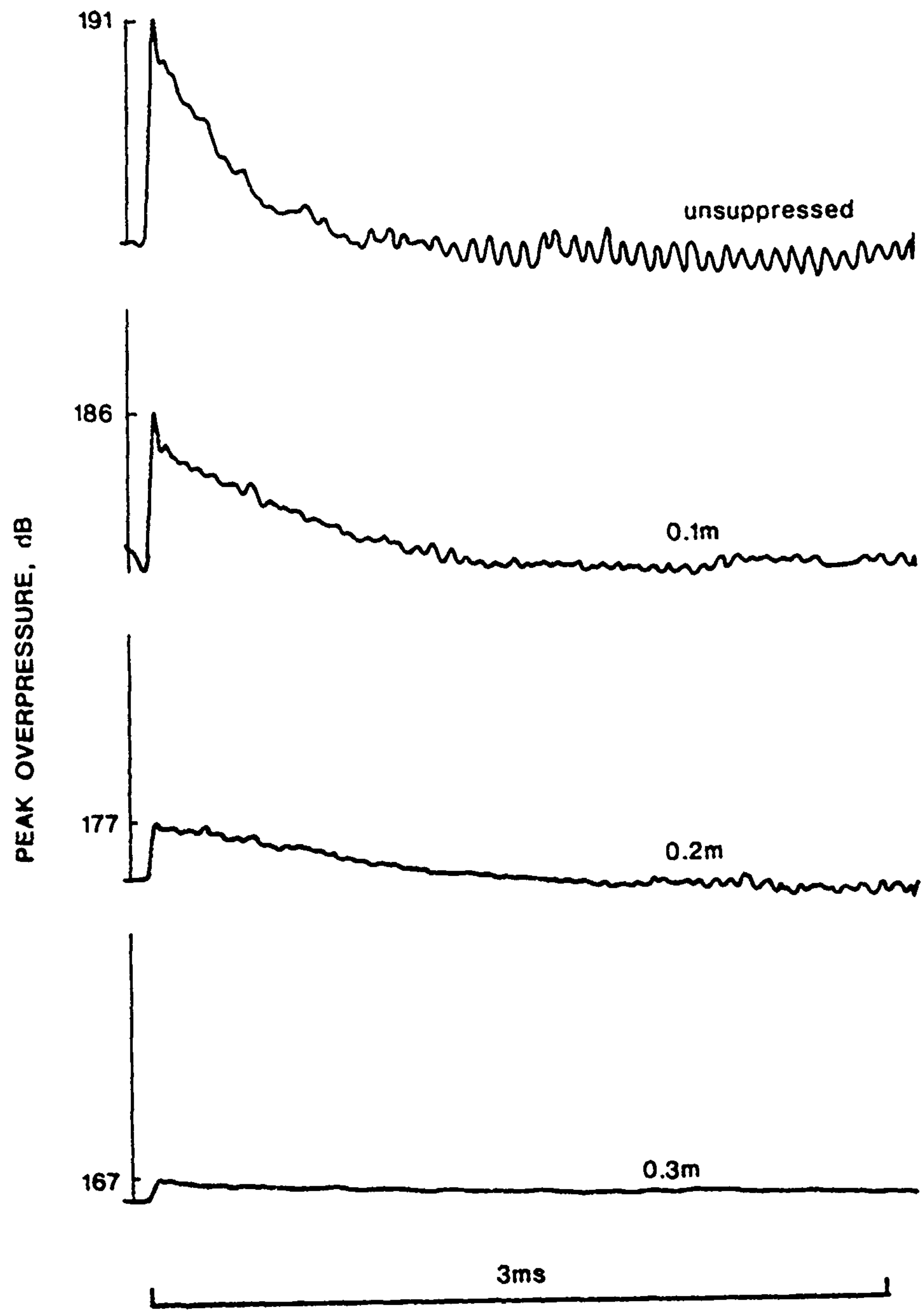

FIG. 5 Suppression effect of varying radii of vermiculite (charge wt 100 g PE4, ground range 1.6 m)

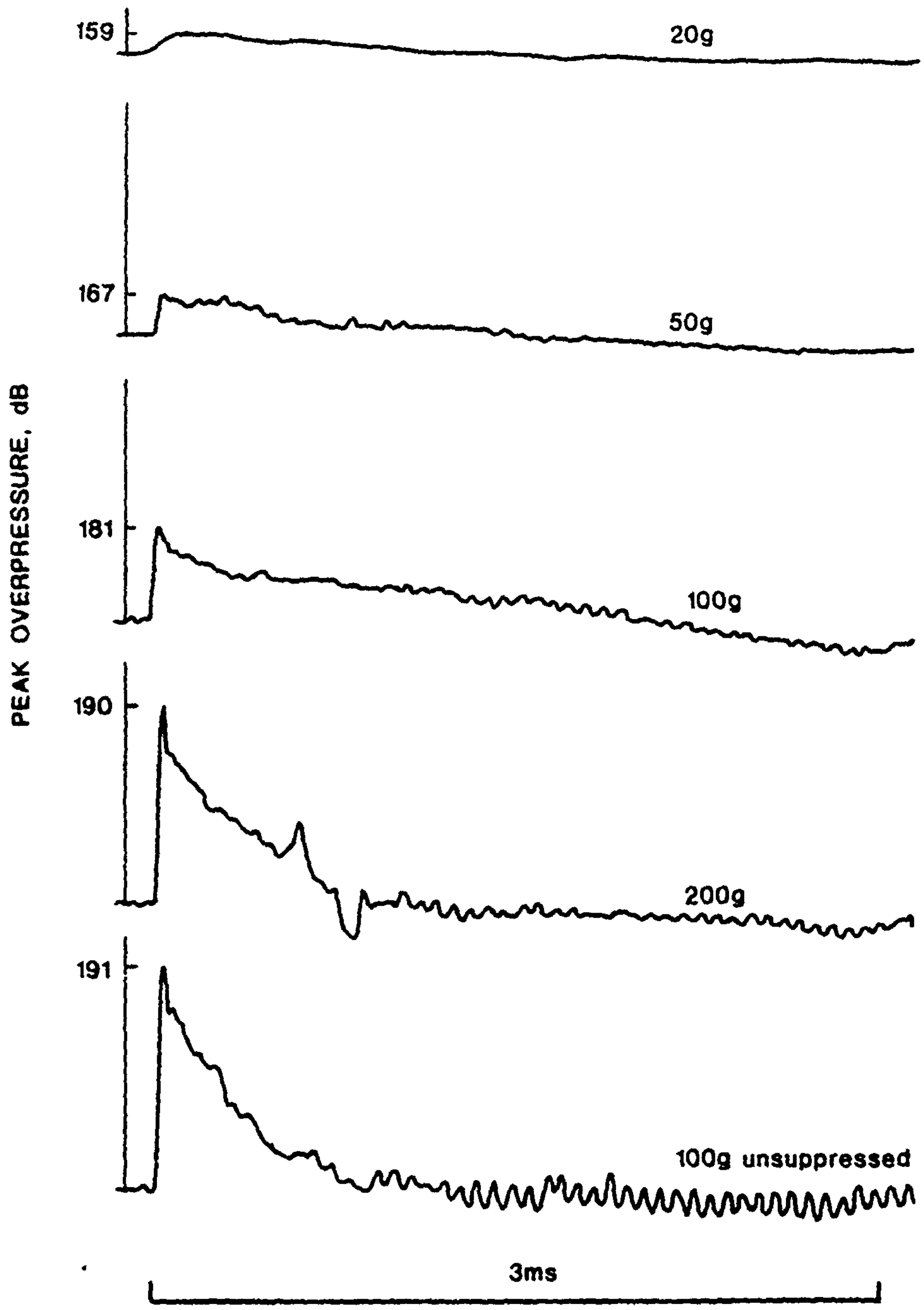

FIG. 6 Suppression effect of .2 mm AFFF foam with varying charge weights

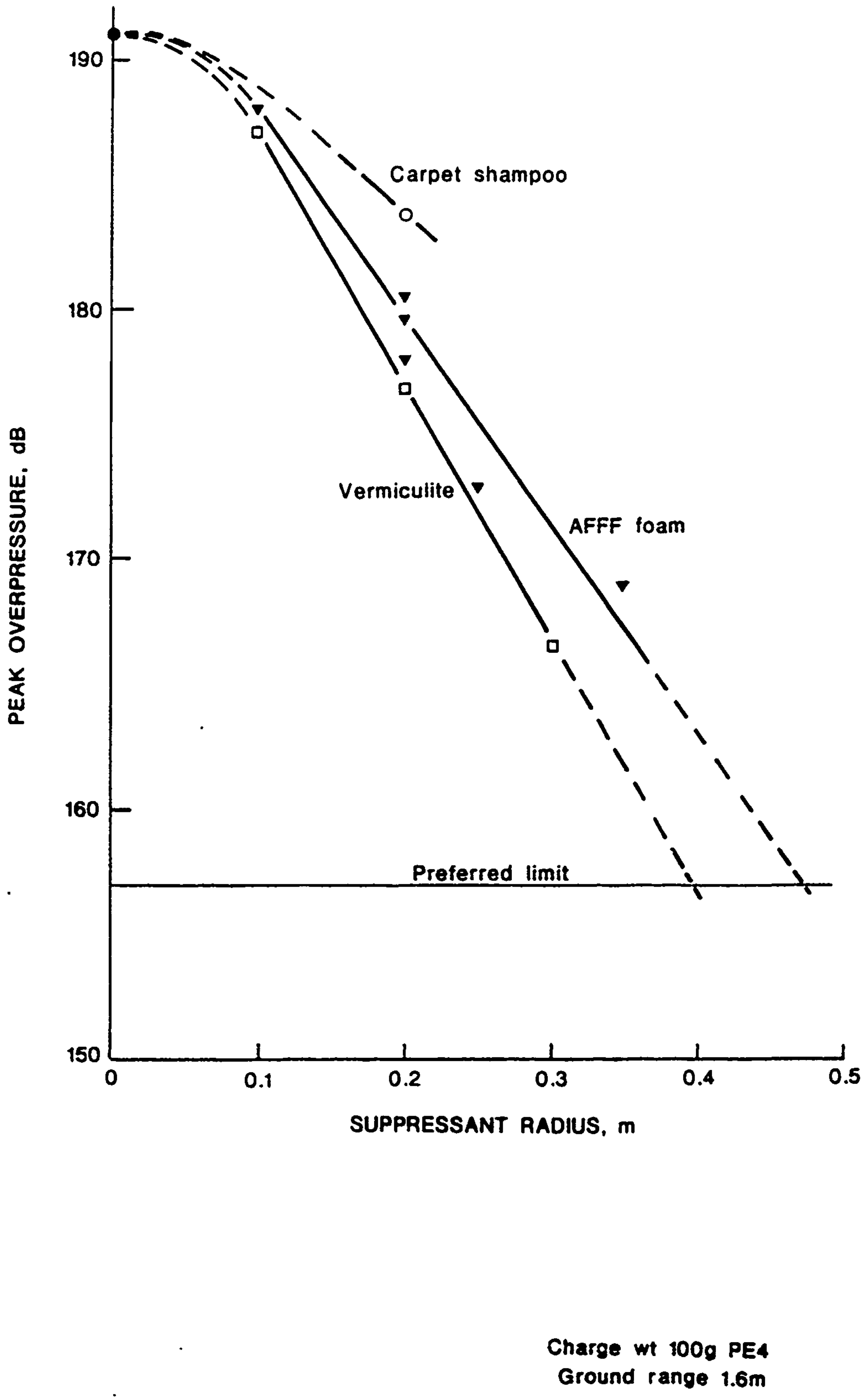

FIG. 7 Comparative performance of three suppressants (100 g PE4, ground range 1.6 m)

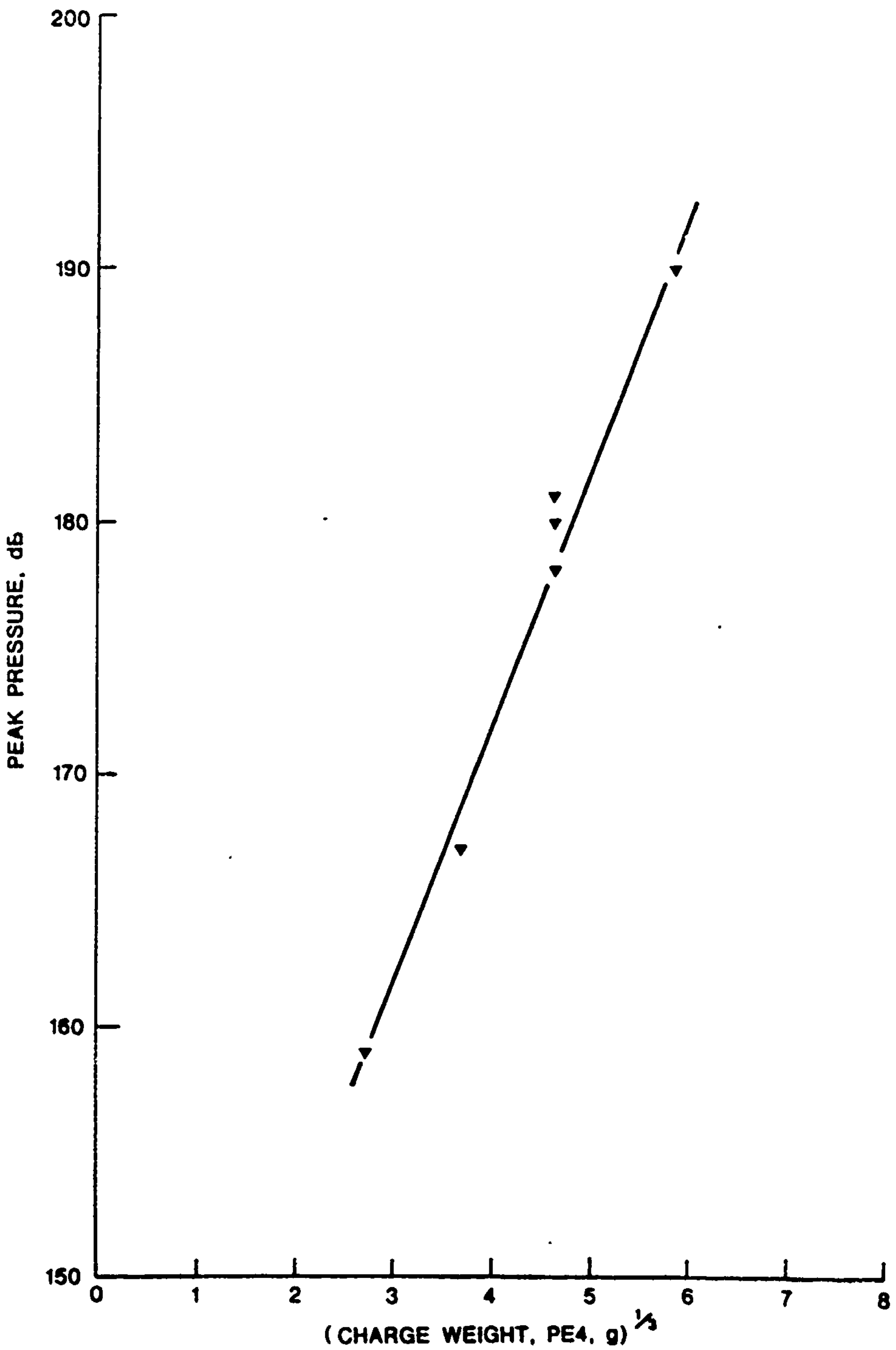

FIG. 8 Charge weight-pressure relationship (for 0.2 m radius of AFFF foam and ground range 1.6 m

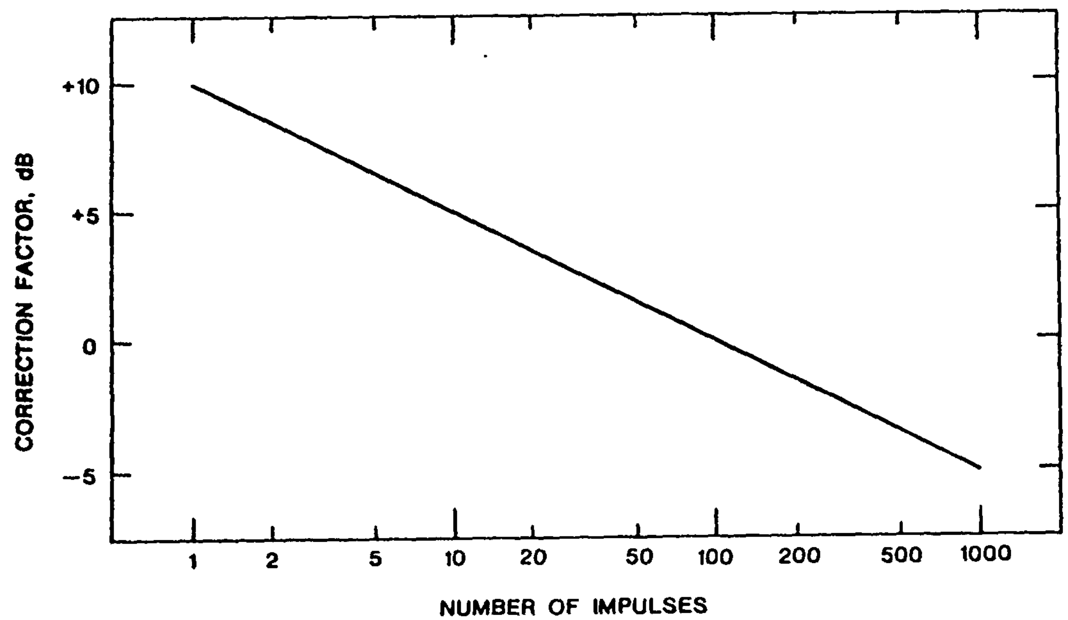

FIG. 9 Correction Factor for Number of Impulses

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