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1 June 1971

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THE EFFECTS OF AIRBLAST ON SHEEP IN TWO-MAN FOXHOLES

D. R. Richmond, E. R. Fletcher, and R. K. Jones

HEADQUARTERS
Defense Nuclear Agency
Washington, D.C. 20305

PREPARING AGENCY

Lovelace Foundation
for
Medical Education and Research
Albuquerque, New Mexico

Contract No. DASA-68-C-0118

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Technical Progress Report
on
Contract No. DASA-68-C-0118

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ABSTRACT

The blast effects in rectangular two-man foxholes were evaluated using sheep. There were two open foxholes (2 x 6 x 4.5 feet) at ground ranges of 560, 650, 830, 940, and 1,300 feet from a 500-ton TNT charge. There were four one-half covered foxholes, one each at the first four ranges, all oriented end-on to the charge with their openings at the upstream ends. Two sheep were exposed in each of the 14 foxholes suspended in a vertical position. At the 830-foot range, one open and one half-covered foxhole, each with two pressure-time gages, were included.

Because of an anomalous detonation, pressures measured adjacent to the foxhole layout were significantly below those predicted. Moreover, luminous jets emanating from the fireball produced shock waves that preceded the main shock. This gave rise to a blast wave with double shocks known generally to be less damaging to biological systems.

All the sheep survived the blast. At the 560- and 650-foot ranges (37 and 21 p.s.i.), some of the sheep sustained slight amounts of pulmonary hemorrhage. In addition, they exhibited a high incidence of eardrum rupture of a severe form. At the three greater ranges, 830, 940, and 1,300 feet (11, 8.3, and 5.5 p.s.i. respectively), blast injuries were limited for the most part to eardrum rupture. The results obtained were discussed in relation to the pressure-time patterns recorded on the surface and in the foxholes.

PREFACE

Operation PRAIRIE FLAT involved the detonation of a 500-ton TNT block-built hemisphere on the ground surface. The event occurred 9 August 1968.

Extreme care must be exercised in using data reported herein because of the effects that jets, emanating from the fireball, had on the blast waveform recorded adjacent to the foxhole layout.

Work was undertaken by the Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, for the DASA Medical Directorate under Contract No. DA-91-68-C-0118.

The valuable assistance of Lt Col William R. Godden, VC, USAF, DASA Medical Directorate, Director of Program 4, is acknowledged.

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THE EFFECTS OF AIRBLAST ON SHEEP IN TWO-MAN FOXHOLES

1-1 INTRODUCTION.

1-1.1 The objective of this project was to determine the airblast protection that two-man foxholes afford a large biological specimen (sheep).

1-1.2 Except when there is a direct hit, foxholes provide good protection against conventional weapons. As far as the immediate effects from a nuclear detonation are concerned, the shielding provided foxhole occupants against ionizing and thermal radiations has been determined and can be predicted with reasonable accuracy. The amount of protection that foxholes provide against long-duration airblasts is not known.

1-1.3 To personnel in foxholes, blast may inflict injuries from the overpressure itself, from displacement, and from collapse of the walls. Only the overpressure effects in the foxholes were investigated in the present test. The animals were held in place to minimize displacement, and the foxholes were revetted to prevent collapse.

1-1.4 Biological subjects were tested in foxholes on two previous nuclear-blast simulation trials. On the 100-ton TNT hemisphere detonation (reference 1), five field shelters (similar to half-covered, two-man foxholes) were tested with one goat standing in the open portion of each structure. The field shelters measured 1.5 x 12 x 5 feet deep. One goat was killed from the direct blast effects at the 40-p. s. i. level, two at the 34-p. s. i. level were killed, and two at the 20-p. s. i. level survived, although one sustained lung hemorrhage. The foxholes were unrevetted, and the one at 40 p. s. i. and one of those at 34 p. s. i. were partly collapsed. The pressure durations were on the order of 100 to 120 milliseconds.

1-1.5 On Operation SNOWBALL (reference 2), a 500-ton TNT charge in the form of a hemisphere detonated on the surface, two-man foxholes were tested with goats being used. The foxholes were of two designs: a simple, deep one measuring 2 x 6 x 7 feet and a deep one with offset which was 2 x 6 x 7 feet with

a 2 x 2 x 6 feet offset parallel with the long axis of the foxhole and 2 feet above the floor. One goat was placed standing on all fours in each of the simple, deep foxholes and one prone in the offsets of the others. The foxholes were all oriented with their long axes perpendicular to the blast winds (side-on). Three of each type were at the 560-, 540-, and 510-foot ranges, predicted pressure levels of 30, 35, and 40 p. s. i. respectively. All structures were revetted with 1/4-inch steel. There were no deaths from direct blast effects, but two goats were killed by ejecta. Direct blast injury was limited to lung hemorrhage of about threshold level; i. e., very slight amounts. This occurred at about the same incidence at each range in both types of foxholes as did eardrum rupture. The pressures measured along the blast line adjacent to the foxhole array were between 34 and 36 p. s. i. instead of between 30 and 40 p. s. i.

2-1 PROCEDURE.

2-1.1 Layout. Sixteen two-man foxholes, 14 of which contained two sheep each, were utilized. The foxhole layout was to the east of the charge on a bearing of approximately 98 degrees. There were two open foxholes, one oriented end-on and one side-on to the blast, at the following ground ranges: 560, 650, 830, 940, and at 1,300 feet. The side-on overpressures anticipated at these ranges were 50, 35, 20, 15, and 7.5 p. s. i. respectively. In addition, there were four half-covered foxholes, one at each of the first four ranges; they were all end-on to the blast with the covered portion over the downstream half of the structure. At the 830-foot range, an additional open foxhole and a half-covered one, both oriented end-on, were included. Pressure-time gages were mounted in these. Two gages were placed in each foxhole 3 feet above the floor, one in the middle of the endwall (downstream end) and one in the middle of the sidewall.

2-1.2 Foxholes. The design of the foxholes was taken from reference 3. They were standard two-man foxholes 2 x 6 x 4.5 feet deep, with earth parapets. The foxholes were completely revetted except for the floors. Those at 560 feet were revetted with 1/4-inch steel while 2- by 8-inch wood planks were utilized in those at the other ranges. With the exception of the closest range, the covers

of the half-covered foxholes consisted of 6- by 6-inch beams, a layer of 5/8-inch plywood, and an earth mound with sandbags along the lip of the cover. At the 560-foot range, the cover consisted of 1/4-inch steel, earth, and sandbags. Preshot views of the foxholes appear in figures 1 and 2.

2-1.3 Animals.

2-1.3.1 Twenty-eight female sheep, approximately 18 months old, with a mean body weight of 90.5 pounds (range, 77 to 104 pounds) were used. The wool coat of each was about 1 inch long. Each animal was put in a special harness of cotton webbing so that it could be suspended in a vertical position in order to approximate a standing or crouching man. Each sheep was suspended by 3/8-inch windowsash lines from either 2-inch diameter pipe that spanned the open portions of the foxholes or from eyebolts under the covered ends. Figures 3 and 4 show the method of suspending sheep.

2-1.3.2 All the sheep faced the charge, the tops of their heads being 4 inches beneath the lip of the foxholes, although they could lower their heads farther. When suspended, the shoulder level was about 3-1/2 feet above the floor. In the open and half-covered end-on structures, the anterior wall of the thorax of the forward animal was between 8 and 12 inches from the front wall. The posterior thoracic wall of the rear animals was 13 to 17 inches from the rear wall. In both cases, the sidewalls were about 7-1/2 inches from their chests. In the foxholes oriented side-on, the sheep were 7 to 8 inches from the downstream wall and 8 to 10 inches from the upstream wall. In each case, the thorax was 14 to 15 inches from the nearest endwall.

2-1.3.3 Animals numbered 15 through 28 were "euthanized" with Nembutal administered intravenously and were autopsied on D-day. The remainder of the animals numbered 1 through 14 were autopsied on the following day. At post-mortem, the lungs were weighed, photographed, and representative portions were taken for histological examination. Particular attention was given to the assessment of the eyes and middle ears of these animals.

2-1.3.4 The sheep used in this test were purchased in Canada. They were housed in pens outside the Toxicology Laboratory of the main station at DRES.

The animals were transported to and from the test site in pickup trucks fitted with stock racks. Postmortem examinations took place in a laboratory trailer located at Drowning Ford, about 3 miles from the test site. This laboratory trailer was transported from the Lovelace Foundation in Albuquerque, New Mexico.

3-1 RESULTS.

3-1.1 Immediate Observations. Personnel entered the test site 15 minutes after the shot. All animals were alive and in place and exhibited normal corneal and ear-pinch reflexes. No obvious clinical abnormalities were noted, and the respiration rate and excursion were essentially normal even in animals at the highest pressure levels. The lesions noted were limited to slight amounts of blood-tinged fluid from the nose or mouth of animals 1 and 2 (in the open, side-on foxhole at the 560-foot range), animal 4 (in the open, end-on foxhole at the 560-foot range), and animal 10 (at the rear of the open, end-on foxhole at the 650-foot position). There was also a trace of singeing about the face of animal 5 in the forward part of the half-covered foxhole at the closest range. There were no foreign bodies lodged in the corneas of their eyes, and the dust that was present was soon washed away. There were dust, and small dirt particles, as well as grass fragments, over the sheep at the first three lines. Although there was little ejecta over the structure area, one clump of earth (about 10 inches in diameter) had entered the open, end-on foxhole at the 650-foot range.

3-1.2 Pathological Findings.

3-1.2.1 The gross pathological findings are summarized in table 1. Their distribution on the layout appears in figure 6.

3-1.2.2 A slight amount of lung hemorrhage was found in animals 1, 4, and 6 from each of the structures at the 560-foot range. Small pulmonary hemorrhages occurred in both sheep 9 and 10 in the open, end-on foxhole at the 650-foot range and in sheep 22 which was located in the rear of the half-covered foxhole at the 940-foot range. Examples of lungs with no injury and with slight lung hemorrhage are illustrated in figure 7.

3-1.2.3 Intra-abdominal injuries were limited to those animals exposed in the two forward rows of foxholes. There were two cases in which the gall bladder was torn from its hepatic attachment, resulting in an associated hemoperitoneum. Two animals had contusions of the submucosal lining of the caecal portion of the gastroenteric tract.

3-1.2.4 Ear injury, graded as to severity, appears in table 1. In general, the severity of ear injury dropped with increased distance from the charge. It was most severe in animals in the two forward rows of foxholes. Even in those cases where no perforation of the eardrum had occurred, there was hemorrhage along the malleus bone of the middle ear. In two instances (sheep numbers 1 and 3), this hemorrhage extended into the external auditory meatus. There was about the same incidence and severity of ear injury in sheep exposed in the open foxholes as there was in those in half-covered foxholes. Figure 8 illustrates the various levels of ear injury in dogs comparable to those found in the sheep on the present test.

3-1.3 Pressure-Time Measurements.

3-1.3.1 Pressure-time curves recorded on the surface along line 2 (103 degrees) was adjacent to the layout of this project, are presented in figure 9 (these were taken from reference 4). Selected pressure-time parameters taken from the curves are presented in table 2. In general, the peak pressures were significantly below those predicted. Furthermore, some of the waveforms were not ideal and were characterized by multiple shocks. As seen in figure 8, at the 830- and 940-foot ranges, distinct multiple shocks were recorded and the peak pressure was not associated with the initial shock. At these two ranges, the peak pressure occurred approximately 20 milliseconds after the arrival time. Likewise, the waveform recorded at 560-feet was not ideal and showed a second rise in 10 to 20 milliseconds.

3-1.3.2 The duration of the overpressures measured on the surface at ground ranges between 560 feet and 1,300 feet ranged from 143 to 290 milliseconds.

3-1.3.3 The pressure-time curves measured in the foxholes at the 830-foot range are illustrated in figures 10 and 11. Selected pressure-time parameters

are given in table 3. In the open foxhole, the initial shock reflected to 22 p. s. i. on the downstream wall. The peak pressure of the second reflected shock was near 29 p. s. i. at 4 milliseconds. The gage in the middle of the sidewall recorded an initial shock of 7.5 p. s. i. which, upon reflecting from the floor and walls, rose to 22 p. s. i. in about 8.2 milliseconds.

3-1.3.4 On the downstream wall of the half-covered foxhole, a peak pressure of 31 p. s. i. was recorded with a time-to-peak of 6 milliseconds. The pressure rose in three steps. In the middle of the sidewall, the first pressure-rise was about 9 p. s. i. and the peak pressure was 15 p. s. i. at 8 milliseconds.

3-1.3.5 The duration of the pressures in the foxholes was between 175 and 200 milliseconds and was near the 195-millisecond duration recorded on the surface at the 830-foot range.

4-1 DISCUSSION.

4-1.1 An important factor to be considered in the interpretation of the biological effects obtained on this test is the anomalous nature of the detonation. According to the information given in reference 5, three luminous jets and several nonluminous jets emanated from the fireball. One of the luminous jets traveled outward along a radial line bearing 106 degrees. This jet markedly altered the pressure-time patterns recorded along the U. S. Blast Line No. 2 (103 degrees) adjacent to the foxhole array (97 degrees to 101 degrees 40 minutes). From photographic records, this luminous jet was observed to move out ahead of the main shock to a range of approximately 870 feet before it was overtaken by the main shock. Since the jet generated its own shock (bow shock), the gage at 830 feet, for example, recorded this shock of 7.5 p. s. i. 20 milliseconds before the main shock, which then increased the pressure to 11 p. s. i. Multiple shocks were also registered at the 940-foot range; the first shock of 4 p. s. i. represented the main shock and subsequent shocks, and the peak pressure of 8.3 p. s. i. was apparently due to the jet effects. Jet effects were not observed at the 1,300-foot range. No explanation was given as to why the pressure-time records obtained at the 560- and 650-foot ranges did not show clear indications of multiple shocks even though the jet was out ahead of the main shock at these ranges.

Because the pressure gages were, for the most part, placed along one radial line, the lateral distances over which the jet influenced the waveforms were not determined.

4-1.2 Pressure-time curves recorded by gages in the foxholes at the 830-foot range to the north side of the layout (90 degrees) did not suggest a second shock at 20 milliseconds as was recorded on line 2. Judging from shock-tube studies with scale models of these foxholes, the incident shock would have to be on the order of 13 p. s. i. to generate peak pressures of near 30 p. s. i. on the downstream wall of the structures. Unless information becomes available to the contrary, it will be assumed here that the pressure-time curves along line 2 represent those incident to the foxholes at corresponding ranges.

4-1.3 If the waveform of the airblast incident to the foxholes consisted of multiple shocks, with the peak pressure occurring subsequent to the first shock, there would be less blast effect on the animals than would occur if the blast wave were of the classical form with the same peak pressure at the leading edge of the wave. The initial shock fronts that entered the foxholes at the 830-, 940-, and 1,300-foot ground ranges were on the order of 7.5, 4.0, and 5.5 p. s. i. respectively. These pressures, even if doubled upon reflection, would not be expected to cause pulmonary hemorrhage or a high incidence of eardrum rupture; according to shock-tube tests with sheep, the 20-p. s. i. reflected pressure, square wave is associated with threshold lung hemorrhage and a 45-percent incidence of eardrum rupture. If the pressure rises in two steps, the reflected pressures to produce these effects would be nearly double that.

4-1.4 At the higher pressure regions, there was less blast injury in animals than might be expected from the near-classical blast waves recorded with peaks of 37 and 21 p. s. i. These results agree with those from Operation SNOWBALL (reference 2), wherein goats in foxholes at pressures on the order of 35 p. s. i. were not seriously injured by blast, but conflict with those from reference 1, wherein goats were killed by blast at pressures of 34 p. s. i. It should be mentioned that there was an anomalous detonation encountered on Operation SNOWBALL which makes the results obtained suspect for reasons already given.

4-1.5 The overall objective of work in the area of predicting blast effects inside structures is to correlate the biological effects with specific parameter(s) of the pressure-time curves characteristic of those recorded within structures of various geometries. As seen in the present tests, the peak reflected pressures inside the foxholes may be multiplied two or more times above that recorded on the surface. However, the pressure is less damaging because it rises in several steps, each separated by time intervals of several milliseconds, and the peak pressure does not occur in the first pressure rise. The initial high peaks are of short duration and have, therefore, little impulse. One approach to relating biological effects and the pressure-time parameters inside structures is to use the partial-impulse criteria (references 6 and 7). These criteria take into account the impulse, I , delivered over the initial portion of the blast wave up to a specified time, T — the time being related to the body weight of the animal species.

$$I = 130(m/70)^{1/3}(P_0/14.7)^{1/2} P_{sw}/61.5 \text{ p. s. i. -milliseconds}$$

$$T = 2.1(m/70)^{1/3}(14.7/P_0)^{1/2} \text{ milliseconds}$$

where P_0 is the ambient pressure (p. s. i.), m is the body weight (kilograms), and P_{sw} is the pressure resulting in 50-percent mortality for a square wave with $P_0 = 14.7$ (p. s. i.).

4-1.6 The partial impulses required to produce a given percentage mortality in sheep are given in table 4 and those recorded in foxholes at the 830-foot range appear in table 3. For 1-percent mortality in sheep, an impulse of 77 p. s. i. per milliseconds must be delivered over the first 1.82-millisecond portion of the blast wave. Those measured in the foxholes at 830 feet ranged from 33 to 13 p. s. i. per milliseconds which corresponds to partial impulses required for threshold lung hemorrhages, 23 p. s. i. per milliseconds (table 4).

TABLE 1

GROSS PATHOLOGICAL FINDINGS

Foxhole Location and Orientation	Animal Number	Lung Hemorrhage, degree	Lung Weight Percent of Body Weight	Ear Injury		Others
				R	L	
560', open, side-on	1	Slight	0.96	+2h ^a	+2h	None.
	2	None	0.86	+3	+3h	Gall bladder detached from liver; hemoperitoneum.
	3	None	1.05	+2h	+2h	None.
	4	Slight	0.94	+3h	+2h	Submucosal hemorrhage caecum; petechia pericardial fat.
	5	None	1.44	NA	NA	None.
	6	Slight	0.82	+3h	+3h	Submucosal hemorrhage caecum.
650', open, side-on	7	None	0.88	NA	NA	Gall bladder detached from liver; hemoperitoneum.
	8	None	0.84	+3h	-h	Right temporal skin hemorrhage.
	9	Slight	0.94	+3h	+2h	None.
	10	Slight	0.92	-h	+2h	None.
	11	None	0.86	-h	+2h	None.
	12	None	1.04	+3h	+2h	2-cm hemorrhage sternum.
830', open, side-on	13	None	1.07 ^b	+2h	-h	None.
	14	None	2.64 ^b	NA	NA	None.
	15	None	0.99	-h	-h	None.
	16	None	1.20	-h	-h	None.
	17	None	1.06	+1h	-h	None.
	18	None	0.80	+2h	-h	None.
940', open, side-on	19	None	1.06	-h	-h	None.
	20	None	0.98	NA	-h	None.
	21	None	0.99	-h	NA	None.
	22	Slight	1.15	+1h	-h	None.
	23	None	0.95	+2h	+2h	None.
	24	None	1.12 ^b	-h	+2h	None.
1300', open, side-on	25	None	0.90	+3h	+2h	None.
	26	None ^b	1.19 ^b	-h	-	None.
	27	None	0.90	-h	-h	Mid-temporal skin hemorrhage.
	28	None	1.14 ^b	-h	-h	None.
^a Indicates the extent of ear injury: - = eardrum intact; NA = not assessable because of middle-ear infection; h = hemorrhage. +1 = eardrum less than 50 percent destroyed. +2 = eardrum more than 50 percent destroyed. +3 = eardrum more than 50 percent destroyed with malleus, either fractured or disrupted. ^b Indicates that the lungs were previously infected with pseudotuberculosis which could account for their increased weight.						

TABLE 2
PRESSURE-TIME PARAMETERS MEASURED ON THE
SURFACE, LINE 2

Range, ft.	Overpressure, p. s. i.		Time to Peak, msec.	Duration, msec.
	First Rise	Peak		
560	36.8	36.8	"Instantaneous"	143
650	20.9	20.9	"Instantaneous"	187
830	7.5	11.2	20	195
940	4.0	8.3	22	235
1300	5.5*	-	-	290*
*Estimated from pressure-distance and impulse-distance curves reference 4.				

TABLE 3

PRESSURE-TIME PARAMETERS MEASURED
IN FOXHOLES AT THE 830-FOOT RANGE

Station	Overpressure, p. s. i.		Time to Peak, msec.	Impulse, p. s. i. per msec. from 0 to 1.82 msec.	Duration, msec.
	First Rise	Peak			
<u>Open Foxhole:</u>					
Endwall	22	29	4.0	33	200
Sidewall	7.5	22	8.2	13	185
<u>Half-Covered Foxhole:</u>					
Endwall	13.5	31	6.0	22	180
Sidewall	9.0	15	8.0	14	175
<u>Surface:</u>	7.6	11.2	20	14	195

TABLE 4

IMPULSE DELIVERED WITHIN 1.82 MSEC.
REQUIRED TO PRODUCE MORTALITY IN SHEEP

Impulse, p. s. i. per msec.	Mortality, percent
23	0*
77	1
93	10
120	50
150	90
180	99
*Threshold lung injury.

Figure 1. --Open Foxhole.

Figure 2. --Half-Covered Foxhole.

Figure 3. --Sheep Suspended in Open Foxhole.

Figure 4. --Sheep Suspended in Half-Covered Foxhole.

Figure 5. --Post-Shot View of Sheep in Foxholes.

Figure 6. --Project LN-401 Layout Showing Distribution of Blast Injuries.

Figure 7. --Top Photograph Shows Lungs of Sheep Number 26 (Uninjured). Bottom Photograph Shows Lungs of Sheep Number 4 (Slight Hemorrhage).

Figure 8. --Graded Levels of Ear Injury in Dogs, Viewed from Middle Ear. Upper Left Shows Eardrum Intact (-), Upper Right is Less than 50 Per Cent Destroyed (+1), Lower Left, More Than 50 Per Cent Destroyed (+2), and Lower Right, More Than 50 Per Cent Destroyed with Fracture of the Malleus (+3).

Figure 9. --Pressure-Time Curves Recorded by Gages Along Line 2
(Taken from Reference 4).

Figure 10. --Pressure-Time Curves Recorded in Open Foxhole at 830-Foot Range (Supplied by Project LN-101).

Figure 11. --Pressure-Time Curves Recorded in Half-Covered Foxhole at 830-Foot Range (Supplied by Project LN-101).

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UNCLASSIFIED

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Lovelace Foundation for Medical Education and Research Albuquerque, New Mexico		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE The Effects of Airblast on Sheep in Two-Man Foxholes			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report of Project LN-401 accomplished on Operation PRAIRIE FLAT			
5. AUTHOR(S) (First name, middle initial, last name) D. R. Richmond, E. R. Fletcher, and R. K. Jones			
6. REPORT DATE 1 June 1971		7a. TOTAL NO. OF PAGES 38	7b. NO. OF REFS 7
8a. CONTRACT OR GRANT NO. DASA-68-C-0118		9a. ORIGINATOR'S REPORT NUMBER(S) DASA 2711	
b. PROJECT NO. NWET L35AAXM			
c. TASK and SUBTASK X408		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d. Work Unit 01			
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Director Defense Nuclear Agency Washington, D.C. 20305	
13. ABSTRACT <p>The blast effects in rectangular two-man foxholes were evaluated using sheep. There were two open foxholes (2 x 6 x 4.5 feet) at ground ranges of 560, 650, 830, 940, and 1,300 feet from a 500-ton TNT charge. There were four one-half covered foxholes, one each at the first four ranges, all oriented end-on to the charge with their openings at the upstream ends. Two sheep were exposed in each of the 14 foxholes suspended in a vertical position. At the 830-foot range, one open and one half-covered foxhole, each with two pressure-time gages, were included.</p> <p>Because of an anomalous detonation, pressures measured adjacent to the fox-hole layout were significantly below those predicted. Moreover, luminous jets emanating from the fireball produced shock waves that preceded the main shock. This gave rise to a blast wave with double shocks known generally to be less damaging to biological systems.</p> <p>All the sheep survived the blast. At the 560- and 650-foot ranges (37 and 21 p. s. i.) some of the sheep sustained slight amounts of pulmonary hemorrhage. In addition, they exhibited a high incidence of eardrum rupture of a severe form. At the three greater ranges, 830, 940, and 1,300 feet (11, 8.3, and 5.5 p. s. i. respectively), blast injuries were limited to the most part to eardrum rupture. The results obtained were discussed in relation to the pressure-time patterns recorded on the surface and in the foxholes.</p>			

DD FORM 1473
1 NOV 65

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Operation PRAIRIE FLAT Blast Effects Blast Biology Blast-Biomedical Criteria						

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Security Classification