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Report 1832

BLAST EFFECTS ON U. S. ARMY WATER-STORAGE CONTAINERS

by

Paul E. DesRosiers
and
Don C. Lindsten

October 1965

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
FORT BELVOIR, VIRGINIA

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BLAST EFFECTS ON U. S. ARMY WATER-STORAGE CONTAINERS

Task 1M624101D55107

October 1965

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The Commanding Officer
U. S. Army Engineer Research and Development Laboratories

Prepared by

Paul E. DesRosiers
and
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Sanitary Sciences Division
Military Department

FOREWORD

The investigation covered by this report was conducted by the Sanitary Sciences Division, Military Department, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia, under Operation SNOWBALL of the Defense Atomic Support Agency (DASA). Basic authority for the work is Task 1M624101D55107 (formerly 1D624101D55107), "Removal of CBR Contaminants from Water." A copy of the task card is included as an appendix.

The period covered by this report was February 1963 through June 1965.

The following personnel were responsible for conducting the study:

<u>General Supervision</u>

Neil K. Dickinson, Chief, Military Department.
Richard P. Schmitt, Chief, Sanitary Sciences Division.

<u>Acquisition and Presentation of Data</u>

Paul E. DesRosiers, Project Officer.
Don C. Lindsten, Chief, Water Research Branch.

Acknowledgment is made of the excellent cooperation and supporting effort given this project by DASA. The following personnel aided materially, administratively, and technically throughout the entire investigation:

Colonel G. E. Hesselbacher, Chief, Blast and Shock Division, DASA.
J. R. Kelso, Chief, Air Blast Branch, DASA.
Charles N. Kingery, Technical Director, Operation SNOWBALL.
Lt Colonel B. Collins, USAF, Director of Program 1, Operation SNOWBALL.
Captain J. Choromokos, Jr., DASA Project Officer, Operation SNOWBALL.

Appreciation is also given to the staff of the Suffield Experimental Station of the Canadian Government for their administrative, technical, and billeting support and for their warm hospitality.

SUMMARY

This report covers a study made at the Suffield Experimental Station, Canada, investigating the blast vulnerability of current military water-storage tanks and experimental, pillow-type, water-storage containers relative to: (1) shock damage, and (2) water contamination resulting from air-borne dust. Tanks filled with water were exposed to the effects of a 500-ton TNT detonation. The results of the study indicate that:

1. Rubberized-fabric, water-storage tanks, both of the pillow and the upright-cylinder type, with the exception of the hipped-type top cover cloth used with the 1500- and 3000-gallon tanks, can withstand the shock effects from a high explosive detonation up to a 9.8-psi overpressure.

2. All rubberized-fabric, water-storage tanks situated in the open, without berm protection, are subject to severe damage from flying debris emitted by a high explosive or nuclear detonation regardless of overpressure.

3. Earthen berms offer some degree of protection against flying debris but afford only limited shielding to air-borne dust brought in by wind associated with the blast.

4. The weakest part of the rubberized-fabric, upright-cylinder, water-storage tank from the point of view of blast damage is the top cover cloth. Even when lashed down securely, it is subject to damage (ripping and tearing in the vicinity of the metal grommets) by the wind associated with overpressures as low as 5.2 psi.

5. Water stored in rubberized-fabric, upright-cylinder-type tanks, at overpressures equal to or greater than 9.8 psi, can become contaminated with sufficient air-borne dust to be above the Maximum Permissible Concentration for radioactively contaminated water if the detonation is nuclear.

6. Water contained in fabric, water-storage tanks of the pillow type does not become contaminated with air-borne dust from a high explosive or nuclear detonation.

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BLAST EFFECTS ON U. S. ARMY WATER-STORAGE CONTAINERS

I. INTRODUCTION

1. Subject. The purpose of this study was to determine the blast vulnerability of current military water-storage tanks and experimental, pillow-type, water-storage containers relative to: (1) shock damage, and (2) water contamination resulting from air-borne dust.

2. Background. In the event of war or national emergency, it is imperative that U. S. Army troops in the field be furnished safe, clean, potable drinking water. Although there are many adverse conditions under which drinking water must be produced, it is now definitely within the capability of the U. S. Army in the field to supply water of a safe and excellent quality equal or superior to many municipal supplies. The workhorse of the Army field water supply system is a family of transportable water purification units frequently referred to as "Erdlator" equipment. Erdlator equipment is available in three commonly used sizes: 3000, 1500, and 600 gph. These units, although of different capacity, are similar in construction and operation. Each unit is a continuously operating device utilizing the processes of coagulation (with ferric chloride and limestone), diatomite filtration, and disinfection (with calcium hypochlorite) to produce a clear, potable water from almost any fresh-water source. However, the Erdlator equipment does not remove soluble substances. Therefore, when saline water sources are encountered, demineralizing processes such as distillation or ion exchange must be used. In all cases, water is purified or made suitable for drinking at centralized field water sites and, after treatment, is stored in tanks prior to use. Because the production rate is usually constant while distribution is uneven and irregular, the finished water is stored in these tanks for subsequent high-rate discharge into tank trucks, trailers, or other organizational-type containers. The tanks are located strategically, sometimes at sites other than at the water-processing points, to make drinking water available as near to the consumer as ground conditions permit. To provide potable drinking water in the field is expensive in equipment, supplies, and manpower. Therefore, it is essential that this supply, once made available, be contained and protected adequately.

The water-storage tanks are available in three standard sizes: 3000, 1500, and 500 gallons. In addition to the storing of finished water, the 3000-gallon tank has another important use: the chemical pretreatment of raw water to remove certain chemical and biological contaminants prior to coagulation in the Erdlator. The pretreatment is accomplished in two 3000-gallon tanks, used in series, from which the effluent is fed into the continuously operating Erdlator.

The standard Army storage tank is an upright cylinder constructed of nylon cloth impregnated with synthetic rubber. It comprises the following items:

a. Tank proper.

b. Ground cloth to protect the tank from stones or other projections present on the ground surface.

c. Spreader bars to keep the tank open when empty.

d. Guy ropes to support the spreader bars in keeping the tank open.

e. Cover cloth to protect the stored water from dust and other air-borne contaminants.

f. Staves to lend vertical strength to the tank walls.

It is important to determine how much blast pressure these tanks can withstand under field conditions and what can be anticipated with regard to air-borne dust contamination. The only previous information available concerning blast effects on military storage containers was obtained from tests on the standard Army GRS coated, nylon fabric, 3000-gallon tanks. In Project 3.9, Operation BUSTER, four 3000-gallon tanks were placed in a direct line at points 2000, 3000, 4000, and 4291 yards from ground zero (see Fig. 1) (1).[1] The tanks were filled with local drinking water from a 900-foot well at Frenchman Flat (AEC's Nevada Test Site) and were left uncovered. The area was entered $3\frac{1}{2}$ hours after the blast (Shot EASY, 31 KT nuclear air burst), and all tanks were examined for blast damage. Table I shows the effects of the blast on the tanks.

1. Figures in parenthesis refer to "LITERATURE CITED," p. 36.

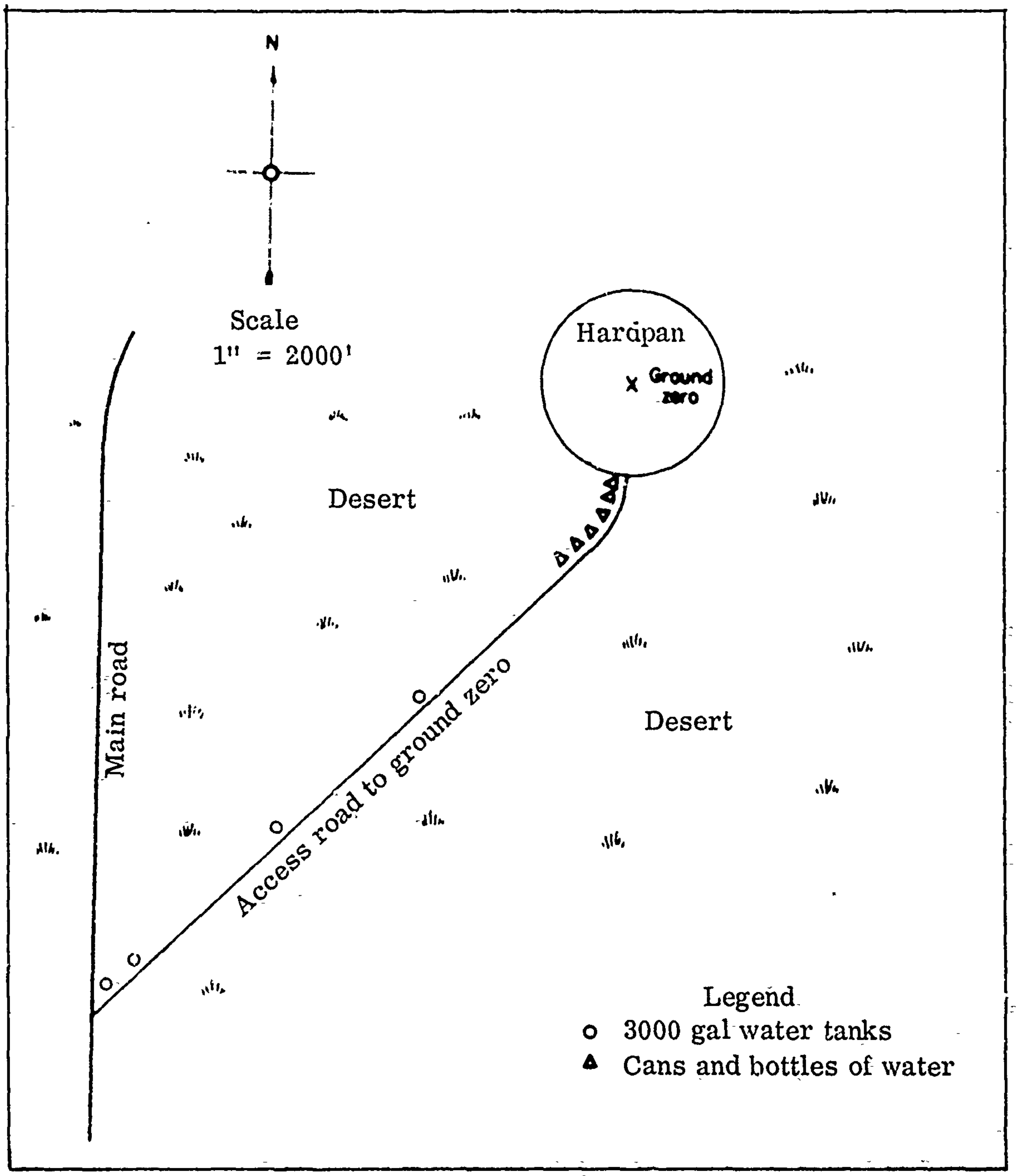

Fig. 1. Operation BUSTER: Location of water-storage tanks.

Table I. Blast Damage to Tanks during Operation BUSTER

Tank	Distance from Ground Zero (yd)	Overpressure (calculated) (psi)	Damage
1	2000	5	Blistering and charring on side exposed to blast
2	3000	3	No essential damage
3	4000	2	No essential damage
4	4291	1	No essential damage

Tank 1, at 2000 yards, contained some twigs driven perpendicularly through the tank sidewall and showed signs of blistering and charring.

In Project 6.8, Operation JANGLE, four 3000-gallon water tanks were placed on a line 50 degrees East of North from ground zero at distances of 500, 925, 1500, and 2030 yards (see Fig. 2) (2). The tanks were filled with local drinking water from well supplies at Frenchman Flat and left uncovered. In addition, one covered, 3000-gallon tank was installed at 500 yards. All tanks were placed at ground level and were not fortified. The results indicated that all of the tanks essentially were undamaged following a 1.2-KT nuclear surface burst. This detonation produced an overpressure of 5 psi and a thermal flux of 20 cal/cm^2 at a distance of 500 yards from ground zero. The top cover sheet of the covered tank located 500 yards from ground zero partially was torn from the ring loops and had dropped into the tank. The wooden staves facing ground zero were charred slightly.

In regard to contamination of stored water by air-borne dust, little information is available. However, test results of Exercise SAGEBRUSH indicated the need for more effective protection of purified water against air-borne dust contamination (3). Considerable air-borne particulate matter entered the tanks under their covers.

In addition to information on upright cylinders and pillow tanks, information is also needed on blast and shock effects on lyster bags (widely used in the field by squads and small groups of soldiers for the treatment and storage of drinking water).

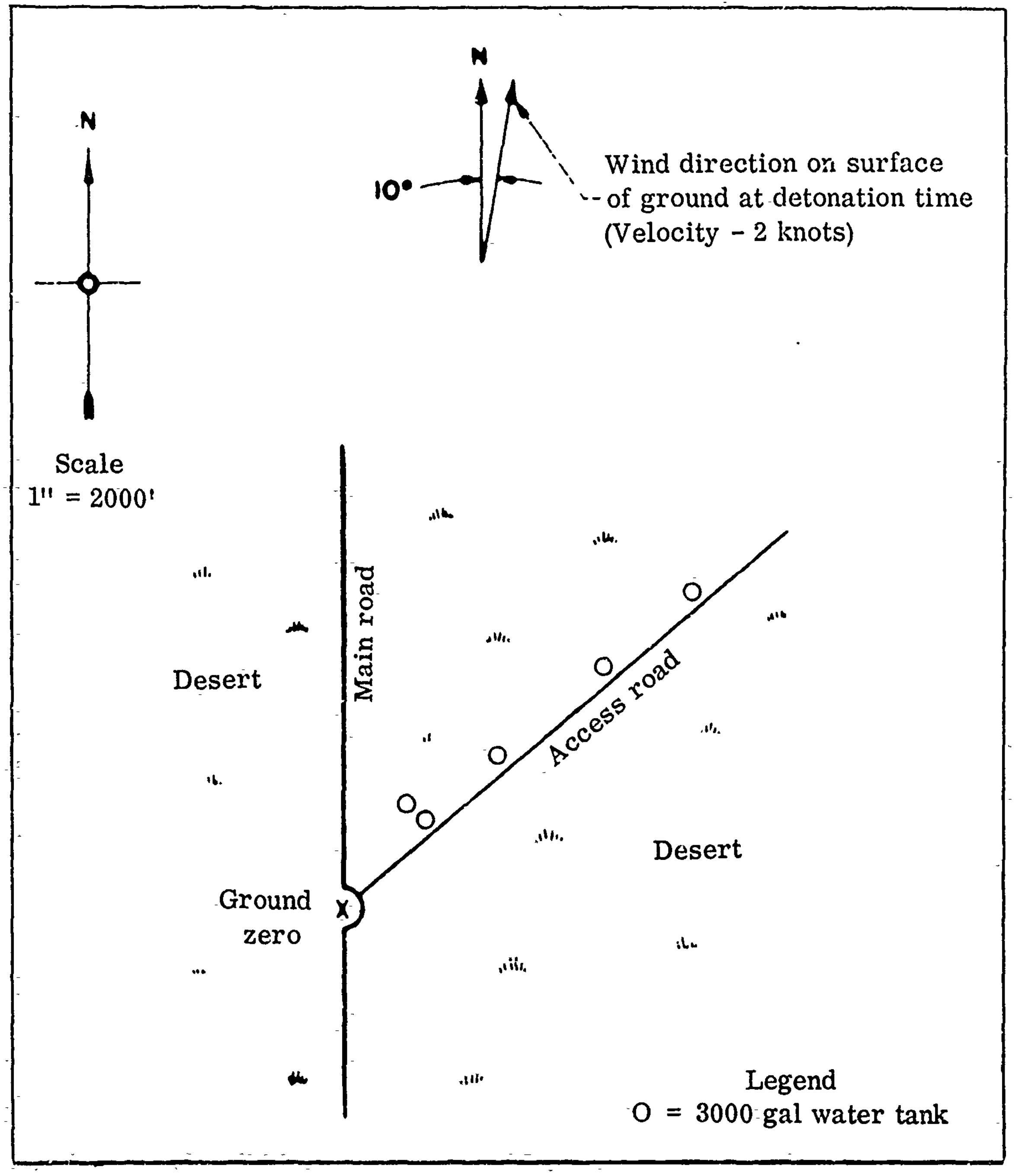

Fig. 2. Operation JANGLE: Location of water-storage tanks.

II. INVESTIGATION

3. General. Operation SNOWBALL was a weapons effect study involving the detonation of 500 tons of TNT and was conducted at the Suffield Experimental Station of the Canadian Government near Medicine Hat, Alberta. The 500-ton charge of TNT consisted of 30,600 cast blocks, each weighing 32.5 pounds and measuring 12 by 12 by 4 inches. The blocks were stacked on the surface so that the completed charge formed a hemispherical shape 17 feet high and 34 feet in diameter. A booster charge of 14 blocks (12 by 12 by 4 inches each) of tetrytol (70 percent tetryl, 30 percent TNT) was placed in the center of the mass (on the ground) with two lead azide detonators.

4. Description of Test. The following test tanks were used in the study:

1 each - FSN 5430-355-4486, Tank, Fabric, Collapsible, Nylon, Water, 3000 Gal. (Upright Cylinder).

4 each - FSN 5430-171-4401, Tank, Fabric, Collapsible, Nylon, Water, 1500 Gal. (Upright Cylinder).

1 each - FSN 5430-171-4518, Tank, Fabric, Collapsible, Nylon, Water, 500 Gal. (Upright Cylinder).

2 each - FSN C5430-835-3351, Tank, Fabric, Collapsible, Water, 3000 Gal. (Pillow).

1 each - Tank, Nylon, GR-S Coated, Mobile Water Storage, 700 Gal. Capacity (Pillow).

3 each - FSN 4610-268-9890, Bag, Water Sterilizing: Cotton Duck, Porous; Olive Drab; Stitched Seams; Suspension Ropes and Cover; 8 Faucets; 36 Gal.; MIL Spec B-273, Type II.

Weight characteristics of major components of these tanks are shown in Table II. Pertinent dimensions are shown in Table III.

Table II. Weight Information on Test Tanks

Tank	Weight (lb)					
	Tank Proper	Ground Cloth	Cover Cloth	Spreader Bars	Staves	Total
3000-gallon upright cylinder	175	41	62	18	99	395
1500-gallon upright cylinder	114	21	41	25	53	254
500-gallon upright cylinder	54	14	15	NA	18	101
3000-gallon pillow	190	NA	NA	NA	NA	190
700-gallon pillow	160	NA	NA	NA	NA	160
36-gallon lyster bag	53	NA	NA	NA	NA	53

Table III. Dimensional Information on Test Tanks
(Erected, Full of Water)

Tank	Key Dimensions	Sideview Silhouette (toward GZ) (upright cylinders; cover not included) (sq ft)	Ground Bearing Surface (sq ft)
3000-gallon upright cylinder	11'-3" dia 4'-6" deep	51	99
1500-gallon upright cylinder	7'-9" dia 4'-6" deep	35	47
500-gallon upright cylinder	5'-6" dia 3'-0" deep	17	24
3000-gallon pillow	12'-4" long 12'-4" wide 3'-8" high	45	152
700-gallon pillow	9'-9" long 7'-3" wide 2'-0" high	15	71
36-gallon lyster bag	1'-8" dia 2'-3" deep	4	2 (projected)

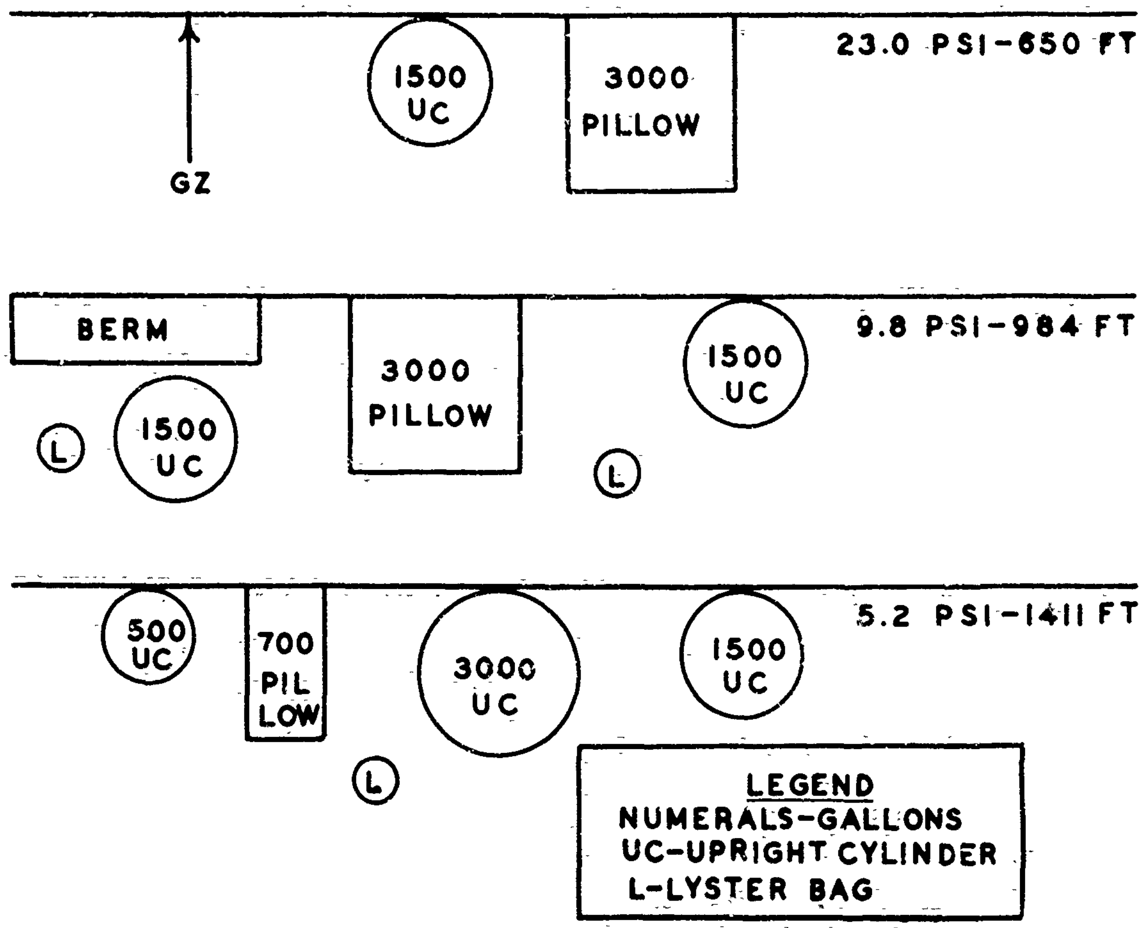

Fig. 3. Tank layout at three overpressure sites.

The tanks were installed at three locations (see Fig. 3) on a radial line from ground zero (GZ) and were filled with locally supplied tap water. The upright cylinders were covered, which is typical of field distribution tanks containing drinking water. The most remote site was located 1411 feet from GZ and consisted of an area approximately 65 feet perpendicular to the GZ radius and 25 feet wide. A 3000-gallon upright cylinder, a 1500-gallon upright cylinder, a 500-gallon upright cylinder, a 700-gallon pillow, and a 36-gallon lyster bag were installed at ground level without berm protection. An intermediate site, established at a point 984 feet from GZ, consisted of an area approximately 70 feet perpendicular to the GZ radius and 35 feet wide. A 1500-gallon upright cylinder, a 3000-gallon pillow, and a 36-gallon lyster bag were installed at ground level without berm protection. A 1500-gallon upright cylinder and a 36-gallon lyster bag were installed behind a protective berm (see Fig. 4). Predicted overpressures at the remote site and the intermediate site were 5.0 and 9.7 psi respectively (4).

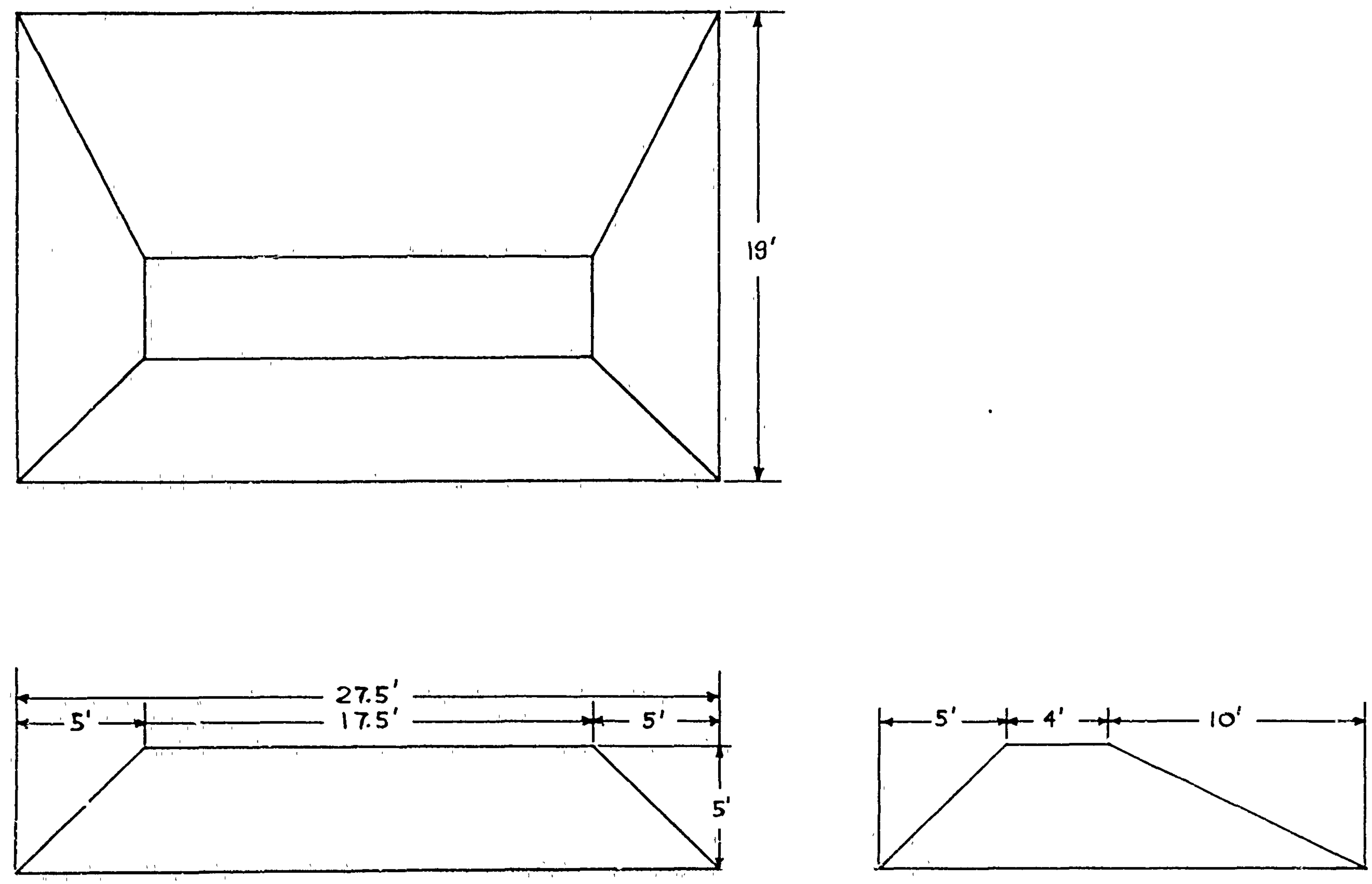

Fig. 4. Operation SNOWBALL: Dimensions of the earthen berm.

A third test site, 650 feet from GZ, occupied an area 15 by 35 feet. Since it was possible that the tanks placed at overpressure sites of 5.0 and 9.7 psi would not be destroyed or damaged seriously by the blast, it was decided to have a tank of each type in the 650-foot area where physical damage would be more probable. Both a 1500-gallon, upright-cylinder tank and a 3000-gallon pillow tank were utilized. Predicted overpressure for this location was 23.0 psi (4).

Samples of water from all tanks were taken both before and after the blast in order to evaluate the magnitude of air-borne contamination.

5. Methods of Analysis and Instrumentation. All water samples were analyzed by field type, analytical procedures developed by the Hach Chemical Company, Ames, Iowa.

Post-shot overpressure-distance curves and overpressure-time curves at the three sites were obtained from the U. S. Army Ballistic Research Laboratory.

Pre- and post-shot documentary photography, accomplished under SNOWBALL Project 9.9, was used to record the physical changes in the water containers. High speed film monitoring of the actual blast effects on the tanks at the three sites was also obtained.

6. Results. On 17 July 1964, at 1058 hours MST, 500 tons of TNT was detonated at the Suffield Experimental Station, Alberta, Canada. Post-shot visual observations of the three test sites, namely, at overpressures of 23.0, 9.8, and 5.2 psi (5), are recorded in Tables IV, V, and VI.

It is apparent, by comparison of Figs. 5 and 6, that severe damage was encountered at 23.0 psi.

At 9.8 psi, damage was evident (see Figs. 7, 8, and 9). The greatest damage at this area was to the unprotected, 1500-gallon, upright-cylinder tank. There was an 18-inch-long by 7-inch-high gash, 31 inches from the bottom of the tank, facing GZ. Upon draining and subsequent inspection of the tank, a $1\frac{1}{2}$-inch-diameter, 46-inch-long steel conduit section was found lying to the rear of the tank (see Figs. 10 and 11). All equipment in the 9.8-psi area was covered with a heavy layer of fine, grey dust. The 3000-gallon pillow tank survived both overpressure and missile damage. All tank covers of the upright cylinders were ripped off, and the water was contaminated with air-borne dust. The burned and dust-covered area was an area encompassed by a circle with an 1100-foot radius from GZ.

Table IV. Visual Blast Damage to Upright-Cylinder-Type Water Tanks

Item	Overpressures					
	23.0 psi	9.8 psi		5.2 psi		
	1500-Gallon	1500-Gal. (in open)	1500-Gal. (behind berm)	1500-Gallon	3000-Gallon	500-Gallon
Ground cloth	Undamaged.	Undamaged.	Undamaged.	Undamaged.	Undamaged.	Undamaged.
Top cover	Blown apart; pieces scattered 100 ft to front, 50 ft to sides, 175 ft to rear.	Pulled off completely; lying near side of tank.	Lying directly to rear, 4 ft; grommets ripped out.	Rear part lying in water.	Ripped off; thrown to rear; grommets pulled free.	Undamaged.
Guy ropes	All 4 pulled loose.	Front rope gone; one in place, two others on ground.	All 4 pulled loose.	One broken; others undamaged.	All in place.	Undamaged.
Tent pegs	2 of 4 gone. One 150 ft to rear.	2 of 4 in place.	3 of 4 in place; others broken.	One pulled loose and broken.	All 5 in place.	Undamaged.
Staves	5 of 10 broken or cracked.	Undamaged.	One of 10 cracked.	Undamaged	Undamaged.	Undamaged
Water: clean/dirty	Dirty.	Dirty.	Dirty.	Clean.	Clean.	Clean.
Tank: clean/dirty	Dirty.	Dirty.	Front dirty, rest clean.	Clean.	Clean.	Clean.
Water loss	1/2 gone.	1/2 gone.	ca. 100 gallons.	4 inches	1 inch	1 inch
Rips in tank	None.	Rip in front, 18 x 7 in.*	None.	None.	None.	None.
Spreader bar top (large)	Scattered pieces up to 75 ft to rear.	One hanging in rear; other 30 ft to rear.	Lying 10 ft to rear.	In place.	Pulled off and hanging to rear.	None used.
Spreader bar bottom (small)	Lost.	Pulled apart, but in place in tank.	In place.	In place.	In place.	None used.

* Rip in this tank in the shape of an inverted "T"; 18 in. long and 7 in. high. Damage due to missile.

Table V. Visual Blast Damage to Lyster Bags

Item	Overpressures		
	9.8 psi		5.2 psi
	Bag in open; 10 ft to front of other tanks	Bag behind berm	Bag in open
Water loss	1/2 gone.	1/2 gone.	Negligible.
Bag: Dirty/clean	Dirty.	Dirty.	Clean.
Bag condition	No tears; faucets undamaged; leaning 45^{o} to rear.	No tears; faucets undamaged; leaning 45^{o} to rear.	No tears; faucets undamaged; slight lean to front.
Water: Dirty/clean	Dirty.	Dirty.	Clean.
Tripod	Torn apart.	Mangled.	Undamaged.

Table VI. Visual Blast Damage to Pillow-Type Tanks

a. 23.0 psi

3000-Gallon Pillow Tank (in open) flattened into two pieces; no water left; nonrepairable.

b. 9.8 psi

3000-Gallon Pillow Tank (in open) very sound; dirty on outside only; no damage.

c. 5.2 psi

700-Gallon Pillow Tank (in open) very sound; previously applied patches peeling; no water loss.

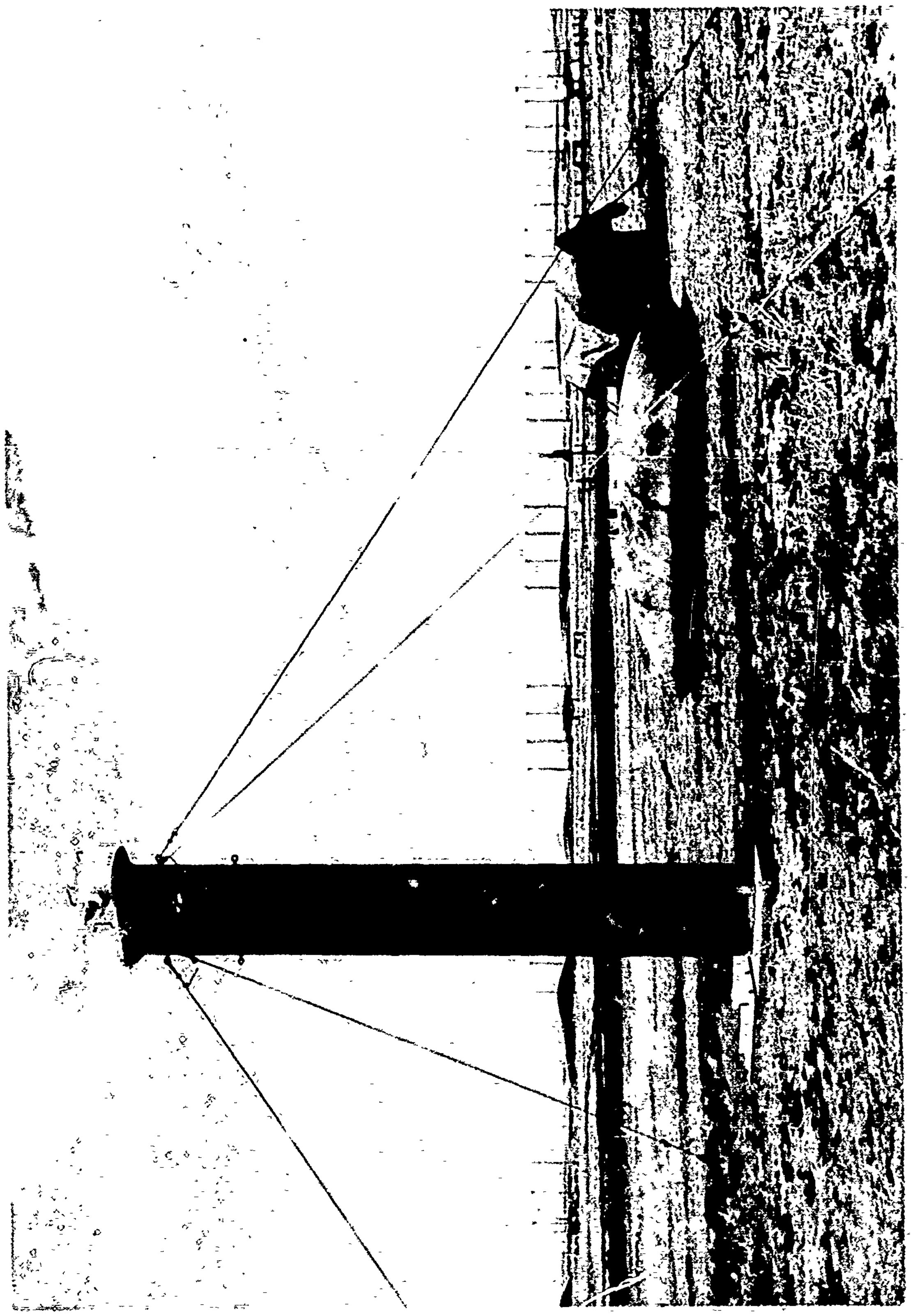

Fig. 5. Pre-shot view of tanks and camera tower at the 23.0-psi overpressure site.

Fig. 6. Post-shot view showing damage to 3000-gallon pillow and 1500-gallon upright, cylinder tanks at 23.0-psi overpressure site.

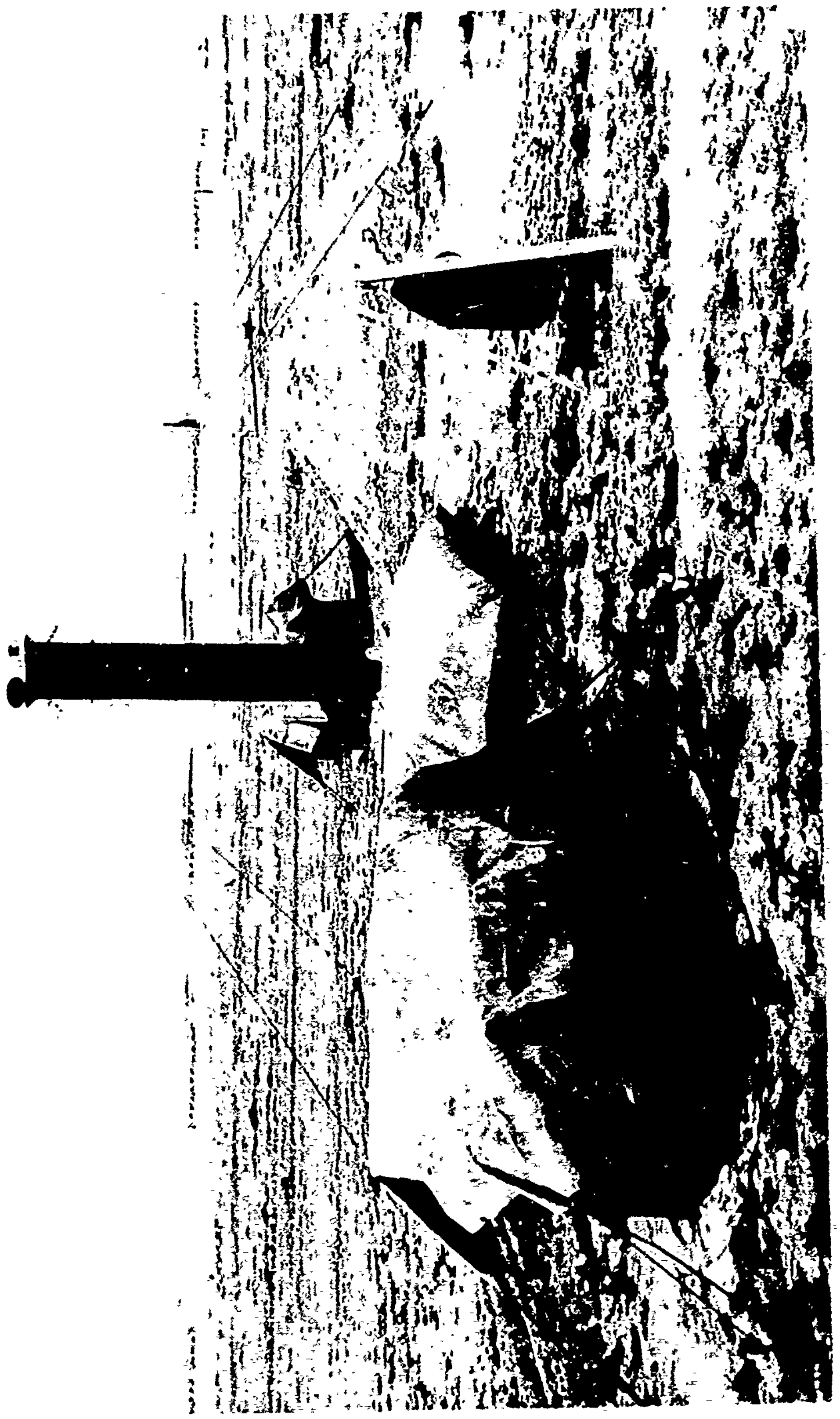

Fig. 7. Pre-shot view of 9.8-psi overpressure site.

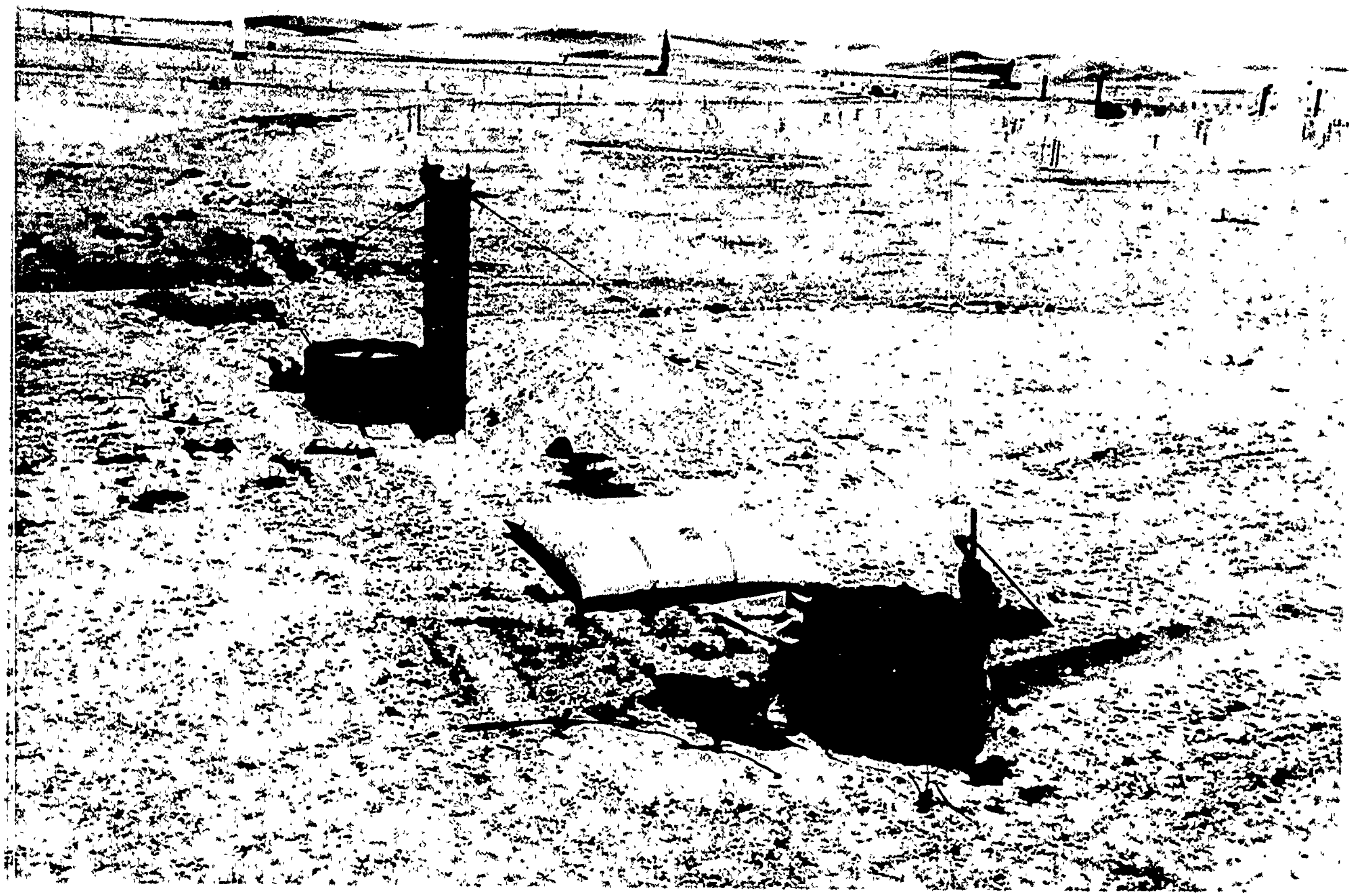

Fig. 8. Post-shot view of 9.8-psi overpressure site.

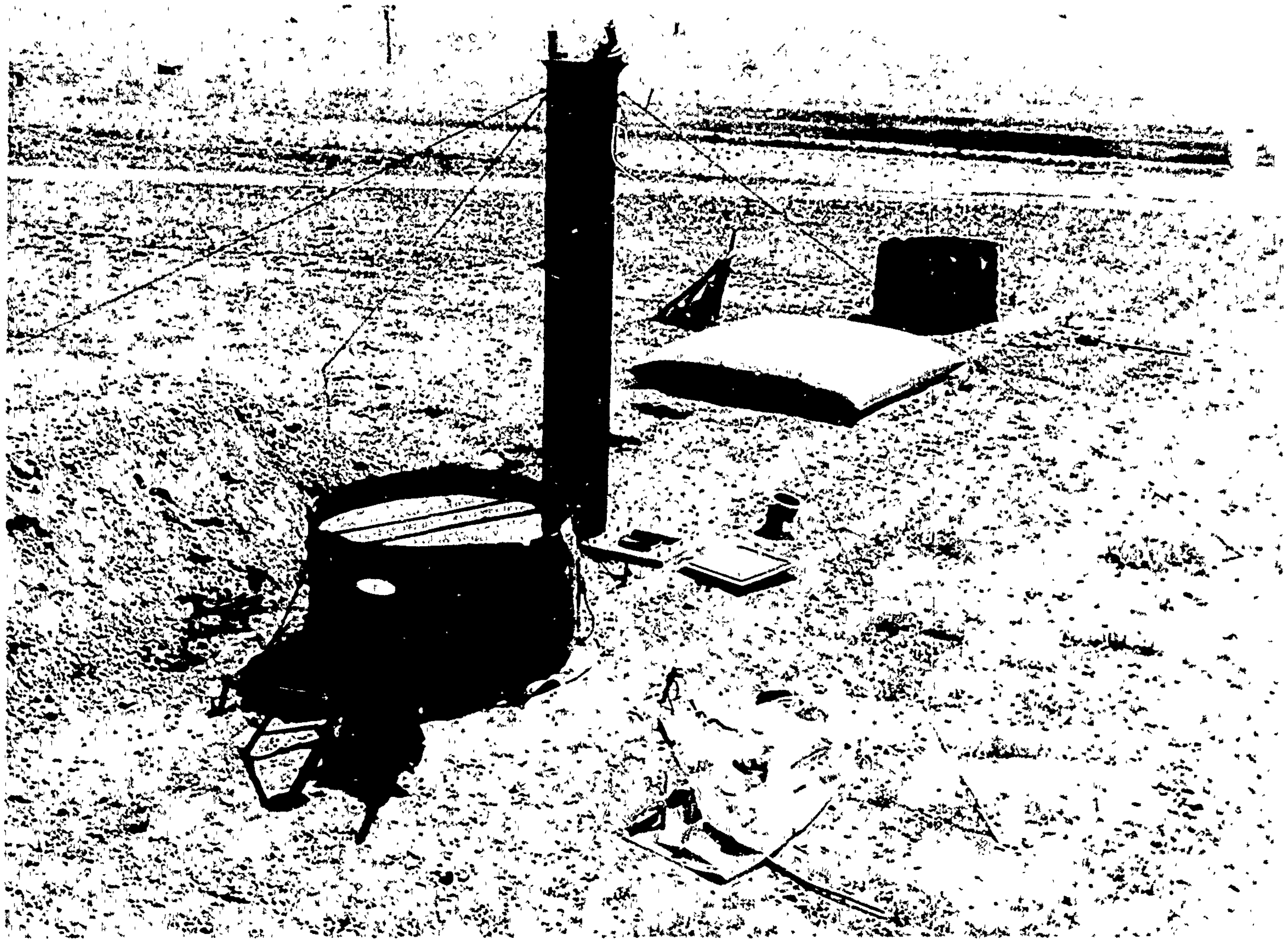

Fig. 9. Post-shot view of tanks and protecting earthen berm at 9.8-psi overpressure site.

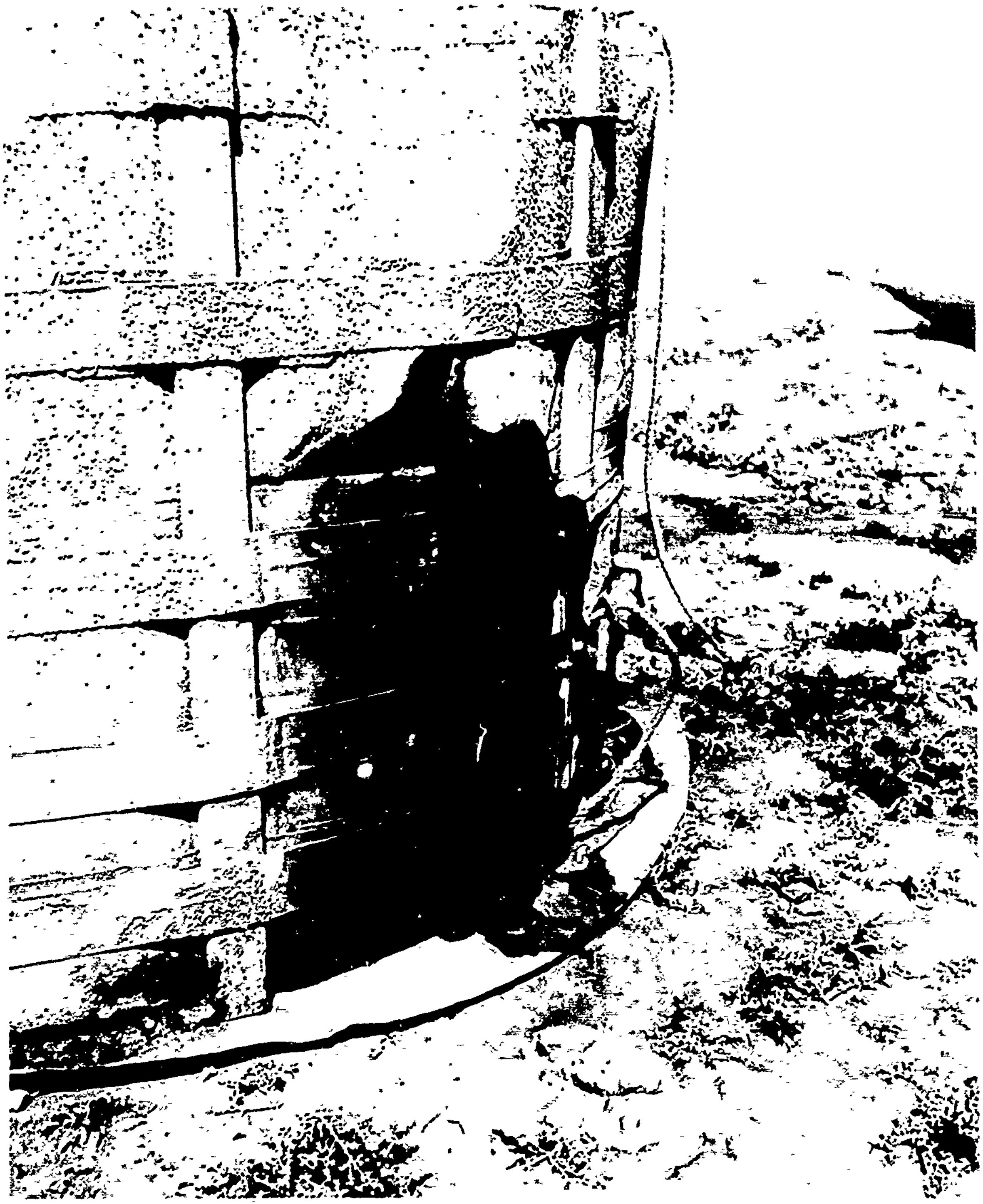

Fig. 10. Close-up of missile damage to 1500-gallon tank at 9.8-psi overpressure site.

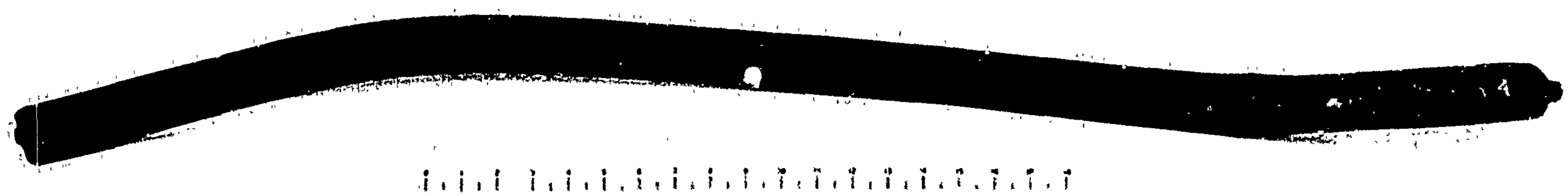

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Fig. 11. Missile recovered from 1500-gallon tank at 9.8-psi overpressure site.

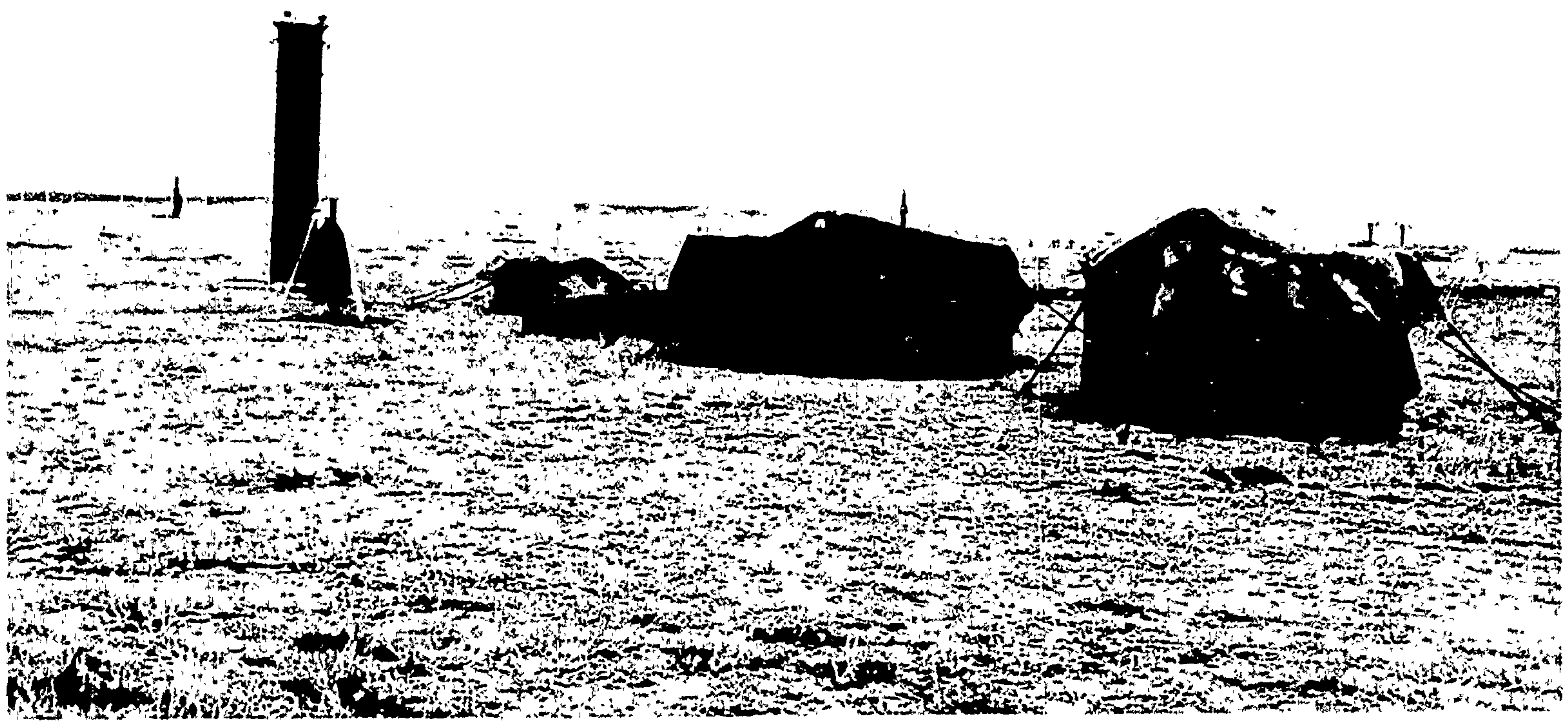


Fig. 12. Pre-shot view of tanks at 5.2-psi overpressure site.

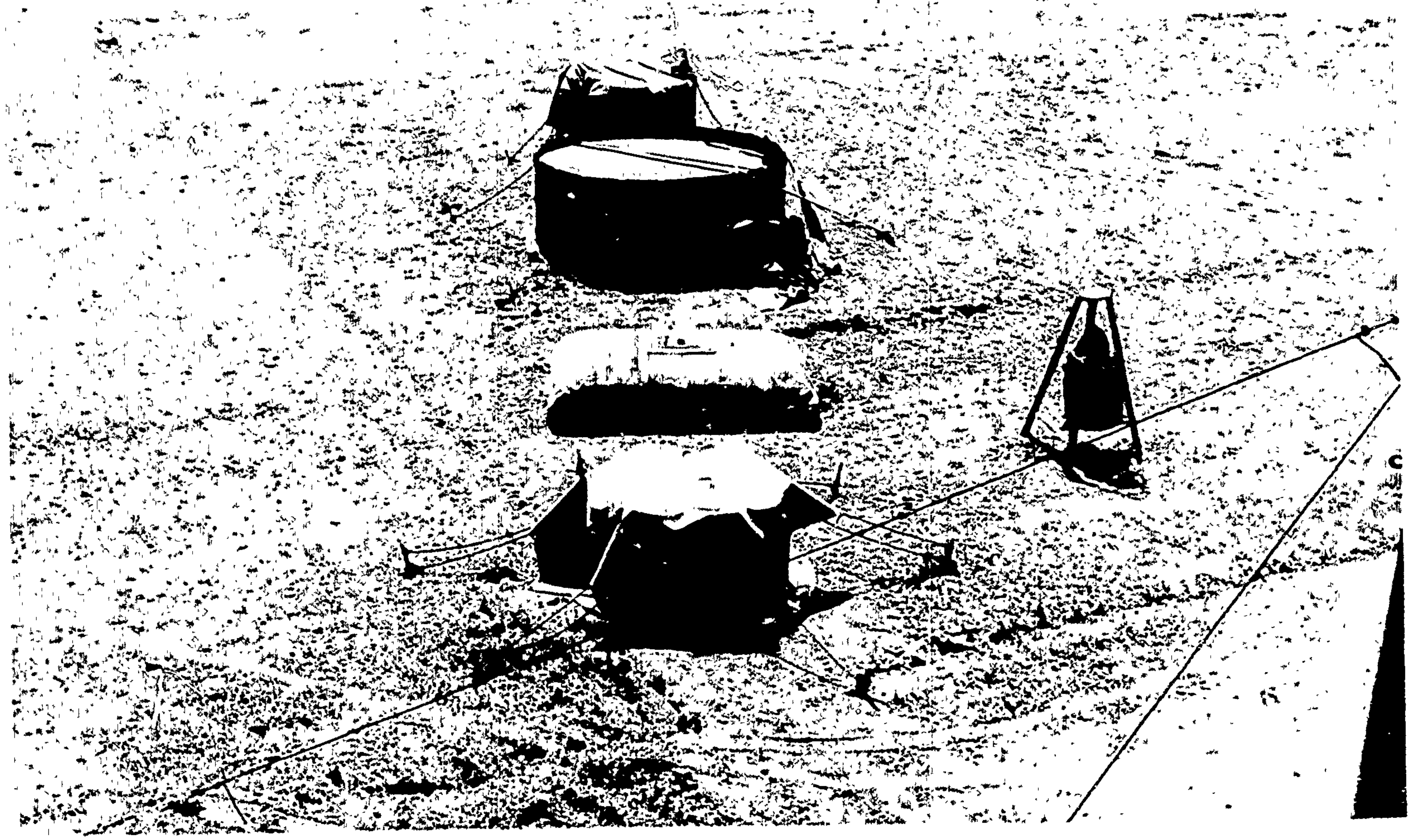


Fig. 13. Post-shot overall view of area at 5.2-psi overpressure site.

Since the 5.2-psi area lay beyond this 1100-foot radius, at 1411 feet, contamination of the water in the tanks at this area was minimal. Figures 12 and 13 show the blast effects on the water containers at 5.2 psi. The cover cloth on the 3000-gallon upright cylinder was ripped off, and the large spreader bar was thrown to the rear. Many of the metal grommets (ring loops) did not hold firmly. The cover cloth on the 1500-gallon tank had fallen into the rear of the tank due to a broken guy rope and a guy rope stake. Water loss was minimal.

The 500-gallon upright cylinder, 700-gallon pillow tank, and 36-gallon lyster bag essentially were undamaged.

Tables VII and VIII contain complete water analyses performed on all pre- and post-shot samples taken from all of the water containers. Pre-shot samples were taken at Z minus 3 hours; post-shot samples, at Z plus 30 minutes.

Technical photography was used to monitor the actual blast effects on the tanks. Four cameras were utilized: a C10a at 658.3 feet; a C11a, looking at the tanks protected by the earthen berm, and a C11b, looking at the unprotected tanks, both at 994.3 feet; and a C12a at 1421.0 feet. The frame rate was 64 frames per second. Times of interest included zero to plus 30 seconds.

Figures 14, 15, 16, and 17 show the passage of the blast wave through the three tank locations. In Fig. 14, the disintegration of the 3000-gallon pillow tank at an overpressure of 23.0 psi can be observed. Figure 15 depicts another 3000-gallon pillow tank sustaining an overpressure of 9.8 psi. However, the 1500-gallon, upright-cylinder tank has been damaged severely by a missile and the top cover cloth has been torn loose. Figure 16 shows the effects of the shock wave upon a similar 1500-gallon, upright tank at an overpressure of 9.8 psi with berm protection. Ejecta can be observed entering the tank. The 36-gallon lyster bag received heavy damage being covered with earth and grey particulate matter both externally and internally. The wooden tripod supporting the lyster bag was torn apart. At an overpressure of 5.2 psi (see Fig. 17), the cover cloths on both the 1500- and 3000-gallon, upright tanks are shown being ripped off. A similar type 500-gallon tank withstood the effects of the blast wave, although the cover cloth flapped violently.

Table VII. Pre-Shot Water Analyses[a]

Sample[b]	Total Hardness $CaCO_3$	Total Alkalinity $CaCO_3$	Chloride Cl	Silica $Si0_2$	Iron Fe	pH Units	Turbidity Units (Hellige)	Color Units
25-1500-B[c]	137	120	7	2.5	0.1	8.1	0.9	5
25-3000P-B	137	137	7	2.5	0.1	8.1	0.6	5
10-36b-B	137	137	7	2.5	0.1	8.2	1.8	5
10-1500b-B	137	137	7	2.5	0.1	8.0	0.7	5
10-1500-B	137	137	7	2.5	0.1	8.1	0.7	5
10-36-B	137	137	7	2.5	0.1	8.2	1.5	5
10-3000P-B	137	120	7	2.5	0.1	8.1	1.4	5
5-500-B	137	120	7	2.5	0.1	8.2	0.7	5
5-36-B	137	120	7	2.5	0.1	8.2	1.0	5
5-700P-B	137	137	7	2.5	0.1	8.1	0.7	5
5-3000-B	120	137	7	2.5	0.1	8.1	0.6	5
5-1500-B	137	120	7	2.5	0.1	8.1	0.7	5

(a) All analyses are expressed in parts per million (ppm).

(b) B - before
P - pillow
b - berm

(c) Sample 25-1500-B means a 1500-gallon, upright-cylinder tank in the 25-psi area before the blast, etc.

Table VIII. Post-Shot Water Analyses[a]

Sample[b]	Total Hardness $CaCO_3$	Total Alkalinity $CaCO_3$	Chloride Cl	Silica SiO_2	Iron Fe	pH Units	Turbidity Units[b] H	Turbidity Units[b] J	Color Units
25-1500-A	154	120	7	2.5	0.1	8.2	–	260	20
25-3000P-A[c]	–	–	–	–	–	–	–	–	–
10-36b-A	137	120	7	2.5	0.1	8.2	–	135	15
10-1500b-A	137	120	7	2.5	0.1	8.0	–	36	10
10-1500-A	137	120	7	2.5	0.1	8.2	10	–	10
10-36-A	137	137	7	2.5	0.1	8.1	14	–	10
10-3000P-A	120	120	7	2.5	0.1	8.0	0.9	–	5
5-500-A	137	137	7	2.5	0.1	8.3	0.7	–	5
5-36-A	137	120	7	2.5	0.1	8.1	1.5	–	5
5-700P-A	120	120	7	2.5	0.1	8.1	1.0	–	5
5-3000-A	137	137	7	2.5	0.1	8.1	0.6	–	5
5-1500-A	137	137	7	2.5	0.1	8.1	0.6	–	5

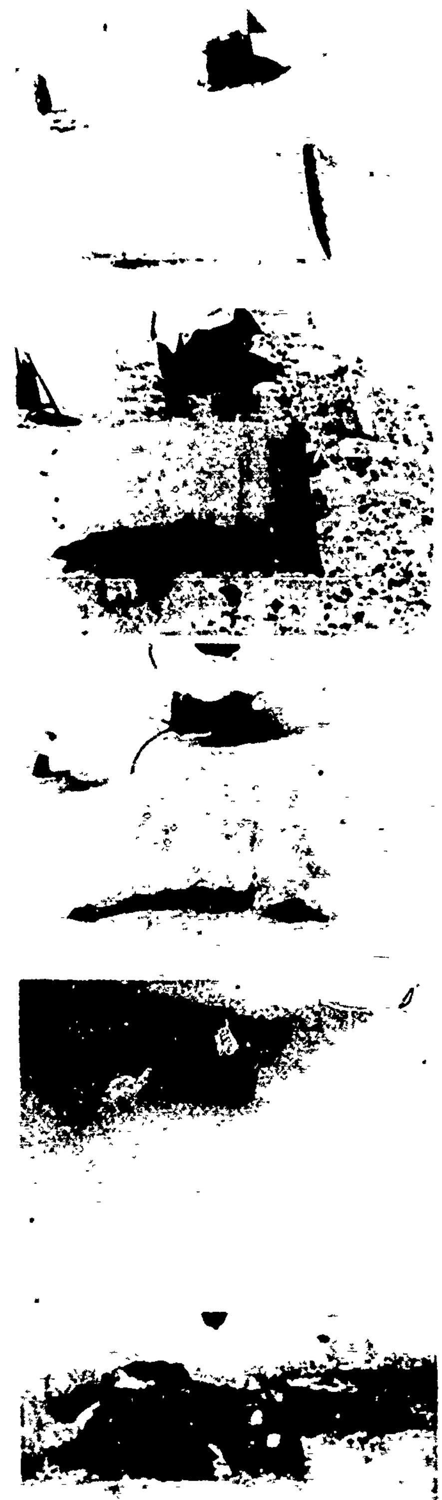
(a) All analyses are expressed in parts per million (ppm).

(b) H – Hellige
J – Jackson
A – after
P – pillow
b – berm

(c) Sample 25-3000P-A not taken; tank destroyed by blast.

M1001

Fig. 14. Effects of blast on water-storage containers at 23.0-psi overpressure (650 ft from GZ).



M1001

Fig. 15. Effects of blast on water-storage containers (no berm protection) at 9.8-psi overpressure (984 ft from GZ).

M1002

Fig. 16. Effects of blast on water-storage containers (with berm protection) at 9.8-psi overpressure (984 ft from GZ).

M1002

Fig. 17. Effects of blast on water-storage containers at 5.2-psi overpressure (1411 ft from GZ).

Table IX. Significant High Explosive and Nuclear Detonations

Location	Explosive Detonated	Weight Detonated (yield)	Calculated Distance from GZ, if Surface Burst; 10 psi Overpressure (feet)	Remarks
Climax, Colorado	HE	208 tons	750	Mining.
Suffield, Canada	TNT	500 tons	984 (measured at 9.8 psi)	Operation SNOWBALL.
Texas City, Texas	Ammonium Nitrate	1000 tons	1,300	Accident; ship explosion.
Ripple Rock, Canada	Nitramex 2H (Dupont)	1400 tons	1,400	Removal of navigational hazard.
Hiroshima, Japan	Nuclear	13 KT	2,400	Wartime.
Alamagordo, New Mexico	Nuclear	19 KT	2,700	16 July 1945 - start of nuclear age.
Red China	Nuclear	Not stated; perhaps 20 KT	2,700	--
Nevada Test Site	Nuclear	100 KT	4,700	Shot Sedan - largest continental shot.
Novaya Zemlya (USSR)	Nuclear	58 MT	39,000	Largest shot ever announced.

III. DISCUSSION

7. Analysis of Test Results. The 500-ton TNT detonation at the Suffield Experimental Station is believed to be the largest, single, manmade, non-nuclear, unconfined surface blast in history. Table IX compares this shot with other important and significant detonations. The detonations are listed in ascending order of yield. The blast and shock results obtained under this project with the 500-ton detonation should be viewed in the light of recognized vulnerability-assessment criteria. For the purposes of this project, the blast phenomenon is best described in terms of peak overpressure developed by the shock wave. The U. S. Military and Civil Defense, for convenience in describing blast damage and protective measures, divide the area surrounding a detonation into three zones as shown in Table X (6):

Table X. Blast Damage Zones

Zone	Overpressure (psi)	Maximum Wind Velocity (mph)	Damage
1	Greater than 10	Greater than 280	Severe
2	3 to 10	100 to 280	Moderate
3	1/2 to 3	25 to 100	Light

The three blast locations in this study fell into the anticipated damage categories as shown in Table XI.

Table XI. Anticipated Blast Damage - This Study

Blast Line, This Study (psi)	Zone	Anticipated Damage
23.0	1	Severe
9.8	2	Moderate
5.2	2	Moderate

The vulnerability-assessment criteria and consideration of the data obtained indicate that pillow and upright water-storage tanks (except for the top cover and spreader bars) can withstand explosive shock effects up to an overpressure of 9.8 psi, or to near the limit where severe damage commences. Also, all rubberized-fabric, water-storage tanks, whether in the open or protected by an earthen berm, are subject to severe damage from flying debris regardless of overpressure. The weak point of upright cylinders is the top cover. Even though lashed down securely, the top cover was vulnerable to damage by wind associated with overpressures as low as 5.2 psi.

The question of water contamination by a large nuclear detonation was answered in part by the trial results. It is noted that the 0.5-KT TNT detonation approximately was equivalent in shock to a 1.0-KT nuclear explosion. Of the three pillow tanks exposed to the shot, one failed completely and the other two sustained no damage. As expected, the two surviving pillow tanks showed no water contamination. With reference to the tanks of the upright-cylinder type, only one of the six exposed--the 500-gallon tank at 5.2 psi--sustained no damage or forced removal of the cover sheet. The survival of the 500-gallon tank was attributed to the fact that this tank was at the lowest overpressure point and also had the lowest silhouette. However, high speed photographic coverage indicated that the cover sheet was blown up and down during the passage of the shock wave. The other two upright-cylinder tanks at 5.2 psi sustained some cover damage but very little water contamination. They were out of the heavy dust zone which extended to a radius of 1100 feet from GZ. At this distance, the measured overpressure was 8.0 psi. The greatest water contamination occurred in the 1500-gallon tank at 23.0 psi where the turbidity level rose from 0.9 to 260 units. The tank also lost half of its water volume, leaving only about 750 gallons. The figure of 260 units was obtained by measuring a sample of the supernatant liquid taken from the tank without stirring, at Z plus 25 minutes (the turbidity would have been much higher had the bottom residue been stirred before sampling). The rise in the level of turbidity to 260 units can be used to estimate the possible level of radioactive concentration if the detonation had been nuclear.

A nuclear explosion releases radioactive dust or fallout as a result of the following:

a. Fission products.

b. Uranium or plutonium which has escaped fission.

c. Induced radioactivity resulting from the neutron bombardment of: (1) components of the soil or air, (2) dissolved minerals in water, or (3) materials of construction of the bomb itself.

So-called "salted" weapons conceivably could be used to produce specific water contaminants, i.e., weapons containing some chemical that would be made radioactive by neutron activation.

The relative importance of these three types of contamination depends principally upon whether the weapon was primarily of the fission or fusion type. Generally speaking, however, the most significant type of contamination is considered to be that of fission products. Fission products are complex mixtures of some 200 isotopes of 36 elements (zinc to terbium on the atomic chart). Most of these isotopes are radioactive and decay by the emission of beta particles frequently accompanied by gamma radiation. The composition of the fission products is not absolutely fixed but depends upon statistical formation and also, from a practical point of view, upon "fractionation." [2]

For fission product contamination 1 hour after detonation, approximately 550,000 megacuries, or 125 pounds, of radioactive materials are released per megaton of blast. The fission products then decay according to the "1.2 law," i.e., when activity is plotted against time on log-log paper, a straight line is obtained with a negative slope of 1.2. It has been calculated that the fission products from a 1-megaton explosion, spread evenly over a 10,000 square mile area, would give a radiation intensity of 6 roentgens per hour at a level of 3 feet above the ground, 24 hours after the blast (7).

More realistically, however, the fission products do not spread evenly but form a circular or cigar-shaped pattern around ground zero with the heaviest deposition close to ground zero and diminishing at farther distances out. The exact shape and size of the fallout pattern depends on many conditions, but usually the height of burst, with particular reference as to whether or not the fireball touches the ground, and the wind are the major controlling factors. Surface bursts give smaller but more highly radioactive patterns than air blasts.

Accurate, detailed, fallout pattern information from the detonation of nuclear devices, particularly the detonation of large nuclear devices,

2. "Fractionation" is a term applied to the separation of fission products, once formed, into enriched and lean portions as a result of selected condensation during the cooling of the fallout particles. For instance, certain fallout material could be richer in strontium-90 than other fallout material, depending upon the condensation behavior of the ancestral (precursor) material (rubidium-90).

is quite limited in its availability. The megaton range information originating at the Eniwetok Proving Grounds must be inferred from relatively few samples taken over the ocean. Furthermore, the presence of sea water in the fallout affects the results. Nuclear tests at the Nevada Test Site have been confined to yields of 100 kilotons and less, and the results have been influenced by such factors as the presence of towers. However, some idea of an actual fallout pattern can be obtained from the TURK shot (7) at the Nevada Test Site. The TURK shot was detonated with a yield of 43 kilotons on 7 March 1955 from a 500-foot tower. The fallout pattern from this shot was very irregular, not at all typical of the idealized cigar-like patterns. At 12 hours after detonation, the dose rate in the direction of the heaviest fallout was as shown in Table XII.

Table XII. Fallout Intensity (Shot TURK)

Dose Rate (mr/hr)	Distance from Ground Zero (feet)
1000	150,000
100	190,000
10	360,000
1	400,000

These dose rates would be several orders of magnitude higher if a large megaton weapon were employed. As noted previously, the largest single nuclear detonation ever reported in the open literature was the Russian shot of 30 October 1961 (58 megatons). If this were a so-called "dirty" weapon (i.e., principally fission), very severe contamination of thousands of square miles may have resulted.

Although samples of contaminated soil resulting from heavy fallout are relatively difficult to obtain, samples have been obtained, upon occasion, in connection with water decontamination studies. For example, a sample of surface soil was obtained from the LITTLE FELLER I nuclear event. This detonation occurred on 17 July 1962 at the Nevada Test Site. The sample was taken 2 days after detonation at the 10 r/hr line and analyzed a week later when it measured 45 microcuries per gram (8). A specific activity of 45 microcuries per gram translated into a water contamination of 259 turbidity units (260 - 0.9) gives a figure of 11,700,000 picocuries per liter. Other pertinent water level contaminations are shown in Table XIII. Since the Maximum Permissible Concentration for radioactive fission products in drinking water is 300,000 picocuries per liter for 1-year consumption (established by The Surgeon General's Office for the U. S. Army under wartime conditions), all of these waters would require decontamination before use.

Table XIII. Calculated Radiological Water Contamination

Tank	Overpressure (psi)	Turbidity (units) Before Shot	After Shot	Calculated Contamination (picocuries per liter)
1500-gallon upright cylinder	23.0	0.9	260	11,700,000
36-gallon lyster bag (behind berm)	9.8	1.8	135	6,000,000
1500-gallon upright cylinder (behind berm)	9.8	0.7	36	1,600,000
36-gallon lyster bag	9.8	1.5	14	560,000
1500-gallon upright cylinder	9.8	0.7	10	420,000

In view of the contamination that can occur to water stored in rubberized-fabric, upright cylinders, consideration should be given to the utilization of the pillow tank which provides very good protection from contamination. The pillow tank also has other advantages. It is lighter in weight and takes less volume in shipping. Basically, it is simpler in construction and has few appurtenances. It is easier to erect and install and takes less time to do so. Its silhouette is lower and is, therefore, less subject to damage from flying debris. However, on the debit side, the present pillow tank is difficult to drain completely, is almost impossible to clean thoroughly on the inside, and cannot be used effectively for purposes other than water storage, e.g., for chemical pretreatment. Also, the water in a pillow tank cannot be observed conveniently.

Because of the many considerations involved, the two tank types should be studied further for optimum application to the field by the U. S. Army.

IV. CONCLUSIONS

8. Conclusions. It is concluded that:

a. Rubberized-fabric, water-storage tanks, both of the pillow and the upright-cylinder type, with the exception of the hipped-type top cover cloth used with the 1500- and 3000-gallon tanks, can withstand the shock effects from a high explosive detonation up to a 9.8-psi overpressure.

b. All rubberized-fabric, water-storage tanks situated in the open, without berm protection, are subject to severe damage from flying debris emitted by a high explosive or nuclear detonation regardless of overpressure.

c. Earthen berms offer some degree of protection against flying debris but afford only limited shielding to air-borne dust brought in by wind associated with the blast.

d. The weakest part of the rubberized-fabric, upright-cylinder, water-storage tank from the point of view of blast damage is the top cover cloth. Even when lashed down securely, the cover cloth is subject to damage (ripping and tearing in the vicinity of the metal grommets) by the wind associated with overpressures as low as 5.2 psi.

e. Water stored in rubberized-fabric, upright-cylinder-type tanks, at overpressures equal to or greater than 9.8 psi, can become contaminated with sufficient air-borne dust to be above the Maximum Permissible Concentration for radioactively contaminated water if the detonation is nuclear.

f. Water contained in fabric, water-storage tanks of the pillow type does not become contaminated with air-borne dust from a high explosive or nuclear detonation.

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APPENDIX

AUTHORITY

RDT & E ~~PROJECT~~ TASK CARD

1. TYPE OF REPORT: ☐ NEW ☐ FINAL [X] REPLACES (No. & Date) 1D64303D55107, 1 Jan 63

REPORT CONTROL SYMBOL: CSCRD-1 (R3)

2. ~~PROJECT~~ TASK TITLE: Removal of CBR Contaminants from Water (U)

3. SECURITY OF ~~PROJECT~~ TASK: Unclassified

4. ~~PROJECT~~ TASK NO.: 1M624101D55107

5. 6.21.41.01.1

6. REPORT DATE: 1 January 1964

7. ~~XXXXXXXXXXXXXXX~~ RD-CAT: Exploratory Development

8. SUB FIELD OR SUBJECT SUB GROUP:

9. CATEGORY: AR

10a. COGNIZANT AGENCY: AMC-MOCOM

b. DIRECTING AGENCY: MOCOM-ERDL

c. REQUESTING AGENCY: CDC

11a. CONTRACTOR AND/OR GOVERNMENT LABORATORY: USAERDL, Ft Belvoir, Va

b. CONTRACT NUMBER:

12. PARTICIPATION BY OTHER MILITARY DEPTS. AND OTHER GOVT. AGENCIES: Munition Command (facilities, equipment)

14. SUPPORTING PROJECTS:

18. EST. COMPLETION DATES: DEV.: ENGR TEST.: USER TEST: OPERATIONAL:

13. COORDINATION ACTIONS W/OTHER MILITARY DEPTS. & OTHER GOVT. AGENCIES: Army Medical Service; Office of Civil Defense

15. DATE APPROVED: March 1960

16. PRIORITY: II

17. BUDGET CODE: 5600

19. EST. SUPPORT LEVEL:
- [X] UNDER $50,000
- ☐ $50,000 - $100,000
- ☐ $100,000 - $250,000
- ☐ $250,000 - $500,000
- ☐ $500,000 - $1,000,000
- ☐ OVER $1,000,000

20.

21. SPECIAL CODES: 5627.12.762

22. REQUIREMENT AND/OR JUSTIFICATION

Requirements are referenced in CDOG para 1439c(9), 612j.

There is a requirement for determination of the effectiveness of Army field water purification equipment and processes now standard and under development for removing chemical, biological, and radioactive agents from water to be used for drinking and other purposes. This requirement has been established by the threat of new and more efficient agents and weapons of war.

23. BRIEF OF TASK AND OBJECTIVE

a. Brief:

The problem involved in this task is to determine the capabilities and limitations of Army field water supply equipment and water treatment processes now standard or under development for purifying water containing chemical, biological, and radiological contaminants.

b. Approach:

The approach to the CBR water decontamination problem is outlined in the following scientific plan:

(1) Definition of Problem. Establish the probable significant CBR agents as water contaminants, and the probable level of water contamination. Relate this to currently established Maximum Permissible Concentrations, and sensitivity of methods of detection.

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TASK RDT & E ~~PROJECT~~ CARD CONTINUATION	REPORT DATE 1 January 1964	~~PROJECT~~ TASK NO. 1M624101D55107

(2) Evaluation of Decontamination Methods and Equipment. Evaluate decontamination processes in the laboratory, followed by full-scale field testing. Utilize live CBR agents in most instances, except that in certain BW studies "simulants" (non-pathogens) could be employed. Exercise all necessary safety precautions, including the use of protective clothing.

(3) Reporting of Results. Report results at intervals as data become available in formal USAERDL reports. Recommend changes in field water supply procedures or developments of new processes and equipment to remove CBR contaminants from drinking water.

c. Tasks. N/A

d. Coordinated Test Plan (CTP).
The studies conducted under this task will be coordinated with the following Federal Agencies:

(1) U. S. Army CBR Agency - Furnishes laboratory information on CW and BW decontamination methods, and provides guidance on agent selection, detection, protective clothing, and safety measures.

(2) Atomic Energy Commission - Provides RW testing facilities, such as Nevada Test Site.

(3) Defense Atomic Support Agency - Jointly sponsors with USAERDL certain subtask work on RW decontamination.

(4) United States Public Health Service - Jointly sponsors with USAERDL certain sub-task work on RW decontamination.

(5) Office of Civil Defense - Jointly sponsors with USAERDL certain sub-task work on CBR decontamination.

(6) U. S. Army Medical Service - Jointly sponsors with USAERDL certain subtask work on CBR decontamination.

(7) U. S. Army Test and Evaluation Command - Technical Liaison.

(8) Department of the Navy - Liaison.

(9) Department of the Air Force - Liaison.

e. Other Information: None

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