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PROBABILITY OF INJURY FROM AIRBLAST DISPLACEMENT AS A FUNCTION OF YIELD AND RANGE

Lovelace Foundation for Medical
Education and Research
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to predict the probability of impact injuries due to whole-body translation by airblast as a function of yield and ground range. Predictions were made for personnel in different orientations in open terrain and near structural complexes.

A mathematical model was used to calculate the time-displacement history of personnel from considerations of aerodynamic

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20. ABSTRACT (Continued)

drag and ground friction. Predicted values of maximum velocity, displacement at maximum velocity, and total displacement were tabulated for 1224 exposure conditions. These conditions included both air and surface bursts with yields from 1 T to 100 MT and peak overpressures from 2 to 97 psi.

Biological criteria were presented which indicate that personnel subjected to decelerative tumbling over open terrain can tolerate much higher velocities than personnel impacting a non-yielding, flat surface at normal incidence. These criteria were used in preparing range-yield plots for 1-, 2.5-, 5-, and 50-percent probabilities of serious injury to prone personnel in the vicinity of a surface burst.

Methods for extending the presented results to other exposure conditions were discussed.

PREFACE

This work unit, Decelerative Tumbling Blast Effects on Personnel. Contract No. DNA 001-74-C-0120, was part of the subtask, Biological Effects of Blast Environments.

This study was under the direction of R. K. Jones. The technical assistance of W. Hicks, K. Saunders, A. Shaw, and W. S. Jackson is acknowledged. T. Minagawa performed the technical photography and prepared the illustrative material. The report was typed and compiled by B. Martinez.

This research was conducted according to the principles enunciated in the "Guide for Laboratory Animal Facilities and Care," prepared by the National Academy of Sciences, National Research Council.

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INTRODUCTION

One of the major hazards to personnel in the vicinity of an explosion is associated with whole-body displacement induced by blast winds. The purpose of this study was to predict the probability of impact injury from displacement as a function of yield and ground range. Predictions were made for personnel in different orientations in open terrain and near structural complexes. A mathematical model (Reference 1) was used to calculate the time-displacement history of personnel from considerations of aerodynamic drag and ground friction. The model had been verified previously using data from anthropomorphic dummies translated over open terrain by high-explosive (HE) and nuclear detonations (References 2 and 3).

Two types of terrain were of interest because of differences in the translational velocities required to produce injuries. In open terrain, personnel undergo decelerative tumbling, in which case the energy of motion is dissipated slowly through a series of glancing impacts, and relatively high velocities can be tolerated. In contrast, personnel translating near a structural complex may impact rigid structures at approximately normal incidence, and the energy of motion is dissipated much more rapidly with a corresponding increase in the likelihood of injuries. The biological criteria used in the present study were derived from experiments (Reference 4) by airblast from a shocktube. Injuries commonly incurred during either type of deceleration included lacerations, contusions, fractures, dislocations, and damage to internal organs.

MATHEMATICAL MODEL

The mathematical model used to calculate blast-induced translation of personnel (Reference 1) was adapted to an electronic digital computer. The computer program is quite general in that it takes into account variable ground friction, aerodynamic-drag characteristics, and blast-wave parameters.

Ground Friction

The average deceleration, due primarily to frictional effects with the ground, of a 165-lb man undergoing decelerative tumbling has been estimated in Reference 1 to be approximately $8.9029\ V_i^{0.38308}$ ft/sec^2, where V_i is the instantaneous translational velocity in ft/sec. This relationship was derived from translational data obtained with guinea pigs, rabbits, dogs, and a goat by scaling to an animal the size of man. Previous calculations have indicated that the ground-friction formula also applies reasonably well to full-scale anthropomorphic dummies (Reference 3).

Acceleration Coefficient

In order to calculate the aerodynamic drag forces on a man it is necessary to know, at each instant, the acceleration coefficient, α , defined as the projected area presented to the wind multiplied by the drag coefficient and divided by the body mass (Reference 5). The α varies as the orientation of a man changes during translation. A value of approximately 0.03 ft^2/lb has been estimated to be the average α for a random orientation (i.e., considering all possible orientations to be equally likely) of an unbent man.

The α for a prone man end-on to the wind is 0.0063 ft^2/lb (Reference 6). Data obtained on 500-ton HE tests (Reference 3) suggest that, for near-ideal conditions, asymetries will cause a dummy which was initially prone and end-on to the flow to turn side-on to the wind after about 13 ft of displacement. The details of the subsequent displacement were not obtained, but the assumption of a random orientation seems reasonable. An emperical fit to the data yielded the following relationships:

$$\alpha = 0.0063 + (D_i/31)^4 \quad \text{for} \quad 0 \leq D_i < 12.2$$

$$\alpha = 0.03 \quad \text{for} \quad 12.2 \leq D_i$$

where α is expressed in ft^2/lb and D_i is the instantaneous displacement in feet.

The α for a prone man in a random orientation is 0.014 ft^2/lb (Reference 6). This value is smaller than the average α for a man considering all orientations because a prone man cannot be face- or back-on to the wind. The data mentioned in Reference 3 suggest that, on the average, a dummy which was initially prone in a random orientation will turn side-on to the wind after about 6 ft of displacement. The following relationships were used to approximate the acceleration coefficient during the displacement of a man initially prone in a random orientation:

$$\alpha = 0.014 + (D_i/47)^2 \quad \text{for} \quad 0 \leq D_i < 5.9$$

$$\alpha = 0.03 \quad \text{for} \quad 5.9 \leq D_i$$

The α for a prone man side-on to the blast is 0.022 ft^2/lb. The data indicate that dummies initially in this orientation will start to roll within a very short displacement

(~1 ft). The average α for a man rolling with his long axis perpendicular to the wind is 0.038. It is not known after what displacement the orientation would typically become more random in nature. Because of these uncertainties, an α of 0.03 ft^2/lb was assumed throughout the displacement of a man initially prone and side-on to the wind.

The only calculations made for a standing man were for the worst case, i.e., for a man initially face- or back-on to the wind. Data obtained with dummies indicate that these two initial orientations will result in approximately the same displacement (Reference 3). It should be noted that orientation probably influences the displacement of a standing man less than in the case of a prone man, in that the α of a standing man can range from only 0.022 to 0.052, whereas the α of a prone man can range from 0.0063 to 0.022 depending on the orientation.

At overpressures below 2.7 psi, the standing dummies toppled over with their feet having undergone almost no displacement. At overpressures above 5.3 psi, the legs were blown out from under the dummies such that they became airborne almost immediately. Typically a standing dummy rotated such that it first impacted the ground on its head after a displacement of from 10 to 15 ft. Rather than attempting to adapt the mathematical model to closely approximate the complexities introduced by the sometimes airborne displacements, a simpler approach was considered. Calculations were made assuming that the α remained constant at 0.052 and that the ground friction was operative throughout the displacement (Reference 3). The predictions agree well with experimental displacements obtained over a limited range of yield (50 T to 38 KT) and overpressure (5 to 50 psi). The good agreement is probably due in part to two compensating errors: (1) assuming the α remains constant at 0.052 should result in the predicted velocities being too high because the dummies rotated, thus reducing the α; (2) assuming the ground friction to always be operative should result in the predicted velocities being too low because the dummies were airborne during the first 10 ft of displacement.

Blast-Wave Parameters

The blast-wave parameters used to predict the displacement of personnel were derived primarily from data for nuclear detonations in References 7 and 8. Calculations were made at selected yields and ground ranges for surface bursts and for upper and lower optimum heights-of-burst (HOB's). The optimum HOB is defined as the one which tends to maximize, for a given ground range, both the peak dynamic pressure and the impulse of the positive dynamic pressure. Thus the optimum

HOB would also tend to maximize the translational velocity of personnel for a given ground range. The airblast data indicate that at intermediate ground ranges there are two local optimum HOB's, with the upper optimum HOB giving the larger dynamic-pressure levels and impulses for scaled ground ranges greater than approximately 770 ft/(KT)$^{1/3}$, and the lower optimum HOB giving the larger dynamic-pressure levels and impulses for smaller scaled ground ranges.

Table A-1 lists the pertinent blast-wave parameters. Note that values are given for both upper and lower optimum HOB's for scaled ground ranges between 400 and 950 ft/(KT)$^{1/3}$. For surface bursts the peak overpressures given in the table range from 2 to 97 psi corresponding to peak dynamic pressures between 0.093 and 140 psi.

Double-exponential equations, of the types used in Reference 8, were fitted to the overpressure and dynamic-pressure waves to facilitate their being entered into the computer program. The Rankine-Hugoniot relations were assumed to apply at the shock front, and changes within the shock wave were assumed to be adiabatic. It was thus possible to use the overpressure to calculate the air density, which in turn could be combined with the dynamic pressure to calculate the wind speed, all of these quantities varying with time.

In calculating a displacement, the blast-wave parameters were evaluated at fixed time intervals, the size of which depended on the yield of interest. For yields of 1 T, 1 KT, 1 MT, and 100 MT the time intervals were 5 μsec, 50 μsec, 0.5 msec, and 2 msec, respectively. These values also represent the time-step sizes used in solving the differential equations of motion by Runge-Kutta methods.

CALCULATED VELOCITIES AND DISPLACEMENTS

Each of the 34 runs listed in Table A-1 was analyzed in connection with nine yields (ranging from 1 T to 100 MT by factors of 10) and four initial orientations (three prone and one standing). Thus a total of 1224 displacements were predicted using the computer. Figure A-1 shows a typical velocity-displacement history for a prone man in a random orientation exposed to an overpressure level of 27.4 psi from a 10-KT surface burst. As was the usual case, the maximum velocity, V, was achieved within a displacement, S, which was short compared to the total displacement, D. Likewise, the time to peak velocity was short compared to the total time of displacement.

The predicted V, S, and D values for all of the computer runs are listed in Tables A-2 through A-5. For a given yield and initial orientation, the V and D values always increased with the peak overpressure. The S values also increased with the peak overpressure except for some slight reversals at the higher overpressures. These reversals may be an anomaly caused by the finite size of the time step used in the calculations. Even if this is the case, the effect on the computed V and D values would be minimal. The predicted maximum velocities in Tables A-2 through A-5 for personnel exposed to a surface burst have been plotted in Figures A-2 through A-5.

INJURY PROBABILITY VS RANGE AND YIELD

Table A-6 indicates the probability of serious injury (fracture or ruptured internal organ) as a function of velocity for personnel undergoing either decelerative tumbling or impact at normal incidence against a nonyielding, flat surface. The velocities are in agreement with estimates of man's tolerance to impact in Reference 9.

Figures A-2 through A-4 were used to determine the scaled ground ranges corresponding to the velocities in Table A-6. Ground range vs nuclear yield was plotted in Figures 1 and 2 for 1-, 2.5-, and 5-percent probabilities of injury to prone personnel and in Figures 3 and 4 for 50-percent

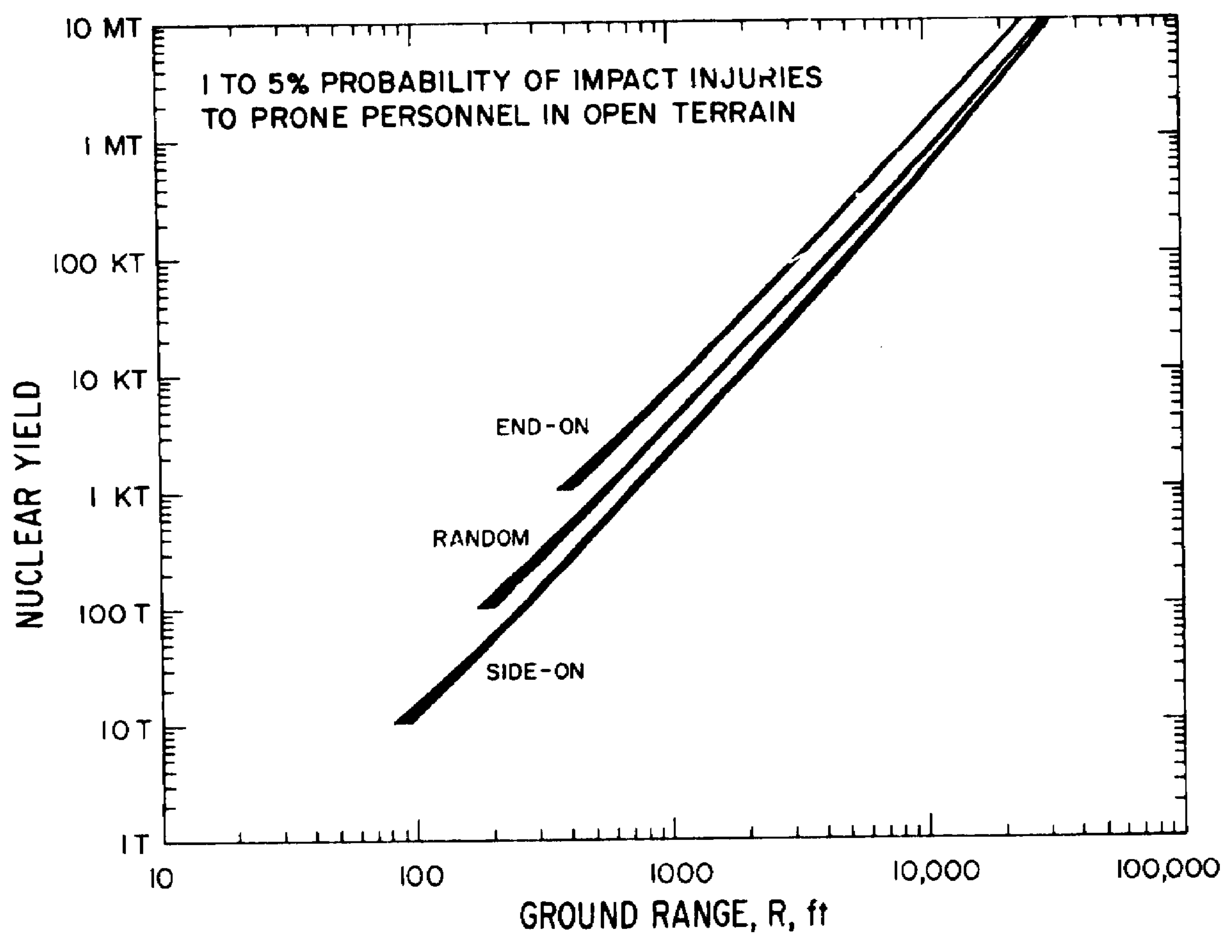

Figure 1. 1- to 5-Percent Probability of Impact Injuries to Prone Personnel in Open Terrain. The right-hand edge, center, and left-hand edge of each curve correspond to probabilities of 1, 2.5, and 5 percent, respectively. Computed for a surface burst.

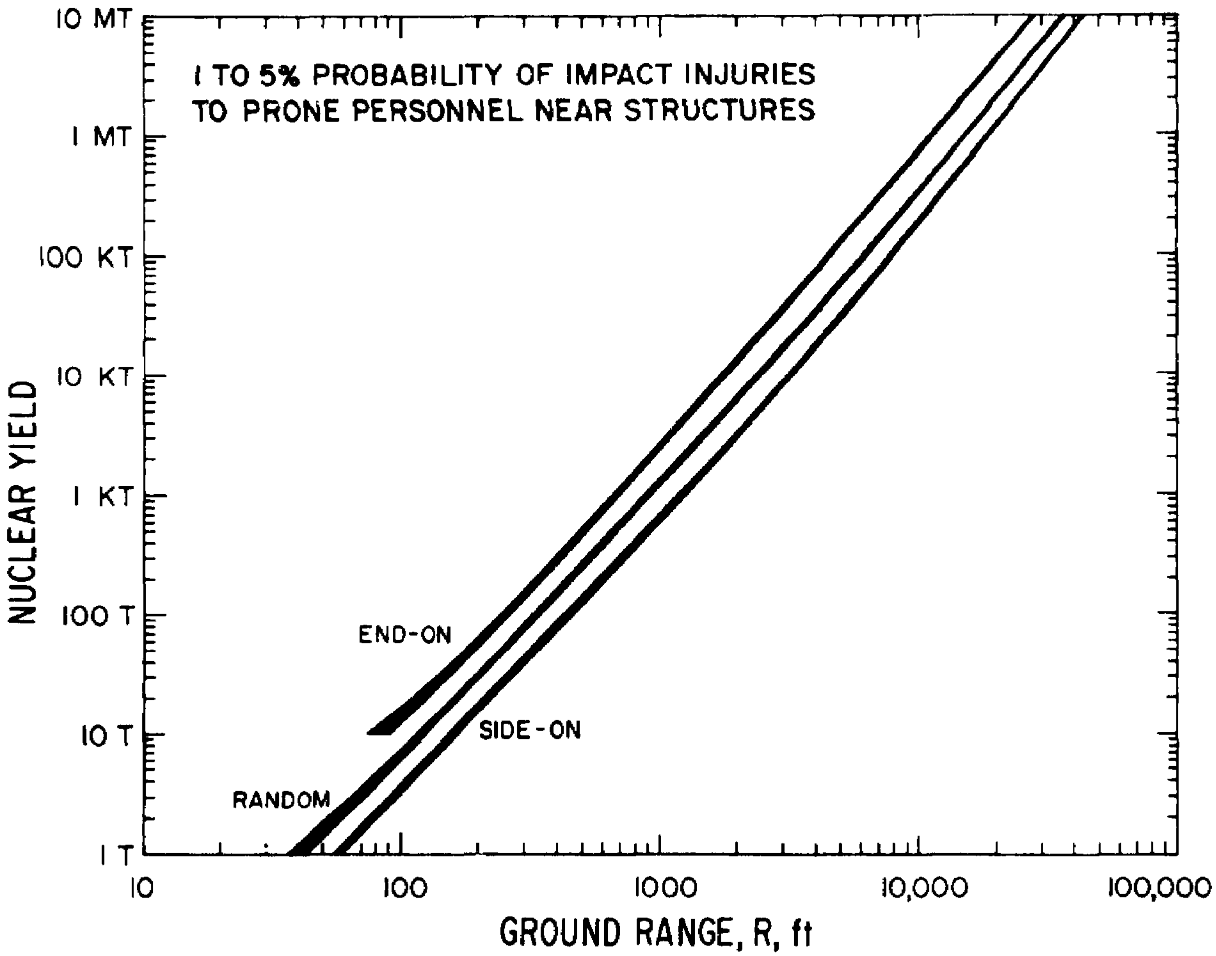

Figure 2. 1- to 5-Percent Probability of Impact Injuries to Prone Personnel Near Structures. The right-hand edge, center, and left-hand edge of each curve correspond to probabilities of 1, 2.5, and 5 percent, respectively. Computed for a surface burst.

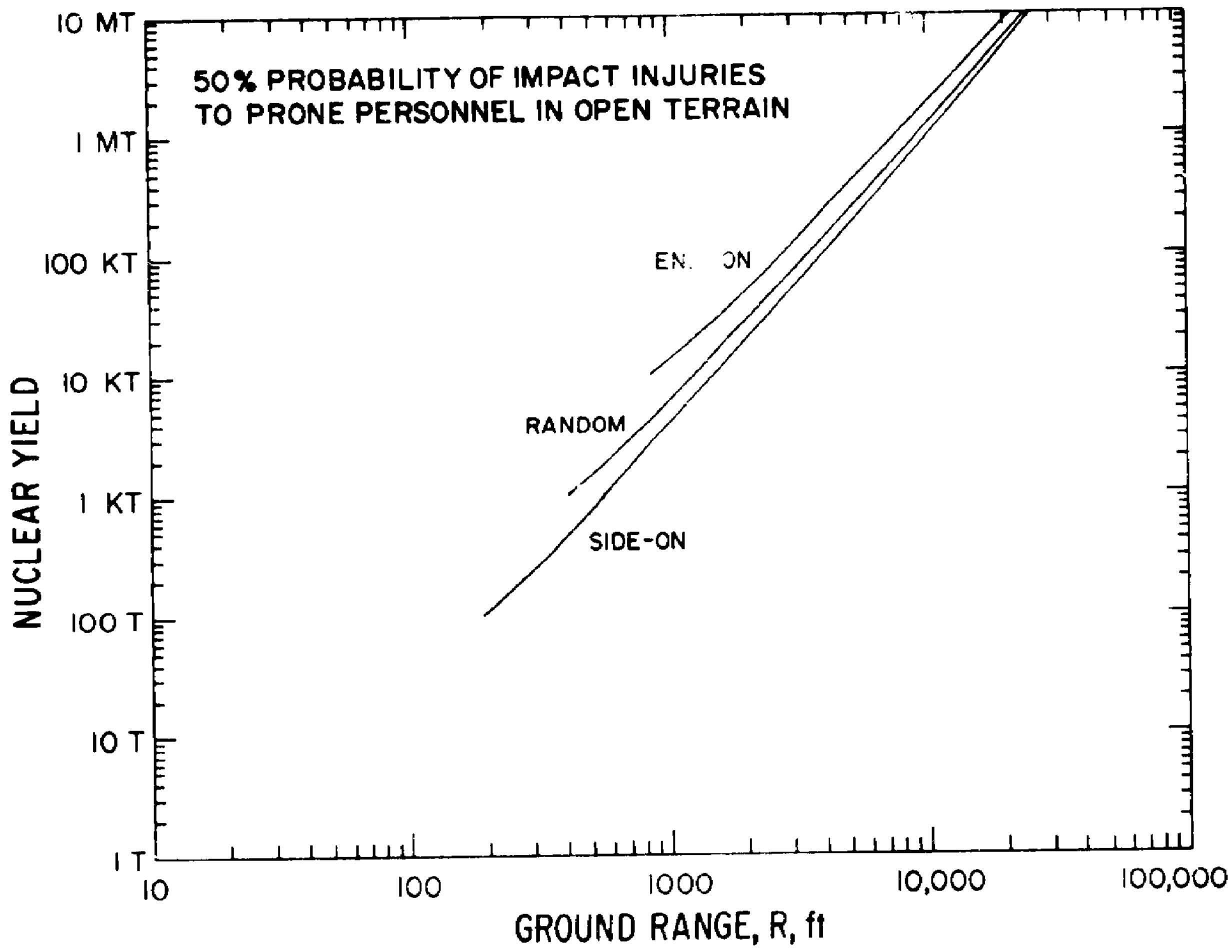

Figure 3. 50-Percent Probability of Impact Injuries to Prone Personnel in Open Terrain. Computed for a surface burst.

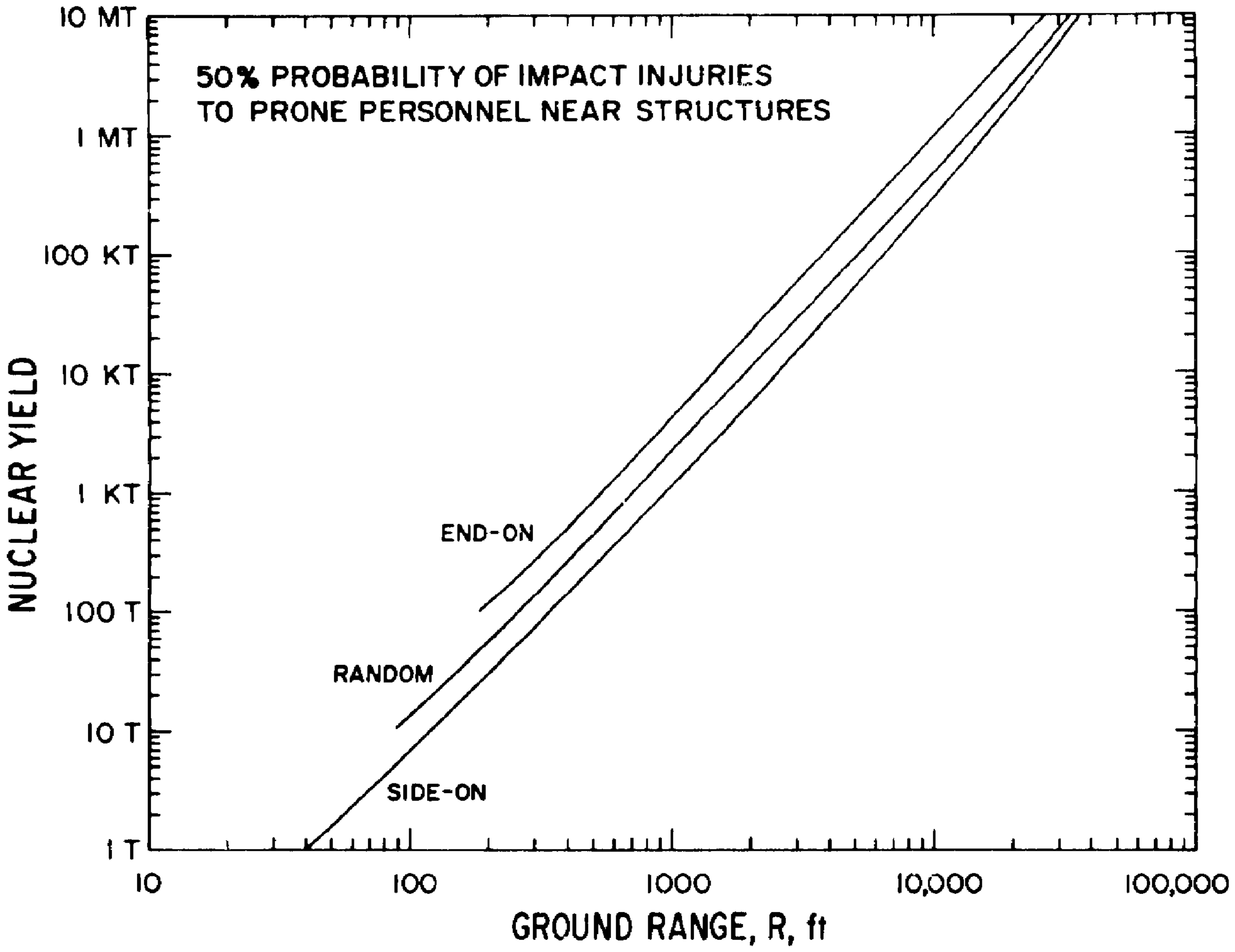

Figure 4. 50-Percent Probability of Impact Injuries tc Prone Personnel Near Structures. Computed for a surface burst.

probabilitiy of injury. Implicit in Figures 2 and 4 is the assumption that personnel near structures impacted, at normal incidence, a nonyielding, flat surface at the instant of maximum velocity.

Some of the curves in Figures 1 through 4 do not extend to 1 T because no attempt was made to extrapolate to yields less than those that could be read directly from the curves in Figures A-2 through A-4. However, the missing portions of the curves correspond to peak overpressures of greater than 55 psi, such that the primary-blast hazard would probably override the displacement hazard.

From Figures 1 through 4 it can be seen that, for a given injury probability and yield, the ground range is very dependent on both initial orientation and type of terrain. For example, for a 50-percent probability of injury from a 10-KT surface burst, the ground ranges for end-on and side-on prone personnel are approximately 850 and 1500 ft in open terrain and 1400 and 2500 ft near structures. In contrast, varying the injury probability from 1 to 5 percent has a relatively small influence on ground range. For example, for a 10-KT surface burst in open terrain, the ground ranges for 1- and 5-percent probabilities of injury are approximately 1200 and 1100 ft for end-on prone personnel and 2000 and 1900 ft for side-on prone personnel.

Four methods of extending the possible applications of the predictions presented in this paper are worth noting:

First, velocities read from Table A-5 or Figure A-5 could be used to estimate injury probability vs range and yield for standing personnel.

Second, it would be possible to predict the approximate displacement of personnel subjected to a near-classical dynamic-pressure wave generated by an unspecified source by assuming that (for a given orientation) V, S, and D are each a function of only the peak dynamic pressure and the impulse of the positive dynamic pressure. Further, as the duration of the wave decreases, the significance of the wave shape and peak dynamic pressure decreases, such that V and D become functions of only the impulse of the positive dynamic pressure, and S approaches zero. All of these functions could be derived from the data in Tables A-1 through A-5.

Third, for a HOB lower than those listed in Table A-1, it is reasonable to use logarithmic interpolation to estimate translational velocities and displacements. For example, for a HOB of 200 $ft/(KT)^{1/3}$, one could interpolate between values for a surface burst and a lower optimum HOB for ground ranges between 400 and 950 ft/(KT)$^{1/3}$, and interpolate between values for a surface burst and an upper optimum HOB for ground ranges between 1100 and 2600 ft/(KT)$^{1/3}$.

Finally, the predictions may be applied directly to an HE detonation by considering a nuclear yield twice as large as the HE yield. Thus, for 500 tons of high explosives, one would read 1 KT on the nuclear yield scales in the figures. This procedure is based on the assumption that approximately one-half of the energy released in a nuclear detonation goes into airblast.

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APPENDIX

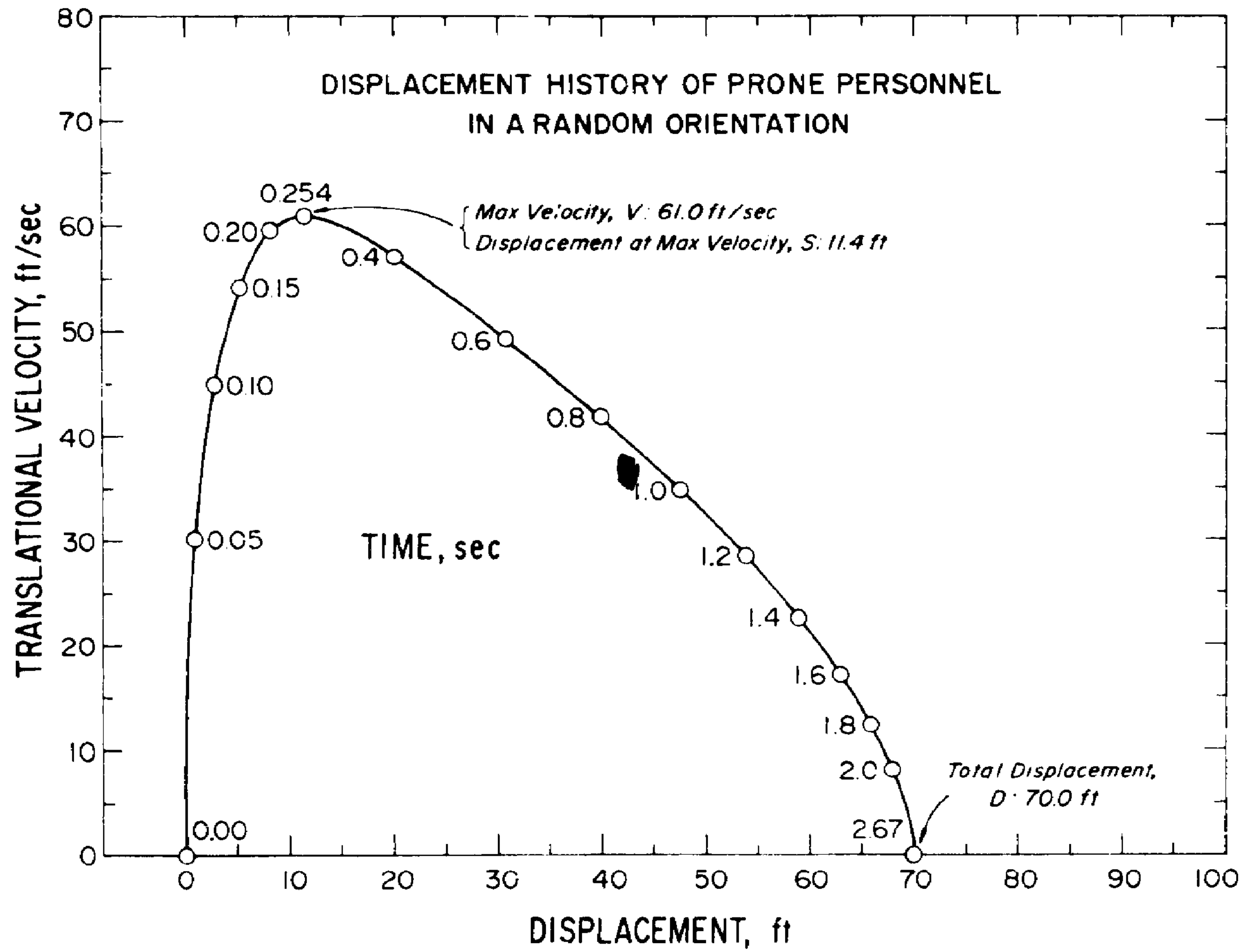

Figure A-1. Velocity-Displacement History of Prone Personnel in a Random Orientation Exposed to an Overpressure Level of 27.4 psi from a 10-KT Surface Burst. The data were taken from run number 10 in Table A-3.

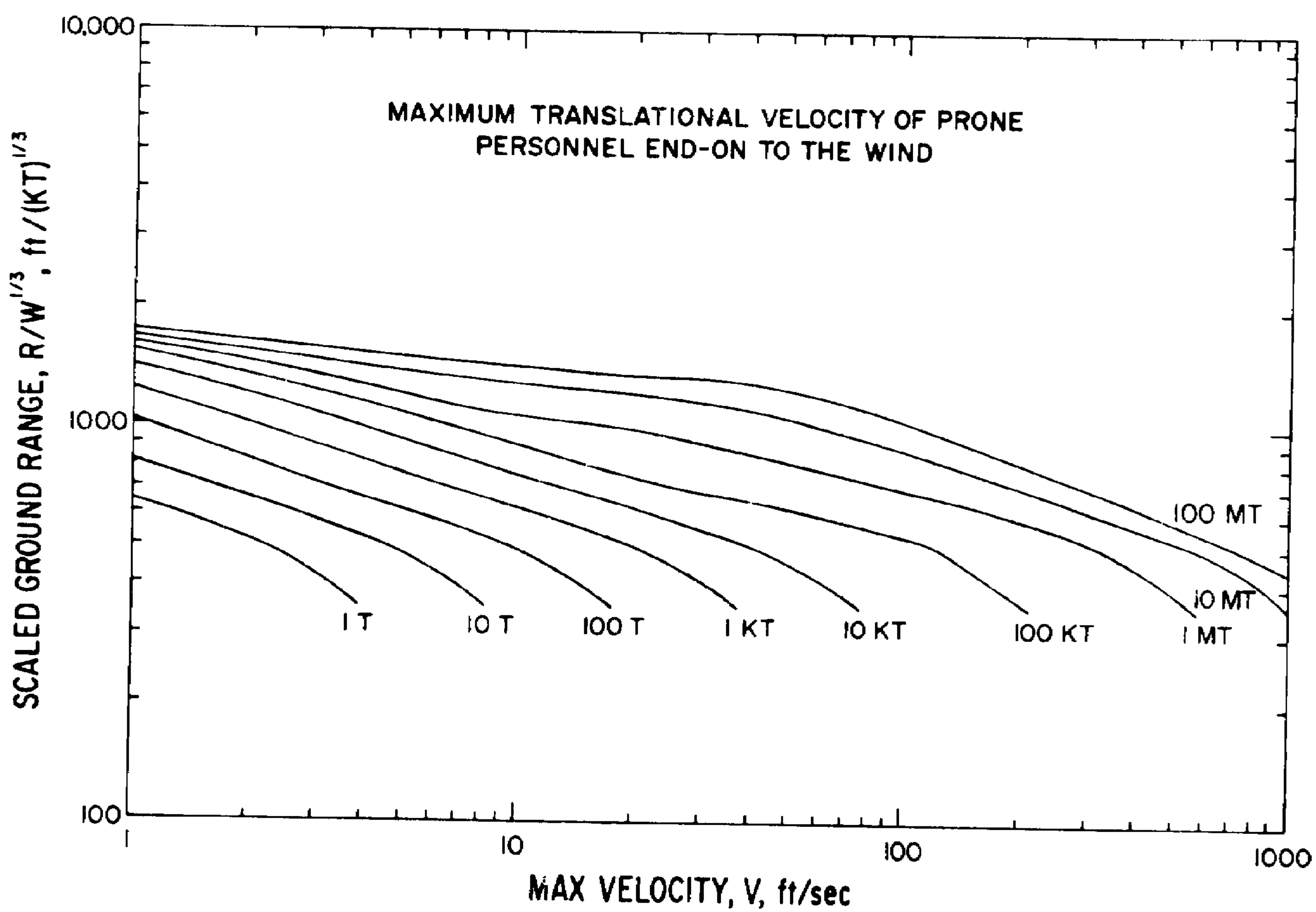

Figure A-2. Maximum Translational Velocity of Prone Personnel End-On to the Wind. Computed for a surface burst.

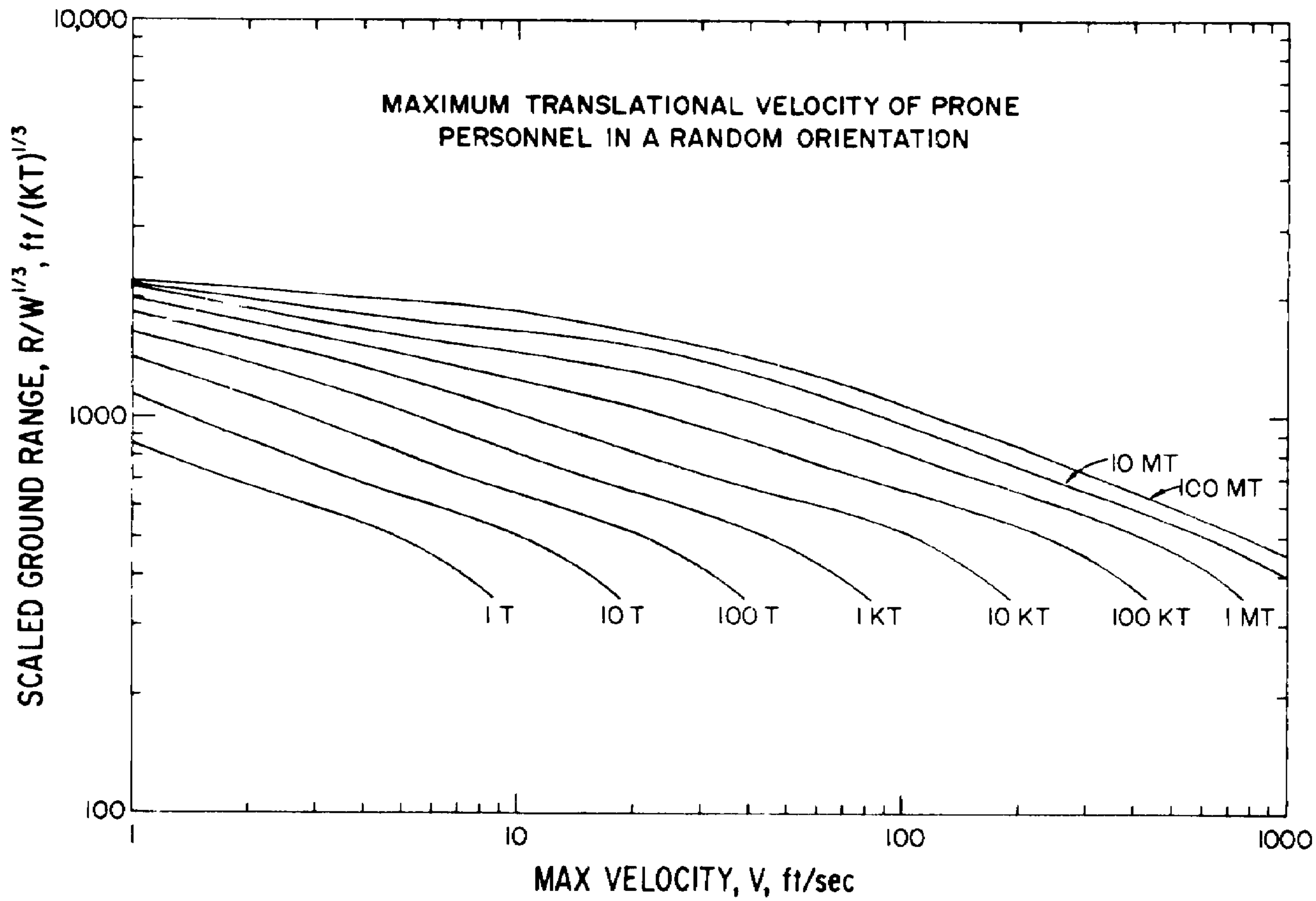

Figure A-3. Maximum Translational Velocity of Prone Personnel in a Random Orientation. Computed for a surface burst.

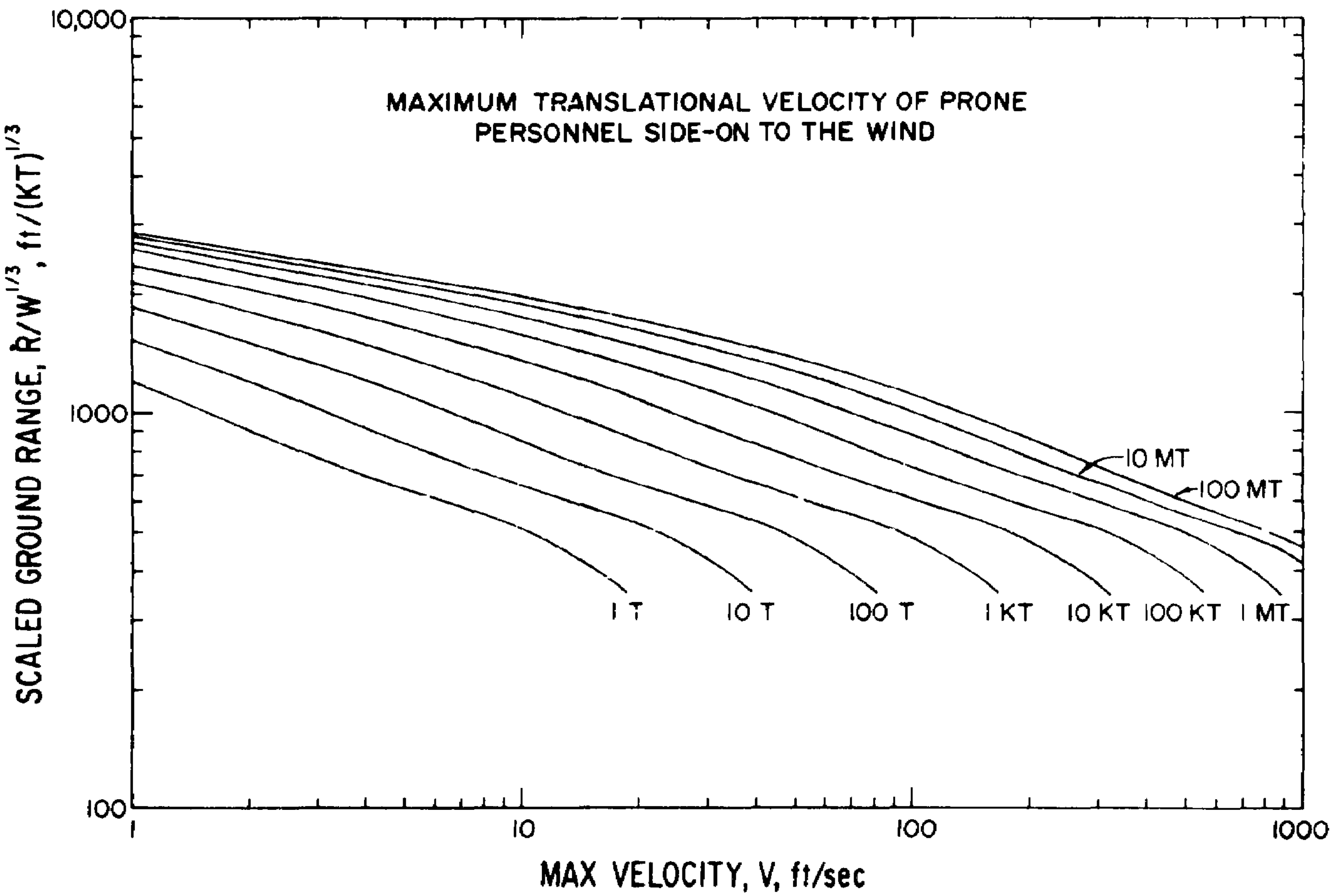

Figure A-4. Maximum Translational Velocity of Prone Personnel Side-On to the Wind. Computed for a surface burst.

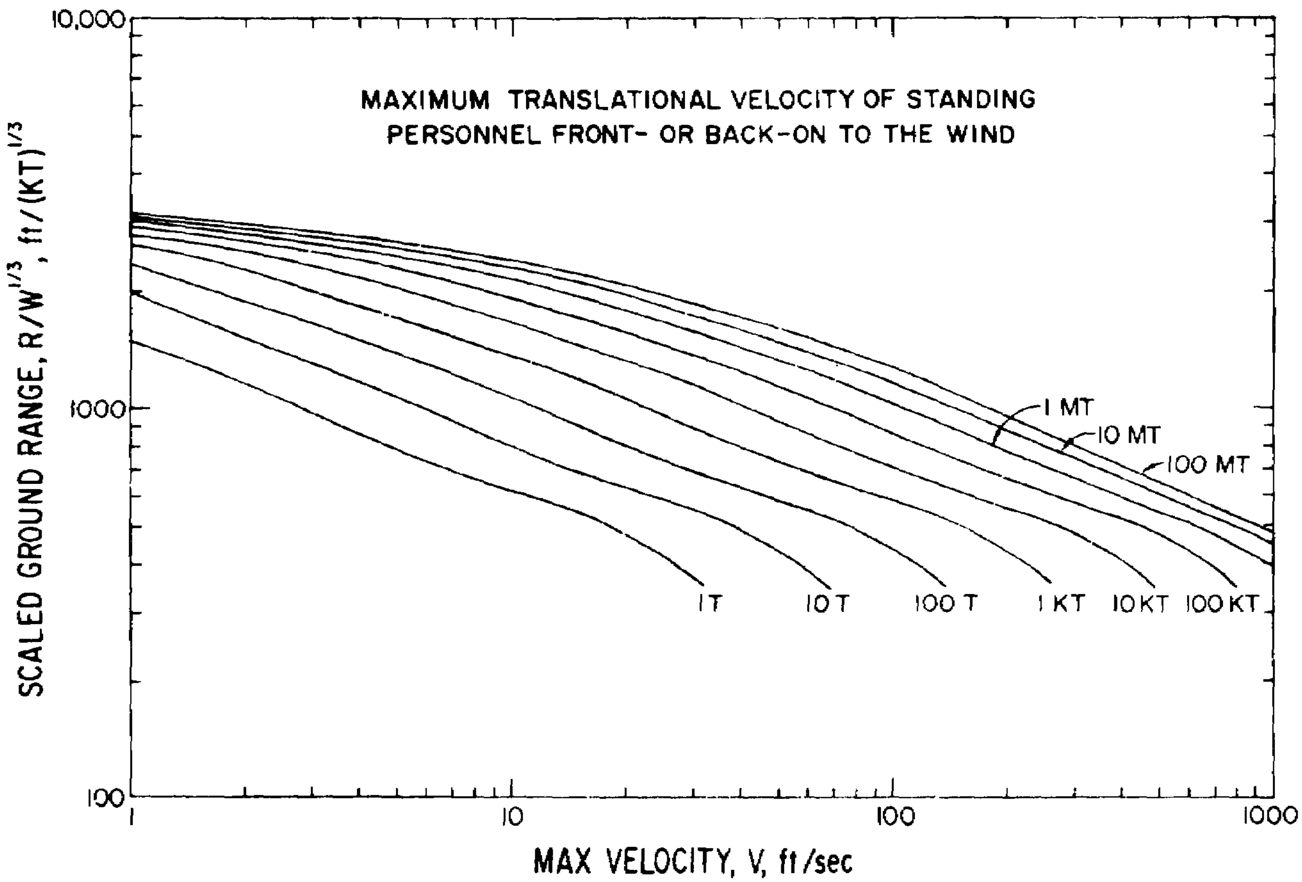

Figure A-5. Maximum Translational Velocity of Standing Personnel Front- or Back-On to the Wind. Computed for a surface burst.

TABLE A-1

BLAST-WAVE PARAMETERS USED TO CALCULATE DISPLACEMENT OF PERSONNEL

Run No.	$R/W^{1/3}$	$H/W^{1/3}$	P	$T_p/W^{1/3}$	$I_p/W^{1/3}$	Q	$T_q/W^{1/3}$	$I_q/W^{1/3}$
1	2600	0	1.98	.450	.411	.0934	.524	.0136
2	2200	0	2.56	.403	.469	.155	.477	.0199
3	1900	0	3.25	.365	.528	.249	.438	.0285
4	1600	0	4.34	.326	.600	.440	.402	.0437
5	1300	0	6.32	.284	.704	.913	.367	.0725
6	1100	0	8.32	.253	.800	1.51	.345	.106
7	950	0	11.0	.229	.880	2.50	.330	.147
8	850	0	13.7	.213	.940	3.71	.324	.184
9	700	0	20.0	.185	1.05	7.70	.314	.301
10	600	0	27.4	.165	1.15	14.0	.312	.474
11	500	0	40.5	.142	1.32	34.0	.314	.795
12	400	0	69.0	.115	1.64	107	.299	1.15
13	350	0	97.0	.100	1.99	143	.263	1.36
14	3000	948	3.14	.349	.371	.232	.421	.0173
15	2600	934	3.93	.328	.420	.362	.403	.0273
16	2200	913	5.19	.306	.485	.622	.387	.0432
17	1900	888	6.60	.290	.550	.958	.380	.0590
18	1600	850	8.62	.273	.635	1.44	.374	.0787
19	1300	795	11.9	.256	.767	2.32	.376	.114
20	1100	744	15.0	.242	.883	3.77	.377	.164
21	950	707	18.0	.228	.962	5.75	.374	.228
22	850	681	20.4	.215	.995	7.95	.367	.309
23	770	660	22.7	.204	1.01	10.7	.360	.401
24	700	636	25.4	.191	1.04	14.5	.351	.475
25	600	590	30.1	.167	1.12	20.4	.327	.537
26	500	529	39.5	.137	1.30	26.5	.299	.581
27	400	448	59.9	.104	1.70	38.6	.264	.644
28	950	320	15.0	.210	.893	4.31	.327	.203
29	850	320	17.5	.190	.935	6.72	.309	.279
30	770	311	20.3	.173	1.00	10.7	.295	.428
31	700	296	23.5	.158	1.09	19.6	.284	.600
32	600	276	30.9	.134	1.28	58.5	.265	.936
33	500	244	44.7	.109	1.58	127	.250	1.21
34	400	209	74.7	.0904	2.10	195	.237	1.49

H. Height of Burst, ft
I_p Impulse of Positive Overpressure, psi·sec
I_q Impulse of Positive Dynamic Pressure, psi·sec
P Max Overpressure, psi
Q Max Dynamic Pressure, psi
R Ground Range, ft
T_p Duration of Positive Overpressure, sec
T_q Duration of Positive Dynamic Pressure, sec
W Nuclear Yield, KT

Note
Runs 1-13 correspond to a surface burst.
Runs 14-27 correspond to an upper optimum height-of-burst.
Runs 28-34 correspond to a lower optimum height-of-burst.

TABLE A-2

DISPLACEMENT OF PRONE PERSONNEL END-ON TO THE WIND

Run No.	1 T V	1 T S	1 T D	10 T V	10 T S	10 T D	100 T V	100 T S	100 T D
1	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00
2	0.02	0.00	0.00	0.03	0.00	0.00	0.04	0.00	0.00
3	0.03	0.00	0.00	0.06	0.00	0.00	0.09	0.00	0.01
4	0.06	0.00	0.00	0.11	0.00	0.01	0.19	0.01	0.02
5	0.13	0.00	0.00	0.25	0.01	0.02	0.46	0.02	0.05
6	0.21	0.00	0.01	0.42	0.01	0.03	0.81	0.03	0.10
7	0.32	0.00	0.02	0.65	0.01	0.05	1.28	0.05	0.18
8	0.43	0.00	0.02	0.87	0.02	0.08	1.74	0.07	0.27
9	0.76	0.01	0.05	1.57	0.03	0.19	3.21	0.12	0.67
10	1.28	0.01	0.12	2.63	0.05	0.40	5.44	0.21	1.58
11	2.18	0.02	0.27	4.60	0.08	0.92	9.65	0.32	3.18
12	3.26	0.02	0.48	6.94	0.07	1.71	14.7	0.31	5.90
13	3.89	0.02	0.65	8.30	0.08	2.26	17.6	0.35	7.81
14	0.02	0.00	0.00	0.03	0.00	0.00	0.06	0.00	0.00
15	0.04	0.00	0.00	0.07	0.00	0.00	0.11	0.00	0.01
16	0.07	0.00	0.00	0.13	0.00	0.01	0.23	0.01	0.02
17	0.11	0.00	0.00	0.21	0.00	0.01	0.38	0.01	0.04
18	0.16	0.00	0.01	0.31	0.01	0.02	0.60	0.02	0.06
19	0.25	0.00	0.01	0.50	0.01	0.04	0.94	0.03	0.12
20	0.38	0.00	0.02	0.78	0.01	0.07	1.57	0.06	0.23
21	0.56	0.01	0.03	1.15	0.02	0.12	2.34	0.09	0.40
22	0.78	0.01	0.06	1.82	0.03	0.19	3.31	0.11	0.67
23	1.04	0.01	0.09	2.16	0.04	0.30	4.44	0.18	1.01
24	1.25	0.01	0.12	2.62	0.05	0.40	5.43	0.21	1.37
25	1.44	0.01	0.14	3.03	0.05	0.48	6.33	0.21	1.67
26	1.58	0.01	0.16	3.34	0.05	0.55	7.41	0.21	1.92
27	1.79	0.01	0.19	3.80	0.05	0.67	7.99	0.20	2.29
28	0.48	0.01	0.03	0.98	0.02	0.10	1.86	0.08	0.32
29	0.69	0.01	0.05	1.43	0.03	0.16	2.91	0.11	0.55
30	1.11	0.01	0.10	2.30	0.05	0.33	4.74	0.10	1.14
31	1.62	0.02	0.17	3.40	0.07	0.59	7.08	0.27	2.03
32	2.63	0.02	0.35	5.59	0.07	1.23	11.8	0.31	1.23
33	3.44	0.02	0.54	7.35	0.07	1.86	15.6	[illegible]	[illegible]
34	4.28	0.02	0.70	9.15	0.08	2.63	19.4	[illegible]	[illegible]

Run No.	1 KT V	1 KT S	1 KT D	10 KT V	10 KT S	10 KT D	100 KT V	100 KT S	100 KT D
1	0.02	0.00	0.00	0.03	0.00	0.01	0.03	0.00	0.01
2	0.06	0.00	0.01	0.08	0.01	0.02	0.10	0.01	0.04
3	0.14	0.01	0.02	0.20	0.02	0.05	0.27	0.01	0.11
4	0.32	0.02	0.05	0.50	0.05	0.13	0.74	0.12	0.36
5	0.83	0.06	0.18	1.42	0.18	0.47	2.31	0.36	1.34
6	1.50	0.12	0.33	2.70	0.38	1.04	4.63	1.15	3.10
7	2.46	0.19	0.60	4.38	0.68	1.95	8.22	2.15	6.13
8	3.41	0.26	0.91	6.52	0.92	2.97	12.1	3.16	9.83
9	6.47	0.48	2.14	12.7	1.80	7.10	26.1	12.8	30.2
10	11.1	0.84	4.67	22.3	3.27	15.6	61.2	22.8	85.3
11	20.0	1.30	10.8	40.9	5.38	38.8	123	14.7	212
12	31.0	1.30	20.1	64.2	5.47	68.7	176	31.7	314
13	17.1	1.16	26.6	77.2	8.32	88.4	215	35.1	415
14	0.09	0.00	0.01	0.13	0.01	0.02	0.18	0.02	0.05
15	0.19	0.01	0.02	0.29	0.02	0.04	0.43	0.05	0.15
16	0.41	0.02	0.06	0.69	0.06	0.17	1.09	0.17	0.47
17	0.70	0.04	0.11	1.23	0.13	0.35	2.05	0.37	1.00
18	1.12	0.07	0.20	2.02	0.22	0.64	3.52	0.69	1.91
19	1.80	0.12	0.40	3.55	0.43	1.36	6.40	1.40	4.04
20	3.09	0.21	0.76	5.94	0.76	2.51	11.0	2.00	8.36
21	4.68	0.33	1.35	9.15	1.22	4.47	17.4	4.48	16.2
22	6.67	0.50	2.25	13.7	1.88	7.47	27.7	13.1	32.7
23	9.00	0.70	1.48	17.9	2.67	11.8	45.8	18.9	59.5
24	11.1	0.82	4.63	22.3	3.18	15.5	80.1	22.1	82.6
25	13.0	0.85	5.89	26.4	3.37	19.1	70.3	22.5	97.9
26	14.5	0.85	6.54	29.8	3.40	21.8	76.8	22.0	107
27	16.7	0.87	7.84	34.2	3.33	26.2	84.6	20.6	118
28	1.91	0.29	1.08	7.53	1.07	[illegible]	14.0	3.74	12.2
29	5.85	0.44	1.87	11.47	1.65	6.20	22.3	7.72	25.4
30	9.61	0.75	3.85	19.1	3.00	12.3	52.0	21.3	70.5
31	14.7	1.08	6.88	29.4	4.30	23.2	87.4	28.3	136
32	24.7	1.27	14.4	51.0	5.77	38.5	144	31.7	248
33	32.9	1.25	21.9	68.3	5.36	72.6	181	29.3	323
34	41.0	1.41	31.0	85.4	6.01	133	228	32.3	450

Run No.	1 MT V	1 MT S	1 MT D	10 MT V	10 MT S	10 MT D	100 MT V	100 MT S	100 MT D
1	0.03	0.00	0.07	0.04	0.00	0.06	0.04	0.00	0.12
2	0.12	0.02	0.08	0.13	0.02	0.19	0.14	0.03	0.40
3	0.34	0.07	0.26	0.41	0.11	0.58	0.46	0.17	1.28
4	1.04	0.27	0.96	1.35	0.53	2.00	1.68	0.84	4.88
5	3.56	1.27	3.59	9.04	16.1	26.5	40.8	66.1	198
6	7.58	3.30	11.0	42.0	47.6	122	81.1	128	424
7	24.9	20.3	43.1	77.9	[illegible]	238	131	196	694
8	47.2	29.2	76.2	111	108	343	178	249	927
9	89.8	57.0	207	207	180	703	307	390	1840
10	184	47.8	460	336	277	1300	457	563	2670
11	390	141	902	570	301	2300	766	758	4600
12	487	113	1180	880	377	2850	1220	766	6070
13	578	146	1410	1020	405	3250	1380	807	6780
14	0.24	0.03	0.12	0.30	0.05	0.26	0.35	0.09	0.58
15	0.60	0.11	0.37	0.70	0.22	0.85	0.98	0.39	1.90
16	1.64	0.41	1.21	2.31	0.82	2.96	3.06	1.64	10.0
17	3.25	0.97	2.72	4.87	2.39	8.17	32.9	47.9	132
18	5.80	1.98	5.66	23.0	25.2	55.4	62.1	86.2	264
19	11.1	4.05	18.9	56.1	52.9	148	108	147	495
20	34.6	23.2	57.0	100	89.4	288	170	220	815
21	65.2	38.1	120	154	133	479	241	307	1210
22	104	59.4	219	215	188	738	317	405	1710
23	148	82.6	350	281	242	1050	398	505	2270
24	183	95.3	454	311	274	1320	478	569	2710
25	213	97.3	526	400	284	1520	564	595	3100
26	233	95.7	569	441	281	1620	623	591	3370
27	258	89.4	615	487	268	1720	716	561	3730
28	52.7	[illegible]	[illegible]	128	120	404	261	178	1060
29	89.3	52.6	181	189	170	638	283	372	1520
30	180	92.7	394	297	263	1140	409	535	2420
31	241	122	651	426	333	1740	587	667	3440
32	400	173	1010	727	375	2540	1010	782	5480
33	511	124	1160	851	360	2770	1360	759	6120
34	620	132	1410	1120	371	3090	1580	754	6660

V Max Velocity, ft/sec
S Displacement at Max Velocity, ft
D Total Displacement, ft

TABLE A-3

DISPLACEMENT OF PRONE PERSONNEL IN A RANDOM ORIENTATION

Run No	1 T			10 T			100 T			1 KT			10 KT		
	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D
1	0.03	0.00	0.00	0.05	0.00	0.00	0.08	0.00	0.01	0.11	0.01	0.02	0.16	0.01	0.04
2	0.06	0.00	0.00	0.10	0.00	0.00	0.17	0.00	0.02	0.27	0.02	0.05	0.40	0.04	0.12
3	0.10	0.00	[illegible]	0.18	0.00	0.01	0.32	0.01	0.04	0.54	0.04	0.10	0.86	0.11	0.29
4	0.16	0.00	0.01	0.34	0.01	0.02	0.82	0.03	0.08	1.[illegible]	0.09	0.25	1.86	0.28	0.75
5	0.34	0.00	0.12	0.88	0.02	0.06	1.31	0.07	0.21	2.17	0.23	0.67	4.48	0.77	2.16
6	0.54	0.01	[illegible]	1.09	0.03	0.12	2.16	0.11	[illegible]	1.17	0.41	1.32	7.86	1.48	[illegible]
7	0.79	0.01	[illegible]	1.62	0.04	0.21	3.26	0.16	0.70	6.43	[illegible]	[illegible]	12.8	2.48	8.13
8	1.02	0.01	0.09	2.11	0.05	0.30	4.30	0.20	1.02	8.61	0.79	1.43	17.4	3.38	12.3
9	1.77	0.02	0.20	3.69	0.08	0.69	7.62	0.34	2.34	15.6	1.08	7.93	33.9	6.89	30.4
10	2.89	0.01	0.12	6.08	0.14	1.48	12.6	0.57	[illegible]	26.2	2.08	17.2	62.0	11.4	70.0
11	4.92	0.05	0.98	10.4	0.19	3.18	21.9	0.81	11.5	[illegible]	3.60	39.7	110	16.2	161
12	7.29	0.04	1.80	15.5	0.33	6.22	12.8	0.76	21.2	69.2	[illegible]	71.6	160	14.8	266
13	9.66	0.05	2.38	19.5	0.22	8.24	39.1	0.85	28.1	82.7	3.74	94.8	192	16.4	352
14	0.06	0.00	0.00	0.11	0.00	0.00	0.18	0.01	0.02	0.32	0.02	0.05	0.53	0.05	0.13
15	0.10	0.00	0.00	0.27	0.00	0.01	0.36	0.01	0.04	0.64	0.04	0.11	1.09	0.12	0.33
16	0.19	0.00	0.01	0.47	0.01	0.05	0.70	0.03	0.08	1.29	0.09	0.27	2.29	0.30	0.84
17	0.28	0.00	0.01	0.55	0.01	0.04	1.08	0.04	0.15	2.05	0.16	0.48	3.77	0.53	1.55
18	0.40	0.00	0.02	0.80	0.02	0.07	1.39	0.07	0.25	3.08	0.24	0.78	5.82	0.85	2.67
19	0.61	0.01	0.04	1.25	0.03	0.14	2.51	0.11	0.47	4.97	0.41	1.56	8.64	1.52	5.24
20	0.92	0.01	0.07	1.90	0.04	0.25	3.87	0.17	0.86	7.77	0.64	2.89	15.5	2.63	10.1
21	1.32	0.01	0.11	2.74	0.06	0.44	5.54	0.25	1.49	11.4	0.87	5.02	23.7	4.48	18.4
22	1.82	0.02	0.21	3.80	0.09	0.72	7.85	0.36	2.46	16.0	1.34	8.23	35.2	7.20	32.2
23	2.39	0.03	0.32	5.02	0.12	1.11	10.4	0.48	3.77	21.4	2.30	12.8	49.1	9.78	51.7
24	2.87	0.01	0.42	6.[illegible]	0.13	1.46	12.6	0.55	4.88	26.1	2.31	17.0	60.5	11.1	68.7
25	3.39	0.03	0.52	6.94	0.15	1.77	14.5	0.55	6.09	30.2	2.34	20.8	69.7	11.1	82.4
26	3.59	0.03	0.59	7.61	0.13	2.04	16.0	0.54	6.88	33.3	2.29	23.7	78.1	10.8	92.1
27	4.04	0.03	0.70	8.58	0.12	2.43	18.1	0.51	8.31	37.7	2.16	28.2	84.9	10.1	108
28	1.15	0.01	0.10	2.37	0.06	0.36	4.85	0.23	1.21	9.75	0.89	4.08	20.0	3.99	14.9
29	1.62	0.02	0.18	3.38	0.08	0.80	8.97	0.32	2.05	14.2	1.28	8.95	30.6	6.45	26.5
30	2.58	0.03	0.96	5.37	0.13	1.23	11.1	0.54	4.18	22.9	2.25	14.3	53.5	10.9	58.8
31	3.70	0.04	0.63	7.79	0.17	2.17	16.3	0.70	7.38	34.0	3.04	25.4	80.9	14.2	105
32	5.91	0.04	1.30	12.6	0.18	4.48	26.5	0.76	15.3	55.8	3.33	52.1	131	14.9	202
33	7.69	0.04	1.96	16.4	0.17	6.78	34.7	0.73	23.1	73.1	3.15	77.8	168	13.8	285
34	9.55	0.04	2.78	20.4	0.19	9.58	43.1	0.85	32.8	90.8	3.49	110	208	15.1	401

Run No	100 KT			1 MT			10 MT			100 MT		
	V	S	D	V	S	D	V	S	D	V	S	D
1	[illegible]	0.07	0.09	0.24	0.05	0.21	0.28	0.07	0.47	0.30	0.10	1.05
2	[illegible]	0.10	0.29	0.72	0.15	0.68	0.88	0.35	1.62	1.04	0.61	5.96
3	1.[illegible]	0.28	0.77	1.84	0.68	2.02	2.65	6.09	9.18	8.43	13.1	37.6
4	[illegible]	0.80	2.20	4.97	3.71	9.31	14.1	15.2	38.8	23.0	33.8	111
5	8.19	[illegible]	[illegible]	21.5	14.9	37.6	39.6	40.9	119	58.1	87.9	301
6	17.7	7.95	19.1	[illegible]	27.0	70.[illegible]	88.1	71.7	221	97.5	148	531
7	[illegible]	12.2	36.4	65.2	11.1	131	107	106	353	118	215	810
8	43.1	15.6	54.2	88.7	52.9	185	144	134	476	198	270	1060
9	82.2	26.9	127	159	85.9	386	248	210	880	330	412	1800
10	111	43.9	267	257	131	719	382	310	1550	490	585	2880
11	246	61.6	542	436	182	1260	634	419	2670	788	782	4870
12	366	57.6	788	571	177	1640	999	418	3280	1280	792	6480
13	424	82.2	999	781	191	1910	1140	446	3700	1450	823	7210
14	0.81	0.12	0.34	1.19	0.28	0.85	1.63	0.60	2.19	2.64	6.46	11.1
15	1.77	0.34	0.92	2.72	0.89	2.82	5.44	6.97	12.9	11.2	17.0	47.8
16	3.92	0.93	2.17	7.30	6.03	11.08	19.0	17.3	45.1	31.9	41.4	130
17	6.80	1.84	5.27	16.7	10.3	24.7	34.4	30.6	86.7	53.9	71.2	232
18	11.2	3.71	10.3	28.7	16.5	45.1	54.4	47.8	145	82.3	109	388
19	21.7	8.01	22.[illegible]	50.2	28.1	88.0	88.6	78.0	256	128	169	610
20	47.7	12.8	44.1	80.9	43.9	158	136	117	421	181	245	945
21	58.7	19.1	79.2	119	63.5	261	193	162	641	264	329	1380
22	85.1	27.9	[illegible]	164	88.9	405	256	218	[illegible]	340	427	1870
23	115	37.6	204	214	110	577	324	276	1280	422	528	2440
24	[illegible]	42.7	263	259	131	719	390	310	1580	505	593	2900
25	162	43.2	311	303	134	828	458	321	1810	595	620	3330
26	178	42.3	346	334	132	896	507	318	1930	658	616	3630
27	199	39.5	392	377	124	979	573	301	2040	756	505	4010
28	49.6	17.6	65.6	101	58.5	217	183	149	547	222	299	1190
29	74.8	25.2	112	148	81.1	347	229	260	815	305	394	1680
30	123	42.0	228	225	127	625	335	298	1360	411	556	2590
31	182	53.8	381	327	160	959	481	389	2030	615	691	3670
32	208	57.4	659	547	175	1430	823	418	2930	1060	812	5880
33	388	53.7	836	720	167	1820	1100	404	3230	1440	792	6600
34	471	57.4	1110	881	174	1900	1240	409	3570	1870	776	7160

V Max Velocity, ft/sec
S Displacement at Max Velocity, ft
D Total Displacement, ft

TABLE A-4

DISPLACEMENT OF PRONE PERSONNEL SIDE-ON TO THE WIND

Run No.	1 T			10 T			100 T		
	V	S	D	V	S	D	V	S	D
1	0.09	0.00	0.00	0.16	0.00	0.01	0.28	0.01	0.03
2	0.16	0.00	0.01	0.30	0.01	0.02	0.53	0.03	0.07
3	0.28	0.00	0.01	0.50	0.01	0.04	0.93	0.05	0.14
4	0.44	0.01	0.03	0.87	0.03	0.09	1.67	0.10	0.31
5	0.82	0.01	0.07	1.65	0.05	0.22	3.27	0.20	0.75
6	1.25	0.02	0.12	2.56	0.08	0.42	5.16	0.31	1.41
7	1.79	0.03	0.21	3.71	0.11	0.72	7.54	0.43	2.42
8	2.29	0.03	0.30	4.77	0.13	1.04	9.76	0.53	3.50
9	3.88	0.05	0.69	8.14	0.21	2.36	16.8	0.94	7.90
10	6.30	0.08	1.48	[illegible]	0.33	5.03	27.3	1.34	16.8
11	10.6	0.11	3.36	22.4	0.46	11.4	44.4	1.85	36.0
12	15.6	0.10	[illegible]	33.1	0.41	21.1	69.1	1.68	69.9
13	18.4	0.11	8.17	38.4	0.45	27.8	88.1	1.85	82.2
14	0.15	0.00	0.01	0.29	0.01	0.02	0.55	0.02	0.08
15	0.26	0.00	0.01	0.52	0.01	0.04	1.00	0.05	0.14
16	0.46	0.01	0.03	0.92	0.02	0.09	1.80	0.09	0.31
17	0.66	0.01	0.05	1.34	0.03	0.18	2.67	0.13	0.53
18	0.92	0.01	0.08	1.88	0.05	0.28	3.80	0.19	0.87
19	1.39	0.02	0.16	2.87	0.07	0.48	5.84	0.29	1.62
20	2.06	0.03	0.26	4.28	0.11	0.88	8.78	0.43	2.85
21	2.92	0.04	0.44	6.10	0.15	1.51	12.6	0.62	5.06
22	4.00	0.05	0.72	8.39	0.22	2.48	17.3	0.88	8.26
23	5.24	0.07	1.11	11.0	0.29	3.79	22.7	1.17	12.6
24	6.26	0.08	1.38	13.2	0.32	4.99	27.2	1.31	16.6
25	7.13	0.08	1.58	15.0	0.34	5.09	31.2	1.30	20.3
26	7.77	0.07	2.03	16.4	0.31	6.85	34.2	1.28	23.3
27	8.70	0.07	2.42	18.4	0.28	8.28	38.4	1.17	27.6
28	2.56	0.03	0.36	5.33	0.14	1.23	10.9	0.58	4.14
29	3.58	0.05	0.61	7.40	0.20	2.08	15.4	0.79	6.95
30	5.60	0.08	1.23	11.8	0.33	4.20	24.2	1.28	14.0
31	8.02	0.10	2.16	16.9	0.40	7.38	34.9	1.63	24.4
32	12.7	0.10	4.45	26.9	0.42	15.2	56.0	1.70	50.4
33	16.5	0.09	6.73	35.0	0.39	23.0	73.0	1.59	76.1
34	20.4	0.10	9.55	43.3	0.42	32.4	80.2	1.73	107

Run No.	1 KT			10 KT			100 KT		
	V	S	D	V	S	D	V	S	D
1	0.45	0.04	0.09	0.68	0.08	0.25	0.96	0.22	0.62
2	0.91	0.08	0.22	1.46	0.24	0.62	2.27	0.62	1.66
3	1.67	0.17	0.45	2.85	0.51	1.35	4.59	1.43	1.79
4	3.09	0.35	0.89	5.48	1.11	3.04	9.18	3.24	8.81
5	6.29	0.72	2.41	11.6	2.44	7.58	20.2	7.54	22.2
6	10.1	1.18	4.59	18.9	4.01	14.2	33.2	12.7	41.0
7	14.8	1.64	7.88	28.2	5.81	24.2	50.1	18.4	68.3
8	19.4	2.01	11.4	37.1	7.16	34.8	66.3	22.8	98.9
9	33.7	3.26	25.4	64.5	11.6	76.5	115	18.6	203
10	54.8	5.16	53.2	104	18.2	154	183	56.7	387
11	93.4	7.11	119	178	24.9	328	310	76.7	731
12	140	6.53	216	270	23.3	560	478	71.3	1070
13	188	7.17	281	319	25.5	723	560	79.6	1310
14	1.00	0.07	0.20	1.72	0.22	0.59	2.85	0.65	1.89
15	1.85	0.16	0.45	3.31	0.50	1.40	5.82	1.49	4.12
16	3.43	0.32	1.02	6.31	1.08	3.20	11.0	3.30	9.52
17	5.18	0.48	1.74	9.72	1.68	5.51	17.3	5.34	16.4
18	7.48	0.70	2.75	14.2	2.47	9.01	25.8	7.97	26.7
19	11.4	1.11	5.31	22.2	3.65	16.8	40.2	12.8	48.1
20	17.6	1.67	0.83	33.8	5.95	29.7	61.1	19.2	84.5
21	25.2	2.38	16.4	48.6	8.51	49.9	87.4	27.2	137
22	34.7	3.38	26.6	66.5	12.0	79.5	116	37.8	211
23	45.5	4.48	40.2	88.7	15.8	118	153	47.3	303
24	54.7	5.02	52.8	104	17.7	153	184	55.0	384
25	62.9	5.01	64.5	121	17.8	186	214	55.8	455
26	68.1	4.88	73.8	133	17.4	212	237	55.0	509
27	78.0	4.56	88.0	151	16.4	252	269	51.6	588
28	21.8	2.23	13.6	41.6	7.97	41.0	74.5	25.4	113
29	30.9	3.06	22.4	58.2	10.9	67.4	105	34.6	183
30	46.4	4.96	44.4	81.6	17.5	130	160	54.0	331
31	69.9	8.27	77.2	133	22.0	221	232	67.6	532
32	113	5.56	158	218	23.2	430	386	72.6	897
33	148	6.14	238	287	21.9	612	531	69.0	1120
34	183	6.86	330	351	23.5	852	618	73.0	1450

Run No.	1 MT			10 MT			100 MT		
	V	S	D	V	S	D	V	S	D
1	1.28	0.44	1.47	1.59	0.81	3.33	1.86	1.33	7.37
2	3.23	1.42	4.12	4.28	2.89	9.68	5.27	5.21	21.8
3	6.88	3.56	9.85	9.55	7.80	23.8	12.2	14.9	54.4
4	14.3	8.39	23.6	20.5	18.9	57.8	27.1	37.1	133
5	32.4	20.4	59.8	47.4	47.2	146	63.0	92.8	330
6	53.5	34.6	108	78.0	79.5	256	103	154	566
7	81.1	50.3	173	118	115	398	155	222	853
8	108	62.8	240	157	144	530	205	276	1100
9	184	98.7	472	283	222	948	339	420	1880
10	288	148	835	400	324	1650	500	594	2930
11	482	200	1420	860	434	2760	812	791	4990
12	754	188	1840	1050	434	3470	1310	795	6660
13	873	211	2120	1200	480	3900	1480	833	7390
14	4.42	1.58	4.48	6.42	3.63	11.1	8.88	7.42	26.6
15	8.98	4.03	11.2	13.3	9.58	28.4	18.2	20.0	66.4
16	18.0	9.13	28.1	27.0	22.1	66.4	37.2	46.0	155
17	28.8	15.1	45.4	43.4	36.9	114	59.9	77.0	262
18	42.7	22.8	72.8	64.8	55.7	179	88.9	115	404
19	66.9	36.2	126	88.6	78.0	256	138	177	652
20	101	53.8	212	150	128	475	199	253	994
21	143	75.1	333	209	174	709	273	338	1420
22	190	102	494	272	230	1010	349	436	1930
23	242	130	681	342	289	1370	431	537	2510
24	297	146	839	410	324	1680	515	603	2880
25	342	150	967	482	336	1930	606	630	3430
26	387	148	1040	534	333	2080	672	827	3740
27	430	140	1140	607	315	2180	773	812	4120
28	121	69.5	178	176	180	804	229	307	1240
29	170	93.6	428	244	212	888	314	403	1740
30	252	142	729	351	309	1450	450	564	2660
31	383	176	1290	503	383	2150	626	700	3710
32	612	194	1600	881	435	3100	1090	827	6020
33	816	188	1820	1160	423	3440	1480	802	6310
34	974	194	2110	1360	425	3790	1710	788	7380

V Max Velocity ft/sec
S Displacement at Max Velocity ft
D Total Displacement ft

TABLE A-5

DISPLACEMENT OF STANDING PERSONNEL FRONT- OR BACK-ON TO THE WIND

Run No.	1 T			10 T			100 T			1 KT			10 KT			100 KT			1 MT			10 MT			100 MT		
	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D	V	S	D
1	0.19	0.00	0.01	0.38	0.01	0.03	0.63	0.04	0.10	1.06	0.11	0.28	1.70	0.30	0.80	2.58	0.77	2.17	3.59	1.69	5.12	4.65	3.38	11.9	5.67	6.04	28.8
2	0.40	0.01	0.03	0.78	0.03	0.10	1.26	0.08	0.23	2.26	0.25	0.77	3.88	0.80	2.18	4.26	2.23	6.13	9.29	5.43	15.6	12.7	11.5	36.9	15.9	21.6	83.1
3	0.61	0.01	0.05	1.22	0.04	0.16	1.88	0.12	0.37	3.48	0.40	1.18	6.06	1.30	3.56	9.92	3.68	15.1	16.0	9.17	26.1	20.7	19.6	61.9	26.1	37.1	139
4	0.83	0.01	0.07	1.66	0.06	0.23	3.23	0.22	0.77	6.08	0.76	2.48	10.8	2.44	7.46	18.2	7.19	21.0	27.7	17.9	54.1	38.5	38.0	127	49.0	69.6	280
5	1.49	0.02	0.16	3.04	0.10	0.55	6.05	0.40	1.82	11.7	1.39	5.81	21.4	5.02	17.4	36.1	14.2	47.4	55.5	35.9	117	76.9	77.2	265	96.8	141	568
6	2.25	0.04	0.30	4.67	0.15	1.02	9.32	0.58	3.39	18.1	2.20	10.7	33.3	7.62	31.4	56.1	21.9	82.3	85.4	54.6	182	117	118	418	145	202	886
7	3.18	0.05	0.51	6.80	0.21	1.74	13.4	0.80	5.75	26.1	3.03	18.0	48.0	10.5	51.8	80.9	29.7	131	122	69.5	292	186	144	593	205	255	1200
8	4.05	0.06	0.74	8.42	0.25	2.52	17.1	0.99	8.29	33.8	3.69	25.8	62.1	12.2	73.3	105	36.2	182	159	89.1	395	218	183	768	265	319	1500
9	6.81	0.09	1.68	14.2	0.39	5.66	28.0	1.54	18.5	56.6	5.69	58.5	104	18.6	154	174	53.9	351	259	130	707	344	260	1330	415	448	2340
10	11.0	0.15	3.57	22.9	0.63	12.0	46.6	2.38	38.8	90.7	8.68	115	164	28.8	294	268	75.4	602	388	163	1120	500	358	2100	589	607	3520
11	18.4	0.20	8.12	38.4	0.81	27.2	78.2	3.18	86.7	152	11.5	248	274	38.9	559	442	102	952	630	238	1680	798	459	3180	927	768	5700
12	26.8	0.17	14.9	56.5	0.72	48.9	116	2.83	158	228	10.3	432	415	33.8	830	679	95.4	1180	981	226	1950	1260	412	3680	1480	741	7060
13	32.0	0.19	19.7	67.2	0.78	88.0	138	3.09	208	268	11.2	562	487	36.6	1040	787	102	1390	1120	238	2180	1420	460	4060	1650	759	7680
14	0.29	0.00	0.01	0.58	0.01	0.05	1.11	0.05	0.16	2.07	0.18	0.53	3.70	0.57	1.62	6.24	1.66	4.87	9.86	4.37	12.5	14.4	10.0	30.8	19.3	20.1	71.0
15	0.50	0.01	0.03	1.00	0.03	0.11	1.85	0.10	0.36	3.69	0.36	1.15	6.69	1.19	3.56	11.4	3.57	10.3	18.1	9.38	27.4	26.3	21.3	66.6	35.0	42.0	152
16	0.84	0.01	0.07	1.71	0.05	0.23	3.40	0.18	0.77	6.55	0.69	2.80	12.1	2.12	7.66	20.9	7.03	21.9	33.2	18.5	57.1	47.8	41.6	135	62.8	79.8	299
17	1.20	0.02	0.11	2.45	0.07	0.39	4.93	0.27	1.30	9.61	1.00	4.19	17.9	3.43	12.7	31.1	10.4	35.6	49.3	27.5	90.3	71.1	61.2	208	92.5	118	450
18	1.65	0.02	0.19	3.41	0.10	0.63	6.68	0.37	2.10	13.5	1.58	6.74	25.3	4.77	20.2	44.0	14.5	55.2	69.8	37.9	135	99.4	83.2	299	128	155	629
19	2.47	0.04	0.34	5.12	0.14	1.17	10.4	0.57	3.47	20.5	2.11	12.3	38.2	7.17	35.9	68.0	21.4	94.3	103	54.5	218	144	116	455	182	212	921
20	3.63	0.05	0.62	7.30	0.21	2.12	15.4	0.79	7.01	30.3	2.98	21.8	56.9	9.89	62.6	97.8	30.4	160	151	76.2	355	208	166	700	260	294	1360
21	5.12	0.07	1.07	10.7	0.28	3.63	21.9	1.12	11.8	43.1	4.19	16.9	80.0	13.9	103	136	40.4	248	206	102	529	280	210	1010	343	368	1840
22	7.08	0.10	1.80	14.8	0.40	6.05	30.1	1.57	19.7	59.0	5.86	59.7	109	18.6	161	180	54.6	362	267	132	739	354	272	1390	425	470	2450
23	8.34	0.14	2.80	19.5	0.56	9.37	39.6	2.19	30.2	77.1	7.83	90.0	140	25.5	232	229	72.4	493	333	168	966	433	331	1820	514	583	3110
24	10.8	0.14	3.54	22.6	0.56	11.9	46.4	2.29	38.4	90.8	8.45	116	165	26.8	289	273	73.9	589	398	174	1120	514	358	2140	608	598	3590
25	11.8	0.13	3.88	25.9	0.57	14.5	50.6	2.07	42.7	99.7	7.59	130	190	28.1	344	302	70.5	632	446	177	1160	600	371	2340	714	628	3940
26	13.5	0.13	4.92	28.2	0.55	16.6	57.8	2.19	53.4	114	8.08	159	209	26.5	388	348	75.3	723	484	149	1550	626	283	2400	781	621	4360
27	15.0	0.11	5.88	31.6	0.50	18.7	61.0	1.74	57.7	128	7.23	188	235	23.7	453	374	63.0	765	572	187	1830	744	330	2650	868	545	4490
28	4.50	0.07	0.88	9.58	0.27	2.88	19.1	1.08	9.78	37.5	4.07	30.4	69.3	13.6	65.7	117	38.7	210	177	97.4	451	238	200	647	293	348	1660
29	6.27	0.09	1.48	13.1	0.36	4.88	26.7	1.42	16.3	52.3	5.46	50.0	96.2	17.8	137	161	50.9	320	240	123	657	319	253	1430	348	446	2210
30	8.76	0.14	2.81	20.3	0.59	10.0	41.4	2.23	32.4	80.3	8.47	96.9	145	27.2	253	237	73.3	540	341	175	1030	440	345	1900	534	579	3240
31	13.8	0.18	5.23	29.0	0.72	17.5	59.1	2.84	58.2	115	10.3	165	206	31.3	409	336	88.2	788	480	206	1410	616	414	2650	730	722	4480
32	22.0	0.18	10.8	46.2	0.74	36.3	94.2	2.88	115	186	10.5	330	335	33.3	498	553	85.7	1070	807	228	1770	1040	444	3270	1250	796	6610
33	28.4	0.18	16.3	59.8	0.67	54.7	123	2.71	174	243	9.58	483	449	32.8	924	749	96.5	1260	1100	235	2070	1440	491	4280	1720	734	7740
34	35.1	0.18	22.8	73.6	0.76	76.4	151	2.64	240	295	9.81	638	535	31.8	1110	875	70.8	1380	1260	199	2060	1630	417	4400	1940	604	7900

V Max Velocity, ft/sec
S Displacement at Max Velocity, ft
D Total Displacement, ft

TABLE A-6

BIOLOGICAL CRITERIA

Probability of Serious Injury, Percent	Impact Velocity, ft/sec, for Normal Incidence Against a Nonyielding, Flat Surface	Maximum Velocity, ft/sec, for Decelerative Tumbling Over Open Terrain
1	6.5 (4.5-8.2)	28.8 (12.7-37.8)
2.5	7.5 (5.4-9.2)	32.9 (16.7-41.4)
5	8.4 (6.3-10.1)	36.8 (21.1-44.8)
50	15.4 (13.5-17.3)	66.4 (58.2-82.9)
95	28.4 (24.8-34.7)	120 (91.8-268)
	$y = -2.384+6.211 \log x$	$y = -6.705+6.423 \log x$

y is the probability of injury in probit units.
x is the velocity.
95% confidence limits for the velocities are given in parentheses.

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