DEPARTMENT OF DEFENSE
U.S. ATOMIC ENERGY COMMISSION

Project

DANNY BOY
NEVADA TEST SITE
5 MARCH 1962

Final Report

CLOSE IN AIR BLAST FROM A NUCLEAR DETONATION IN BASALT

L. J. Vortman
SANDIA CORPORATION

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POR-1810
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PROJECT 1.1b

CLOSE-IN AIR BLAST FROM A NUCLEAR DETONATION IN BASALT

L. J. VORTMAN

Sandia Corporation
Albuquerque, New Mexico

June 1962
ABSTRACT

Close-in air blast from the Danny Boy event resulted almost entirely from the ground-shock-induced air blast. Little pressure resulted from venting gases. Consequently, measured pressures were only one-third to one-fourth of those predicted. Ground-shock-induced pressures from the nuclear charge were found to attenuate less rapidly than those from chemical explosives.
ACKNOWLEDGEMENTS

The author wishes to thank Mr. D. P. LeFevre, Ballistic Research Laboratories, for making the blast measurements and reducing the data for Project Danny Boy and Mr. F. Shoemaker for coordinating the project in the field.
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CHAPTER 1
INTRODUCTION

1.1 OBJECTIVE

The objective of the air blast measurement program was to determine the overpressure-time-distance relationship at ground level along one blast line for the purpose of determining the extent of close-in blast suppression. This experiment extends blast observations from charges buried in basalt to 430 tons, a yield larger by a factor of 20 than yields of Project Buckboard. The new data permit some indication of the extent to which differences in close-in blast can be attributed to differences in the type of explosive used (nuclear or chemical explosive).

1.2 BACKGROUND

Close-in air blast along the ground surface has been measured on underground detonations from high explosives in Nevada Test Site desert alluvium using high-explosive charges of 256 (References 1, 2, and 3), 2,560 (Reference 1), 40,000 (References 1 and 4), and 1,000,000 (Reference 5) pounds. It has also been observed on a surface nuclear detonation (References 6 and 7) and on two relatively shallow nuclear detonations (References 6, 7, and 8) in the same medium. On Project Buckboard (Reference 9) blast overpressures were measured along the ground from three 40,000-pound detonations at three different burst depths in basalt. The Buckboard experiments led to the conclusion that no difference in the suppression of peak overpressure is attributable to the harder medium; that is, with high explosives, suppression of peak overpressure is essentially the same in alluvium and basalt.

A typical overpressure waveform from an underground high-explosive detonation shows a ground-shock-induced pressure pulse (often referred to as the "front porch") followed by the main portion of the blast wave
generated by the venting of the explosion gases (Figure 1.1a). The waveforms from Project Danny Boy (Figure 1.1b) are explained later.

1.3 INSTRUMENTATION

1.3.1 Gage Locations

Gages were located along an approximately SE radius at radial distances along the ground at 200, 265, 350, 470, 630, 840, 1120, 3100, and 8500 feet. Typical gage installations are shown in Figure 1.2. Figure 1.3 shows the completed gage installation with the cleared area immediately around the gage. This photograph was taken looking toward surface zero.

1.3.2 Gage Types

Measurements were made using Ballistic Research Laboratories self-recording pressure gages (Figure 1.4). In these gages, a battery-operated motor drives a turntable carrying either an aluminized glass disc or a stainless steel disc. A pressure sensitive diaphragm, connected directly to a scribe, permits the pressure record to be inscribed on the disc as the turntable rotates. The gage motor is started by a timing signal at -1 second. Standard pressure-time gages (PT's) were used at Stations 1 through 7, and very low pressure gages (VLP's) were used at Stations 6 through 9). Both types of gages were installed at Stations 6 and 7.
Figure 1.1 Typical Waveforms from Buried HE and Nuclear Detonation
Figure 1.2 Typical Cage Installation

Figure 1.3 Cleared Area Around Gage Installation
CHAPTER 2

TEST RESULTS

2.1 SUMMARY OF RESULTS

Table 2.1 summarizes the results of the pressure measurements. Because peak pressures only were obtained at Stations 5, 6B, 7B, and 8, records of pressure-time are not reproduced. Pressure records from the remaining seven gages are shown in Figures 2.1 through 2.4. Time in the figures is time from the arrival of the signal shown. The pressure wave illustrated is the first wave in all cases except at the 3100-foot station (Station 8), where the wave shown, as explained later, is from another source.

2.2 PEAK OVERPRESSURE

Figure 2.5 shows peak overpressures as a function of ground range. Also shown is the curve predicted before the shot for a slightly larger yield and a comparatively deeper burst depth; set ranges of the gages were based upon this curve. As indicated by the figure, all pressure records obtained were one-third to one-half of the set range.

2.3 POSITIVE PHASE

The positive-phase impulse of the pressure records is shown in Figure 2.6. The duration of the positive phase as a function of ground range is given in Figure 2.7. As is usual in pressure measurements, the scatter in positive-phase duration data is considerably greater than that in either peak overpressure or positive-phase impulse.

2.4 ARRIVAL TIMES

Arrival times are plotted in Figure 2.8.
### TABLE 2.1 SUMMARY OF RESULTS

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Figure 2.5 Maximum Overpressure versus Ground Range
Figure 2.6 Positive Impulse versus Ground Range
Figure 2.7 Positive Phase Duration versus Ground Range
Figure 2.8 Arrival Time versus Ground Range
CHAPTER 3

DISCUSSION

3.1 WAVE SHAPE

The most unusual thing about the waveforms from the Danny Boy detonation is that upon first examination they showed only a single pressure pulse, that shown in Figures 2.1 to 2.4. This is in contrast to waveforms from high-explosive detonations in basalt and desert alluvium (Buckboard Shot 12 and Scooter) at an only slightly greater burst depth; these have shown two distinct pulses, the second one dominant.

Initial plotting of the arrival times of these waves (Figure 2.8) only added to the confusion, since they fell between those of the first and second waves of Scooter scaled to the Danny Boy yield. In addition, the arrival time at 3100 feet (Station 8) was far too late to be directly associated with the waves whose arrivals were noted from the closer stations.

Careful scrutiny revealed barely discernable signals following the main signals at the four closest stations (Stations 1, 2, 3, and 4). Plots show (Figure 2.8) that these waves follow the preceding ones by about the same interval that the Scooter waves followed the first. This suggested that the main signals were ground-shock-induced waves, and that the very weak secondary waves were caused by venting gases. These latter waves were too much attenuated to be observed at Stations 6, 7, and 8.

Similarly, close examination of the record from Station 8 shows a very weak earlier wave whose amplitude was only 0.027 psi. Its arrival time was in agreement with arrivals of the dominant (first) wave at the other stations. This fact, together with the observation that the second wave had disappeared at even closer stations, leads to the conclusion that the weaker wave was the first or ground-shock-induced wave, that the second wave had disappeared, and that the third and dominant signal at Station 8 must have had a different origin. Since amplitudes at Stations 8 and 9 are nearly the same, the wave must have attenuated very slowly. The arrival of the third wave at Station 8
at 11.25 seconds and its amplitude justify its being attributed to a 2400-
pound microbarograph calibration charge detonated 11,800 feet away at zero
time. Obviously, the values from this wave cannot be considered further in
relation to Project Danny Boy.

3.2 PEAK OVERPRESSURE

Peak overpressures of the main (first) wave as a function of ground
range scaled to a 1-pound charge are shown in Figure 3.1. The relatively
constant overpressure beyond 12 ft/lb$^{1/3}$ represents the third wave, attributed
to the microbarograph calibration shot. Also shown in Figure 3.1 is a curve
representing expected pressures from the second or gas-venting pulse based on
high-explosive data at the same scaled burst depth. For this pulse, there
was essentially no difference in peak overpressure from high explosives de-
tonated in alluvium and basalt, and it was upon the combined data that the
estimates of expected overpressures had been based. Since the arrival times
(Figure 2.8) were bracketed by the arrival times of first and second pulses
of Project Scooter scaled to Danny Boy yield, they could not be used without
the later arrivals at the three closest stations to indicate conclusively
whether the single pulse shown on the Danny Boy records represented a ground-
shock-induced air shock or a gas-venting pulse.

An examination of Project Buckboard data shows that the first ("front
porch") wave from Buckboard Shot 11 at a scaled burst depth of 0.75 ft/lb$^{1/3}$
is given by $p = 1.2 r^{-0.97}$, where $r$ is the scaled ground range. For Buck-
board Shot 12 at a scaled burst depth of 1.25 ft/lb$^{1/3}$, the relationship was
$p = 0.9 r^{-1.1}$*. Interpolation between these relationships gives a predicted
"front porch" wave for Danny Boy of about $p = 0.95 r^{-1.1}$. This relationship
is shown in Figure 3.1. The close agreement of the measured data to this
prediction is taken as final evidence that the dominant pulse measured is,
in fact, the ground-shock-induced air shock. A best-fit pressure-distance
relationship for the measured pressures is about $p = 0.32 r^{-0.70}$. Even with
this spread between measured and predicted pressures, it is clear (1) that
peak pressures from the nuclear shot are less than were predicted from high-
expllosive data and (2) that the pressure attenuates less rapidly from the
nuclear detonation than it did from high-explosive detonations in the same
medium and at comparable burst depth.

*Pressures in the first wave in alluvium are less; the corresponding
relationship for Scooter being $p = 0.52 r^{-1.1}$. 
Peak overpressure values for the gas-venting pulse at the three closest stations are also shown in Figure 3.1. These signals are so small a part of set range that great precision cannot be obtained. They do show that the gas-venting pulse is only about one-third as large as the ground-shock-induced pulse. This is in contrast to high-explosive experience where the ground-shock-induced pulse at nearly the same scaled burst depth is about one-third of the gas-venting pulse.

All values from the gage at Station 6A are low, but a careful re-evaluation revealed no reason for modifying the numbers shown.

3.3 POSITIVE-PHASE IMPULSE

Although it is possible to define the peak overpressure associated with each portion of the blast wave, it is not worthwhile to define their positive-phase impulses. This is because the amplitudes of all but the dominant wave of Danny Boy are so low (only a few mils on the original record) and such a small portion of set range that scatter in data is especially large. Also, comparisons with high-explosive data are difficult, because there the "front porch" typically runs into the dominant wave, making it impossible to define them separately. Therefore, it was to be expected that the values measured on Project Danny Boy, consisting only of impulse from the ground-shock-induced wave, would fall below the impulses predicted from high-explosive waves, which are made up of contributions from both the ground-shock-induced and gas-venting waves (Figure 3.2).

3.4 POSITIVE-PHASE DURATION

As in the case of the positive-phase impulse, only the positive-phase duration of the dominant wave of Danny Boy can be compared with the total positive-phase duration from high explosives, which includes both first and second waves. Danny Boy results and a comparison with total positive-phase duration from high-explosive tests scaled to 1 lb are shown in Figure 3.3.

3.5 EXPLOSIVE IMPLICATIONS

Close-in air blast from above-ground detonations is known with sufficient accuracy that estimates of explosive yield can be made from pressure-distance observations. Only slightly less accurate estimates can be made for
high-explosive detonations underground where the gas-venting pulse is domi-
nant. For nuclear charges in basalt at deeper depths below ground, as
evidenced by Danny Boy where the dominant pulse is ground-shock-induced,
such estimates appear to have little meaning. Because the dominant wave
from the nuclear detonation appears to attenuate less rapidly then the first
wave from high-explosive detonations, estimates of Danny Boy yield vary with
the ground distance of the peak pressure observations from 75 tons near the
closest station to 325 tons at 1120 feet.

The very small gas-pressure pulse from the Danny Boy event may be attrib-
uted to the almost total lack of moisture in the basalt. More significant,
second pulses may be expected from detonations in media with greater water
content or in media (such as limestone) where chemical reactions can be ex-
pected to produce higher gas pressures. These measurements are useful in
determining the relative importance of gas pressure as a mechanism of crater
formation and, hence, should be continued on nuclear cratering events.
Figure 3.1 Maximum Overpressure versus Scaled Ground Range
Figure 3.2  Scaled Positive Impulse versus Scaled Ground Range
Figure 3.3 Scaled Positive Phase Duration versus Scaled Ground Range
CHAPTER 4
CONCLUSIONS

The dominant pressure pulse from the Danny Boy event is shown to have been the ground-shock-induced air blast. Only a very small pressure pulse resulting from the venting of explosive gases was recorded at the three closest stations. Since a significant pulse results from the venting gases of high-explosive detonations at the same scaled burst depths, this is the most pronounced difference between close-in air blast from nuclear and high-explosive detonations underground. Peak overpressures from venting gases were only about one-third those of the ground-shock-induced pulse, while with high explosives at the same scaled burst depths they were about three times the ground-shock-induced pressure. This drastic reduction in venting-gas pressures accounts almost entirely for the fact that the close-in blast from nuclear charges is suppressed more by charge burial than that from high-explosive charges.

The peak ground-shock-induced air pressure is shown to attenuate less rapidly for a nuclear charge in basalt than for high-explosive charges in the same medium.

The TNT equivalent of the blast from Project Danny Boy can be deduced only from the peak overpressures of the ground-shock-induced wave. Since the waves are attenuating at different rates, the apparent blast yield ranges from 75 tons at the closer stations to about 325 tons near the station at 1120 feet.
REFERENCES


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elements

ARD ACTIVITIES

1. Deputy Chief of Staff for Military Operations, D/A, Washington 25, D.C. ATTN: Dir. of SMAR
3. Assistant Chief of Staff, Intelligence, D/A, Washington 25, D.C.
10. Director of Special Weapons Development Office, Head-Quarter ENODN, Ft. Bliss, Tex. ATTN: Capt. Chester I. Peterson
13. Commandant, U.S. Army Command & General Staff College, Ft. Leavenworth, Kansas, ATTN: ARCHIVES
21. Director, Army Forces Institute of Pathology, Walter Reed Army Med. Center, 300 15th St., N.W., Washington 25, D.C.
22. Commanding Officer, Army Medical Research Lab., Ft. Knox, Ky.
23. Commandant, Walter Reed Army Inst. of Res., Walter Reed Army Medical Center, Washington 25, D.C.
25. Commanding Officer, Chemical Warfare Lab., Army Chemical Center, Md. ATTN: Tech. Library
27. Director, Waterways Experiment Station, P.O. Box 631, Vicksburg, Miss. ATTN: Library
28. Commanding Officer, Picatinny Arsenal, Dover, N.J. ATTN: GEOS-R
30. Commanding General, Aberdeen Proving Grounds, Md. ATTN: Director, Battallion Research Laboratory
31. Commanding General, Frankford Arsenal, Bridge and Tacony St., Philadelphia, Pa. ATTN: OREM-B
32. Commanding Officer, Watervliet Arsenal, Watervliet, New York. ATTN: OREM-BR
33. Commanding General, White Sands Missile Range, N.M. ATTN: OREM-BR
34. Commander, Army Ballistic Missile Agency, Redstone Arsenal, Ala. ATTN: OREM-BR
35. Commanding General, Ordnance Tank Automotive Command, Detroit Arsenal, Centerline, Mich. ATTN: GBMC-BO
40. Commanding General, U.S. ORS Special Weapons-Ammunition Command, Dover, N.J.

NAVY ACTIVITIES

42. Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-75
43. Chief of Naval Research, D/N, Washington 25, D.C. ATTN: Code 811
44. Chief, Bureau of Naval Weapons, D/N, Washington 25, D.C. ATTN: HELL-3
47. Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: D-440
48. Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Mrs. Katherine B. Case
49. Commander, U.S. Naval Reserve Laboratory, White Oak, Silver Spring 10, Md.
50. Director, Material Lab. (Code 900), New York Naval Shipyard, Brooklyn 1, N.Y.
51. Commanding Officer and Director, Navy Electronics Laboratory, San Diego 70, Calif.
52. Commanding Officer, U.S. Naval Mine Defense Laboratory, Panama City, Fla.
54. Commanding Officer and Director, U.S. Naval Civil Engineering Laboratory, Fort Huachuca, Calif. ATTN: Code 121
56. Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
57. Commanding Officer, U.S. Fleet Sonar School, U.S. Naval Base, Key West, Fla.
58. Commanding Officer, U.S. Fleet Sonar School, San Diego 41, Calif.
60. Commanding Officer, Nuclear Weapons Training Center, Atlantic, U.S. Naval Base, Norfolk 12, Va. ATTN: Nuclear Warfare Dept.
61. Commanding Officer, Weapons Training Center, Pacific, Naval Station, San Diego, Calif.
63. Commanding Officer, Air Development Squadron 5, VA-3, China Lake, Calif.
CONFIDENTIAL

81 Commanding Officer, Naval Air Materiel Center, Philadelphia, Pa., ATTN: Technical Data Br.

82 Commanding Officer, U.S. Naval Air Development Center, Warminster, Pa., ATTN: NAS Librarians.

83 Commanding Officer, U.S. Naval Medical Research Institute, National Naval Medical Center, Bethesda, Md.

84 Commanding Officer, Director, David W. Taylor Model Basin, Washington, D.C., ATTN: Library

86 Commanding Officer and Director, U.S. Naval Engineering Experiment Station, Annapolis, Md.

87 Commander, Norfolk Naval Shipyard, Portsmouth, Va., ATTN: Underwater Explosions Research Division

88 Commander, E.M. Corps, Washington, D.C., ATTN: Code A00

89 Director, Marine Corps Landing Force, Development Office, Quantico, Md.

90 Chief, Bureau of Naval Weapons, Navy Department, Washington, D.C., ATTN: NRP


AIR FORCE ACTIVITIES


102 Manager, USAF, ATTN: Operations Analysis Office, Office, Vice Chief of Staff, Washington, D.C.


110 Commander, Tactical Air Command, Langley AFB, Va., ATTN: DOS, Security Branch

112 Air Force Reserve Command, Buckley AFB, Colorado.

113 ATTN: Operations Analysis Section, ADOCA


115 Director, Air Force Ballistic Missile Div, M.R., ARDC, Air Force Test Center, Los Angeles, Calif., ATTN: MDRS

116 Commander, Second Air Force, Vandenberg AFB, La., ATTN: Operations Analysis Office


118 Director, Air University Library, Maxwell AFB, Ala.

119 Commander, Lowry Technical Training Center (TW), Lowry AFB, Denver, Colorado.

120 Commander, School of Aviation Medicine, USAF Aerospace Medical Center (ATC), Brooks AFB, Tex., ATTN: Col. E. L. Rehnke

122 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, Ohio. ATTN: WADC (For WADC)

131-132 Director, USAF Project MARD, VFA USAF Liaison Office, The RAND Corp., 1700 Main St., Santa Monica, Calif.

135 Commander, Rome Air Development Center, ARDC, Griffiss AFB, N.Y., ATTN: Document Library, NORSE-1

135 Commanding, U.S. Air Technical Intelligence Center, USAF, Wright-Patterson AFB, Ohio. ATTN: AWP-2B, Library

135 Chief, Staff, Intelligence, N.M., USAF, APO 639, New York, N.Y. ATTN: Directorate of Air Warplanes

135 Commander-in-Chief, Pacific Air Force, APO 639, San Francisco, Calif. ATTN: PPOE-9S, Base Recovery

OTHER DEPARTMENT OF DEFENSE ACTIVITIES


137 Chairman, Armed Services Explosives Safety Board, DOD Building T, Crystal City Point, Arlington, Va., ATTN: Major W. V. Green


139-140 Commander, Field Command, USAF, Sandia Base, Albuquerque, N.M.

144 Commander, Field Command, USAF, Sandia Base, Albuquerque, N.M., ATTN: AFSC

145-146 Commander, Field Command, USAF, Sandia Base, Albuquerque, N.M., ATTN: DMSC

147 Administrator, National Aeronautics and Space Administration, 1200 K St., N.W., Washington, D.C., ATTN: MR. B. Y. Road

148 Commander-in-Chief, Strategic Air Command, Offutt AFB, Neb., ATTN: OAMS

149 U.S. Documents Officer, Office of the United States National Military Representative - SHAPE, AFSC, 7, New York, N.Y.

ATOMIC ENERGY COMMISSION ACTIVITIES


155-156 Los Alamos Scientific Laboratory, Report Library, P.O. Box 1663, Los Alamos, N.M., ATTN: Holm Redman


SUPPLEMENTARY DISTRIBUTION

156 Assistant to the Secretary of Defense for Atomic Energy, Department of Defense, Washington, D.C., ATTN: Dr. Gerald W. Johnson


173-175 Chief, Air Force Technical Applications Center, Washington, D.C.


179-180 Headquarters, DOD Test Organization, Field Command, USAF, F. O. Box 207, Mercey, Neb.


200-201 Holmes & Harner, Inc., 125 South Broadway, Los Angeles 14, Calif. ATTN: Project Officer, Proj. 3-1

202-203 Applied Physics Research Laboratory, College Park, Md. ATTN: Project Officer, Proj. 3-4

204-205 Edgerton, Gernsheim & Grier, Inc., 500 Wall Street, Las Vegas, Nev., ATTN: Project Officer, Proj. 1-3

206-207 United ElectroDynamics, Inc., 200 Allendale Road, Pasadena, Calif.

208-209 Director, Waterways Experiment Station, Jackson, Miss. ATTN: Project Officer, Proj. 9-1

210-211 Los Alamos Scientific Laboratory, F. O. Box 1663, Los Alamos, N.M.


216 Battelle Memorial Institute, 505 King Avenue, Columbus 1, Ohio. ATTN: Dr. R. W. Russell

217 Director, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

217 University of California, Lawrence Radiation Laboratory, Technical Information Division, Berkeley 4, Calif. ATTN: Dr. R. W. Waddington

218 University of California, Lawrence Radiation Laboratory, Technical Information Division, F. O. Box 500, Livermore, Calif. ATTN: C. G. Craig

219 Union Carbide Nuclear Company, X-10 Laboratory Records Department, P. O. Box 8, Oak Ridge, Tenn.

220 Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Ill. ATTN: Dr. Roylan D. Young

221 University of California, Lawrence Radiation Laboratory, Technical Information Div., P. O. Box 500, Livermore, Calif. ATTN: Glorv Craig (For Test Group Div., Mercury, Nev.)