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NWC TP 5430

ESKIMO I Magazine Separation Test

by

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Naval Weapons Center
CHINA LAKE, CALIFORNIA ■ APRIL 1973

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ABSTRACT

In a fully instrumented test in December 1971 at China Lake, Calif., 200,000 pounds of TNT explosive contained in 155-mm projectiles were detonated simultaneously in an earth-covered magazine surrounded by four earth-covered igloos placed at various distances from the donor magazine. The principal objective was to evaluate magazine spacing. Based on data from this and previous tests, the Department of Defense Explosives Safety Board reduced the separation distances for earth-covered steel-arch magazines to 2.0 $\times$ $W^{1/3}$ for face-to-rear orientations and 2.75 $\times$ $W^{1/3}$ for face-to-side orientations. The report contains data on fragment sizes and distribution, igloo damage and structural motion, and blast pressures at the site.

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FOREWORD

This report describes a full-scale magazine separation test conducted at the Naval Weapons Center in December 1971. The test work was conducted for the Department of Defense Explosives Safety Board (DDESB) using funds provided by that organization. The work was identified by Army Program Element Number 6.57.02.A and Project and Task Area Number 4A765702M8570.

Based on data derived from the test, DDESB has made significant adjustments in criteria for magazine spacing.

This report has been reviewed for technical accuracy by DDESB staff members.

Released by
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9 March 1973

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CONTENTS

INTRODUCTION

The Department of Defense Explosives Safety Board (DDESB) is engaged in a program to determine more accurately minimum safe separation distances between magazines storing explosives. These distances are the least that will provide assurance that an explosion in one magazine (donor) will not propagate to another (acceptor), although the acceptor magazine, and possibly its contents, might be extensively damaged.

Previous tests have demonstrated that earth-covered steel-arch igloo magazines can be safely spaced side-to-side at a distance in feet determined by $1.25 \times W^{1/3}$, in which W is the weight in pounds of the high explosive in storage. However, little information has been developed which will indicate the minimum safe distance between the concrete headwall of a magazine and the earth-covered side and rear walls and barricaded headwall of another magazine. The most recent data (obtained from a test in 1962) showed that a spacing of $4.5 \times W^{1/3}$ for a face-to-rear orientation was quite conservative (Ref. 1). Increasing land values and siting problems for new and projected construction have made it desirable to further evaluate this separation standard. The ESKIMO I test was designed for this evaluation. (ESKIMO is an acronym for Explosive Safety Knowledge IMprovement Operation.)

ESKIMO I was conducted at the Randsburg Wash Test Range of the Naval Weapons Center, China Lake, Calif., on 8 December 1971.

PRINCIPAL CONCLUSIONS

Based on the results of this test and supporting data from previous tests, DDESB has authorized the following new separation distances for earth-covered steel-arch magazines without intervening barricades:

Face-to-rear orientations: $2.0 \times W^{1/3}$
Face-to-side orientations: $2.75 \times W^{1/3}$

DDESB also adjusted the spacing requirements for face-to-face orientations to $11 \times W^{1/3}$ without an intervening barricade and to $6 \times W^{1/3}$ when a substantial barricade exists between the igloos.

Additional conclusions are given in the Conclusions section.

TEST OBJECTIVES

The principal test objective was evaluation of igloo magazine spacing. Other objectives were

1. Measurement of fragment mass and distribution resulting from the mass detonation of typical high-fragmentation ammunition stored in a standard earth-covered igloo.
2. Measurement of air blast in the area surrounding such an explosion.
3. Measurement of the structural motion of an earth-covered igloo in response to the explosion in an adjacent magazine.

GENERAL PLAN

Four igloos of standard height and width were placed about a donor magazine which contained 200,000 pounds of high explosive. The four acceptor igloos faced the donor and were located at various distances ranging from $1.25 \times W^{1/3}$ to $2.75 \times W^{1/3}$. Two concrete block structures simulating one type of Air Force storage building were also placed in the area at distances of $2.0 \times W^{1/3}$. Fig. 1 and 2 show the arrangement.

In order to obtain data on the distribution of fragments resulting from a magazine explosion, 155-mm projectiles were used as the explosive in this experiment. Most of the previous testing has been with bulk high explosive or with ordnance having a low metal-to-explosive ratio, and so only a small amount of data has been obtained on fragment hazard. To measure fragment distribution in this test, three radial sectors of terrain were cleared of brush and debris and smoothed by a bulldozer to provide fragment collecting areas. In addition, a B-29 aircraft was placed 1,800 feet from the donor magazine to obtain information on fragment damage that might be incurred by an aircraft at that distance from such an explosion.

To measure overpressure within and near the igloos, the Mason & Hanger Silas Mason Co., Inc., under contract to the Atomic Energy Commission, installed gauges and recorders at the test site. Appendix A contains extracts from the company's report of these measurements. Other overpressure measurements were made by NWC.

About 20 minutes after the detonation, Air Force aircraft were allowed to fly over the test site to determine the extent to which aerial IR surveys could be used to detect and count steel and concrete fragments. Appendix B contains unclassified extracts from an Air Force report of these flyover operations.

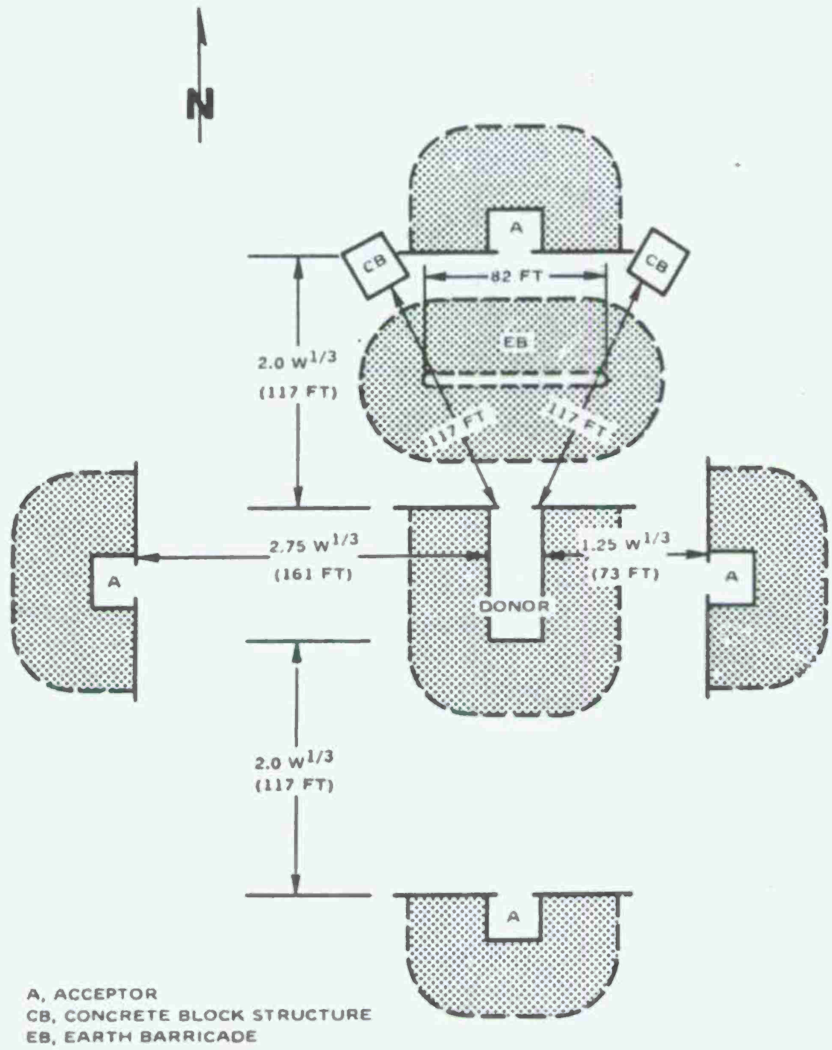


FIG. 1. Layout of Test Structures for ESKIMO I Magazine Separation Test.

FIG. 2. Aerial View of Test Complex, Looking Southeast.

TEST STRUCTURES

The donor magazine (Fig. 3) used for this test was a slightly damaged 59- by 25-foot steel-arch igloo that was one of two acceptor structures remaining from a 1963 magazine separation test. New standard steel magazine doors were put on this donor magazine, and the compacted earth cover was repaired, with a slope of 1 in 2. The donor charge in this magazine consisted of 200,000 pounds of TNT contained in 13,696 155-mm M101 projectiles. These were installed in the magazine in 1,712 pallets at eight to the pallet.

Four acceptor steel-arch igloos (Fig. 4, 5, and 6) were built at various distances from the donor igloo to measure the effects of the 200,000-pound explosion. Each of these 25-foot-wide by 14-foot-high igloos was built in accordance with the Office of the Chief of Engineers, U.S. Army, standard drawing AW-33-15-64, except that their length was limited to 20 feet, steel wing walls were used in lieu of concrete, and the ventilating and lighting equipment was omitted in order to reduce the costs. The igloos were covered by 90% compacted earth to a 2-foot depth at the top of the arch, with side slopes of 1 in 2. They were located along the center lines of the donor magazine, as shown in Fig. 1, at the distances shown in that figure. The floors of the acceptor igloos to the north, east, and south of the donor magazine were placed level with the donor floor. The floor of the west acceptor igloo was 4.5 feet lower than the other floors because the site had to be scraped down to make it level.

Two 20-foot-wide and 25-foot-long storage structures (Fig. 7) were built near the corners of the north acceptor igloo, with their solid front wall 117 feet from the nearest corner of the donor magazine. The walls of the structure were concrete

FIG. 3. Donor Magazine. Separation of wing wall from headwall was caused by 1963 test.

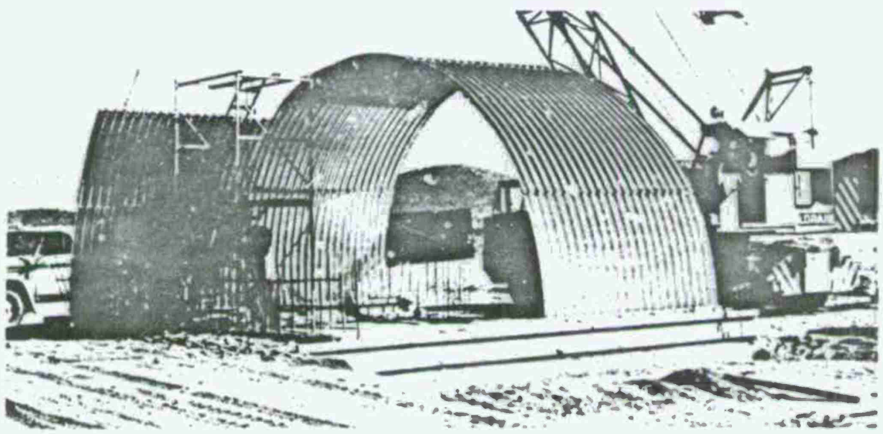


FIG. 4. Construction of Acceptor Igloo, Showing Attachment of Steel Arch.

block, the floors were omitted, and the roof was wooden. The construction details were in general conformance with Department of Air Force drawing AD 33-13-17.

A 15.5-foot-high earth barricade (uncompacted) was installed between the donor magazine and the north acceptor igloos with the toes of its side slopes 25 feet from the acceptor and 27 feet from the donor. This barricade can be seen in Fig. 2. It was 3 feet thick at the top and had side slopes of 1 in 2. Its length of 82 feet at the top provided a barrier between the donor igloo and the array of the north acceptor igloo and the two acceptor storage buildings beside it.

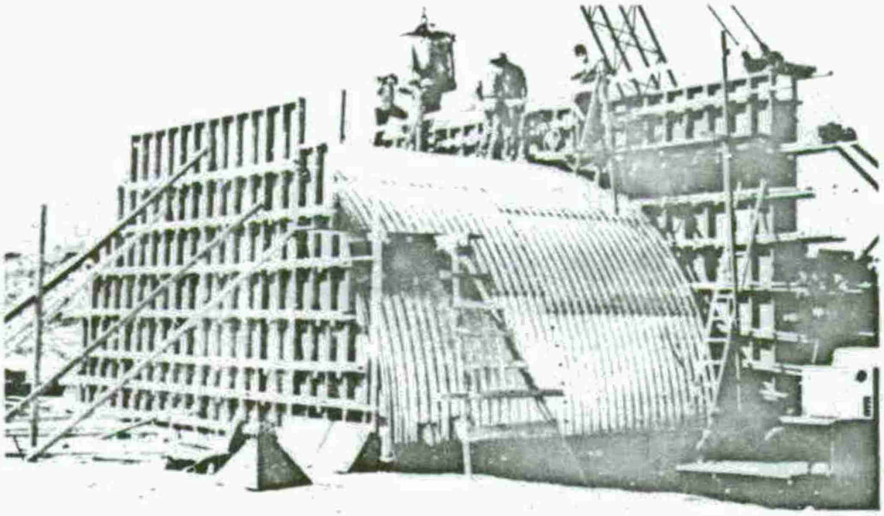


FIG. 5. Pouring Concrete Headwall of Acceptor Igloo.

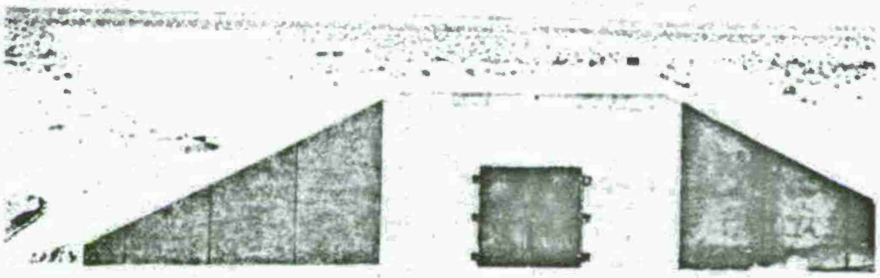


FIG. 6. Front Face of West Acceptor Igloo as Seen From Top of Donor Magazine.

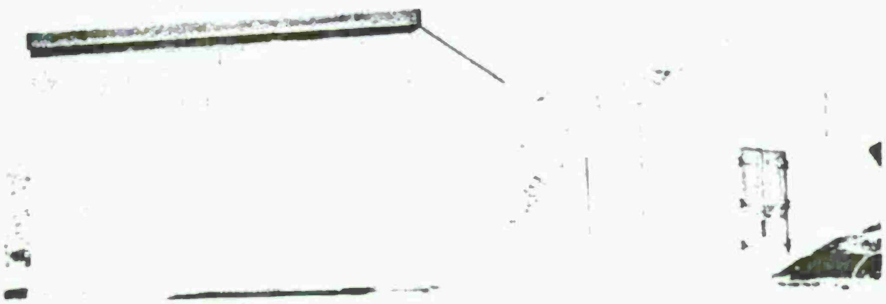


FIG. 7. Northwest Concrete Block Structure Adjacent to North Igloo.

DONOR AND ACCEPTOR CHARGES

The 1,712 pallets of 155-mm projectiles were stacked in the donor igloo in general accordance with U.S. Army Ordnance Corps drawing 19-48-4003-1PL1000, except that the stacks were arranged to allow one more horizontal row and one more layer of pallets, principally by eliminating a 30-inch inspection aisle. The general cross section of the stack is shown in Fig. 8. This stacking procedure allowed for the installation of the 1,712 pallets with some vacant space remaining at the front. Fig. 9 shows the magazine partially loaded, and Fig. 10 shows it fully loaded. The last pallets were placed along the sides, as shown in Fig. 10, in order to give the forklift truck maneuvering room; this gave the stack a U-shape, with the open end of the U toward the door.

Selected projectiles in the ammunition stack were primed by packing high explosive (Composition C) in the projectile fuze well (Fig. 11) and equipping each with a length of Primacord leading to a nonelectric detonator. Primed projectiles were located at each of the eight corners (upper and lower) of the bottom layer, which was two pallets high, of the ammunition stack. Interior projectiles on the pallets were chosen, so that each primed projectile was surrounded by unprimed ones. Primed projectiles were also placed in each of the five layers of pallets in a column in the center of the stack. Since there was no access to the rear of the igloo after the ammunition was installed, the projectiles were primed as the pallets were loaded in, and the Primacord leads were brought forward during the loading process. All 13 Primacord leads had the same total length and the same length extending outside the magazine; these exterior lengths were bundled.

High-explosive acceptor charges were located in each of the acceptor igloos to provide further evidence of the probability of the explosion propagating to the acceptor magazines. Each igloo contained eight acceptor charges, arranged in two rows of four across the face of the magazine, one about 18 inches off the floor, and the other above it, about 5 feet off the floor.

Six acceptor charges were located in the northeast concrete block storage building and two Class 7 missile rocket motors, one a Polaris A-3 second stage and the other a Minuteman third stage, were located in the northwest storage building (Fig. 12).

DATA COLLECTION

FRAGMENT COLLECTION AREAS

To measure fragment distribution, three radial sectors of 5-degree width were cleared and smoothed to the north, south, and west of the donor magazine, beginning at a distance of 500 feet from the magazine (Fig. 13). The south and west sectors were cleared to 3,000 feet, although the south section was searched

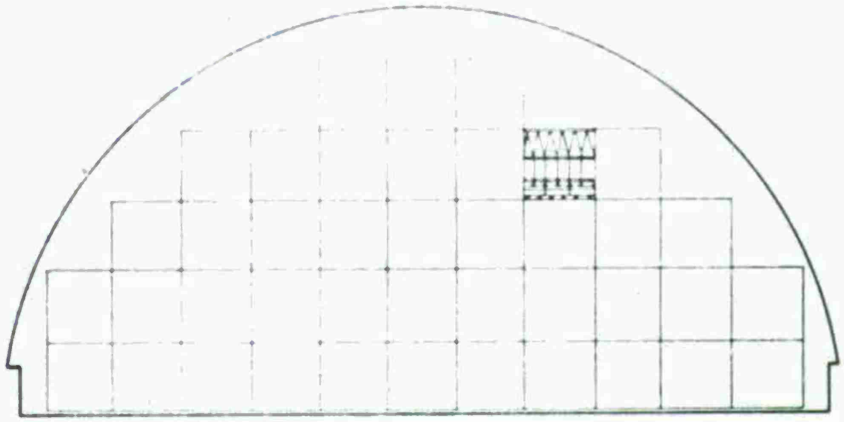


FIG. 8 Cross Section of Pallet Stacks in Igloo Magazine

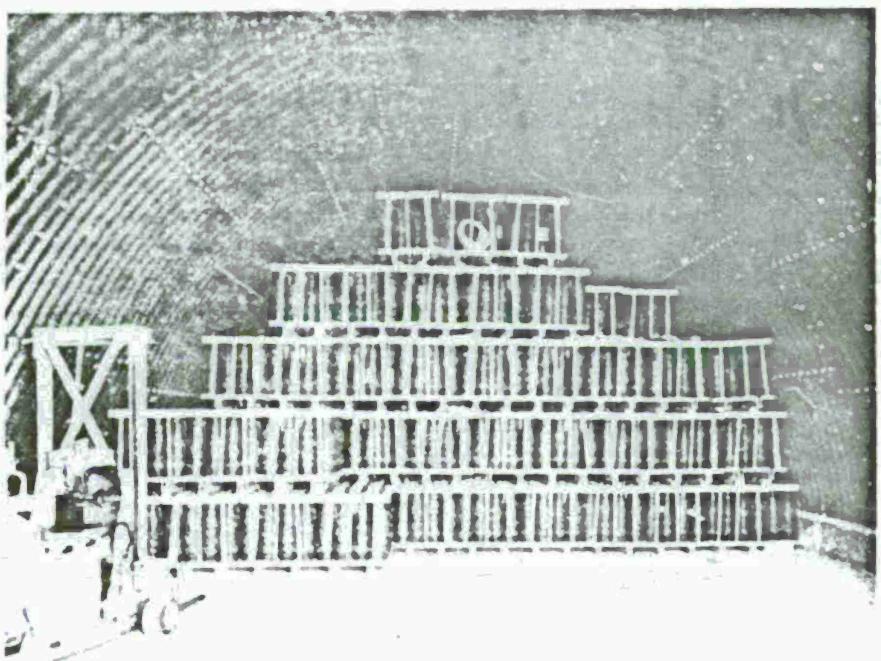


FIG. 9 Partially Loaded Igloo Magazine

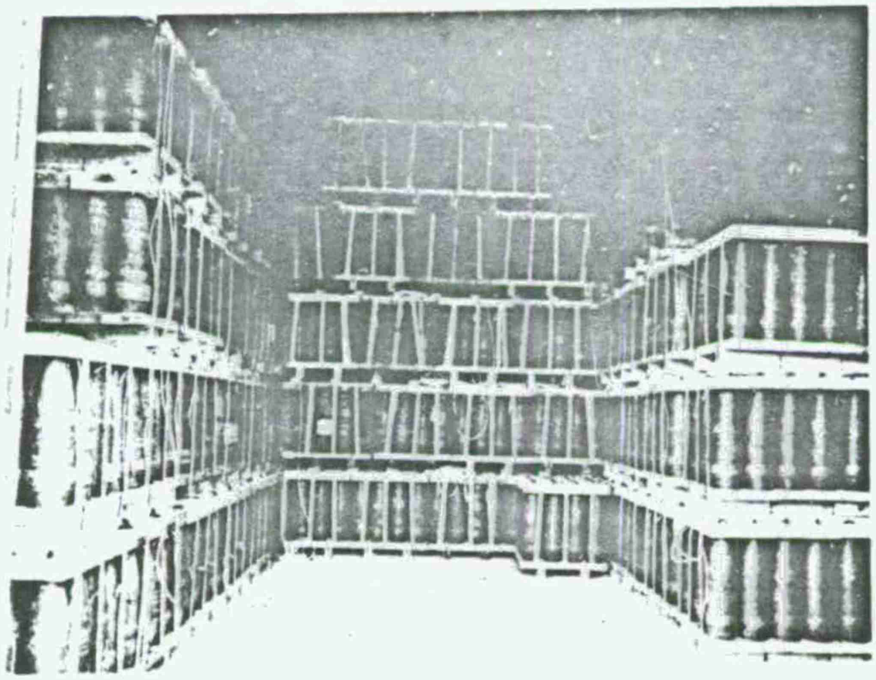


FIG. 10. Fully Loaded Donor Magazine.

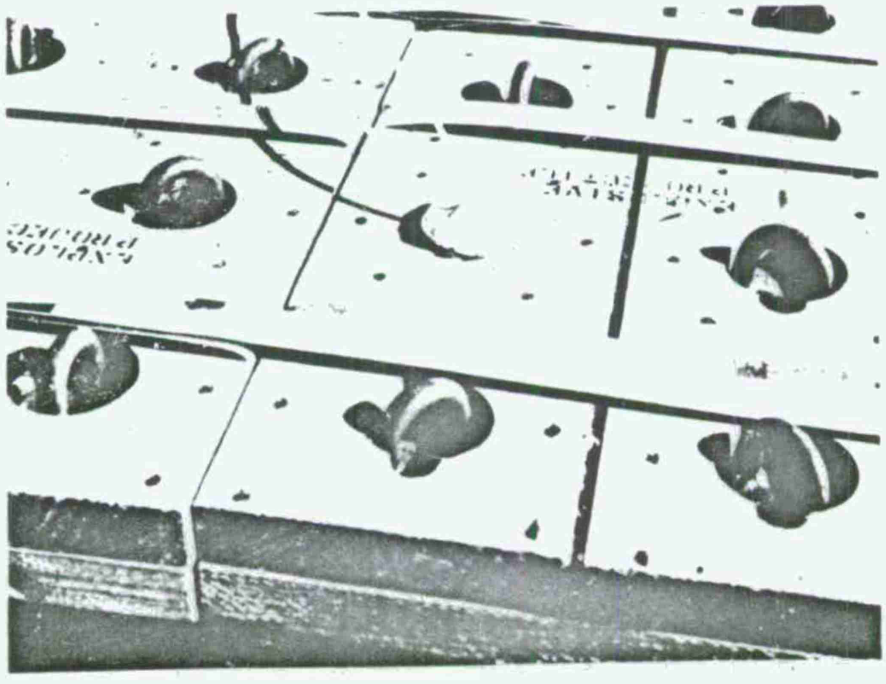


FIG. 11. Primed Projectile With Other Projectiles in Pallets.

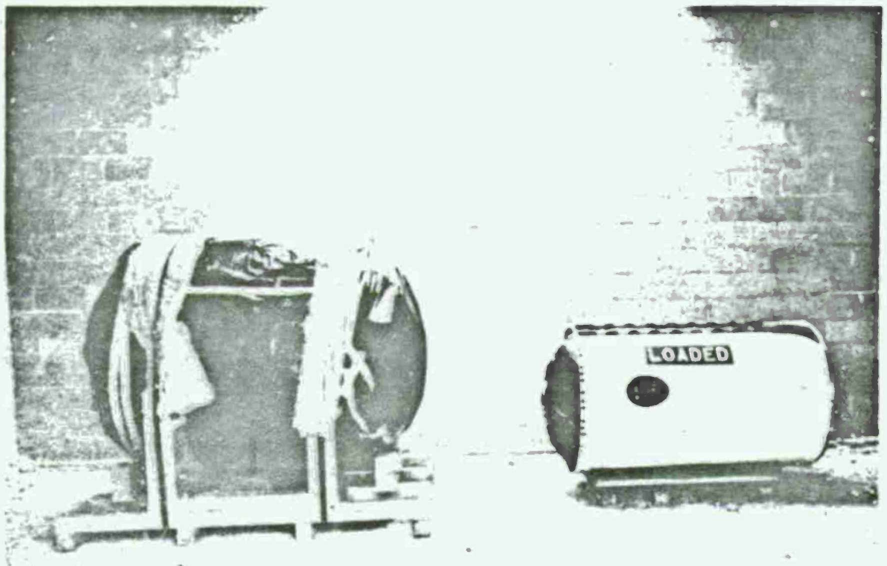


FIG. 12. Northwest Storage Building With Rocket Motors in Place. Polaris motor is on the left, Minuteman on the right. The missing roof section was replaced before the test.

only to 2,000 feet. The north sector ended at 1,617 feet because of a hill. The south sector actually extended along 171 degrees true, not 180, to avoid a hill. Each sector was divided into several search areas called cells.

In addition, a number of search areas, mostly 100-foot squares, were surveyed and marked but not cleared. These areas were located adjacent to and beyond the three sectors and also on lines extending 135 and 330 degrees true from the donor magazine center. Some of the areas shown in Fig. 13 were added after the test. The general plan was to search these small areas on foot and to search the cells with a magnet truck.

The number and severity of fragment strikes on an aircraft of a size directly approximating that of typical present-day commercial aircraft were observed by placing a B-29 aircraft 1,800 feet from the donor magazine on a line about 335 degrees true, which located the aircraft near one of the 100-foot squares. Large holes from previous tests were covered with sheet metal or screen, and the top surfaces and near side of the aircraft were painted white to aid in distinguishing between new fragment holes and old ones.

OVERPRESSURE

To measure blast overpressure time history in the field beyond the test

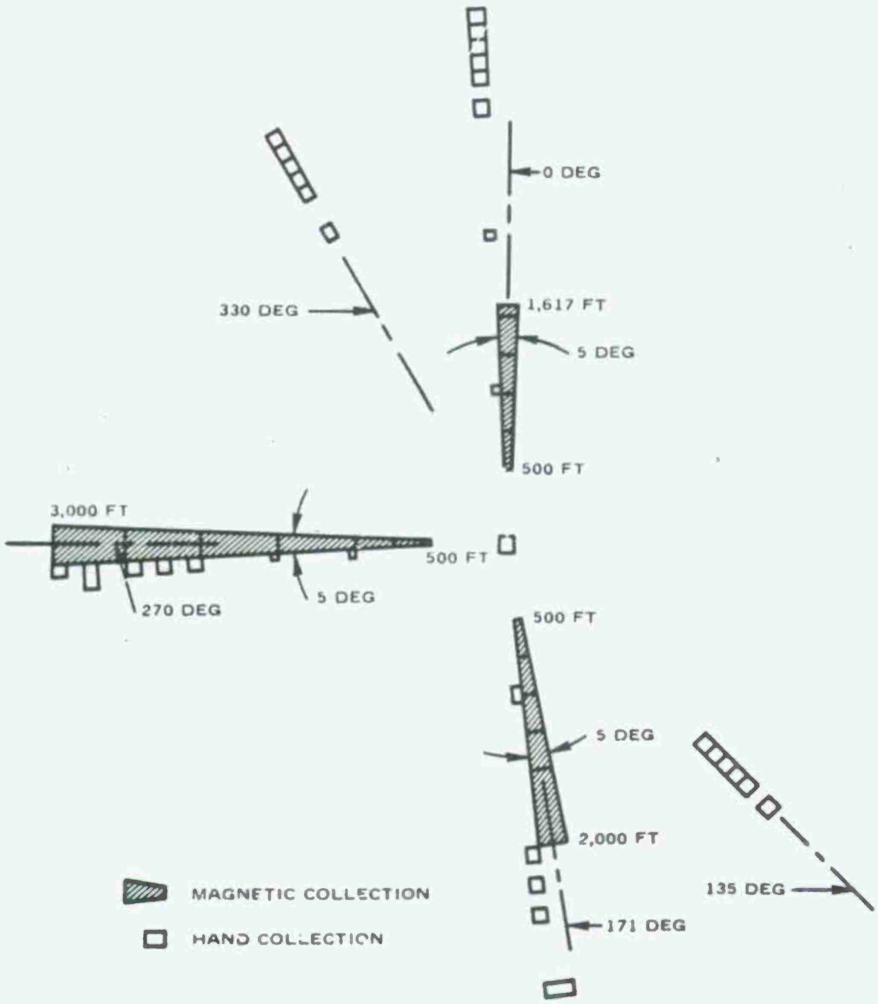
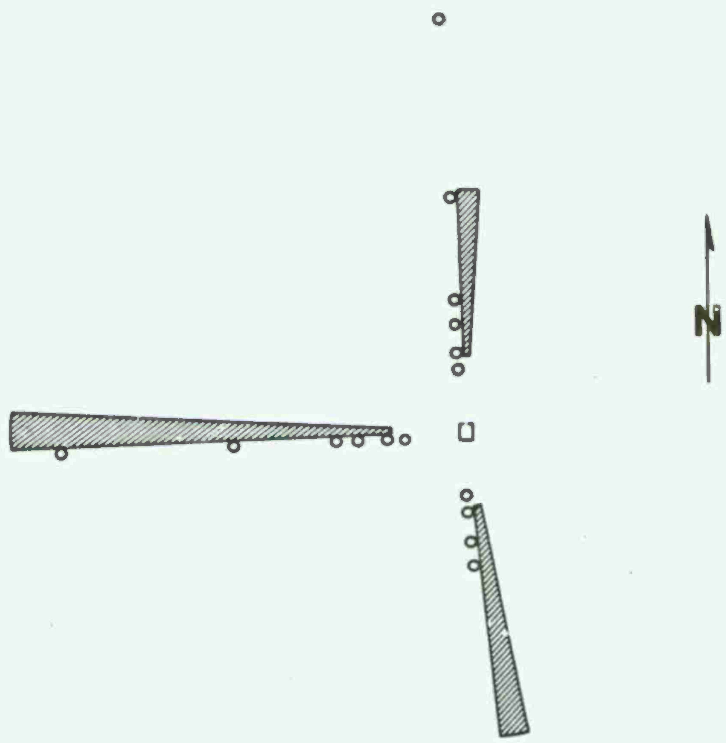


FIG. 13. Fragment Collection Areas.

structures, 16 Ballistics Research Laboratories self-recording blast gauges, were installed from 410 feet to 2,690 feet to the north and west of the donor magazine, and from 410 feet to 880 feet to the south. These were installed along the edges of the cleared sectors, as shown in Fig. 14.

To measure the overpressure time history near the face of the acceptor igloos, 10 Kistler piezoelectric overpressure gauges were installed. Two of these were installed in the ground, flush with the surface, 2 feet forward of the headwall of each of the four acceptor igloos. Two gauges were also installed in the wing walls of the south igloo to measure the face-on overpressure.



EXPECTED OVERPRESSURE AT 410 FT: 20 PSI
EXPECTED OVERPRESSURE AT 2,690 FT: 1 PSI

FIG. 14. Blast Gauge Locations.

STRUCTURAL MOTION

Part of the initial motions and velocities of the acceptor igloo headwalls and doors was recorded by three sets of electric probes. Each set comprised probes of various lengths mounted on a post and set against microswitches. These sets were installed in the north, east, and south igloos at the middle height of one door near the opening edge.

A linear motion transducer was mounted on the inside top center of the headwall in the north, east, and south igloos. A 4-foot-long section of railroad rail, suspended horizontally by chains from the top of the arch, was placed in contact with the transducer in each igloo. Headwall movement would thus be sensed relative to this suspended rail, which would remain initially fixed in space due to its inertia.

Vertical and horizontal floor motions were recorded by eight accelerometers (two per igloo) installed on the center lines of the floors, near the front.

PHOTOGRAPHY

Photographic records of the test were obtained by 10 high-speed (up to 4,000 frames per second) 16- and 35-mm ground-based cameras and by three cameras running at near normal speeds. Most cameras were located 1,500 feet to the west and south of the test site; one was 3,500 feet south, and one was 30,000 feet to the northwest.

Oblique views of the headwalls of the donor and the four acceptor igloos were obtained, as well as overall views of the entire site. Photography of the interior of the west and south igloos was also accomplished, showing the inward collapse of the doors.

SUPPLEMENTAL INSTRUMENTATION

AEROLOGY

Measurements of temperature, pressure, humidity, and wind velocity and direction were made at the surface and every 1,000 feet above ground up to 15,000 feet one hour before and one hour after the test event.

OVERPRESSURE WITHIN AND NEAR IGLOOS

The Mason & Hanger–Silas Mason Co., Inc., installed pressure gauges and time-of-arrival gauges at selected position inside and outside the acceptor igloos using company sensors and recorders.

SEISMIC DATA

The event was coordinated with the California Institute of Technology to provide it an opportunity to identify the seismic effects resulting from the test. No results were reported to NWC.

POST-TEST DATA

Post-test measurements of headwall position were made for comparison with pretest measurements to determine the permanent displacement of various points on the face of each acceptor igloo headwall. In addition, general photographic records were made of the effects of the explosion.

ESKIMO I DETONATION

At noon on 8 December 1971, the donor charges were detonated by simultaneously initiating the 13 bundled Primacord leads with two engineer's specials. The electrical impulse for the two detonators originated in the Randsburg Wash fire control building 6 miles away from the test site. No personnel were within 6 miles of the test site at detonation.

Figures 15 through 30 show the event as viewed from the northeast. These 16 photographs are selected frames from motion pictures taken from a helicopter slightly more than 2 miles away from the test site. The camera was a 70-mm Hulcher with a 162-mm lens operating at 10 frames per second.

Figures 15 through 18 are consecutive frames 0.1 second apart, and Fig. 19 through 30 are frames selected at progressively increasing time intervals up to 40 seconds after the detonation.

TEST RESULTS

GENERAL

Figure 31 is an aerial view of the test site after the detonation. Table 1 summarizes the principal effects. Details or the response of the acceptor structures, charges, and motors are presented with illus.rations in the following sections.

SOUTH IGLOO

None of the eight acceptor charges received sufficient damage to induce burning or explosion. The donor explosion resulted in the following structural response:

1. The doors were forced inward (Fig. 32). They remained in a generally upright position although hinge separation occurred at several points.

2. Earth cover from the donor magazine was thrown into the igloo (Fig. 33) and also against the headwall and wing walls.

3. The concrete headwall was cracked, particularly around the door frame, from blast overpressure but showed little evidence of fragment damage (Fig. 34).

In general, the south igloo was the least damaged of any of the acceptor structures.

WEST IGLOO

None of the eight acceptor charges received sufficient damage to induce

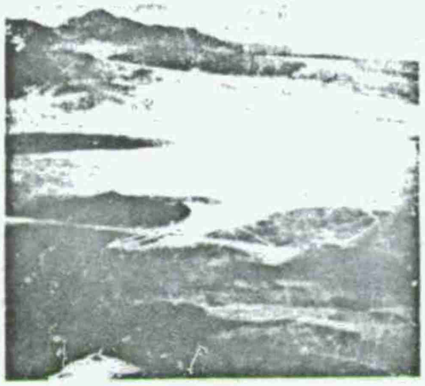


FIG. 15. Test Site Immediately Before Detonation (-0.1 Second).

FIG. 16. Detonation.

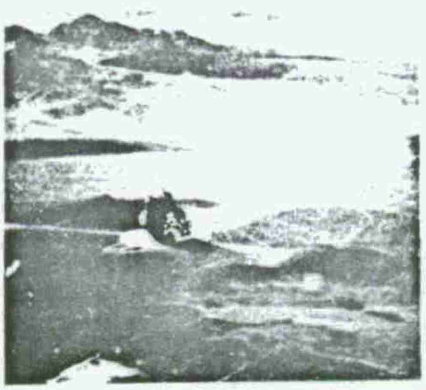


FIG. 17. Detonation Plus 0.1 Second. Note circular area of dust raised by passage of shock wave, also visible in Fig. 18 through 21.

FIG. 18. Detonation Plus 0.2 Second.

FIG. 19. Detonation Plus 0.5 Second.

FIG. 20. Detonation Plus 0.8 Second.

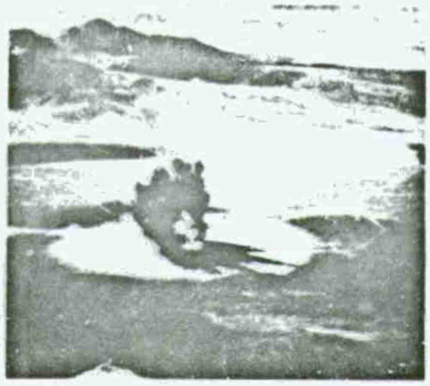


FIG. 21. Detonation Plus 1.3 Seconds.

FIG. 22. Detonation Plus 2 Seconds.

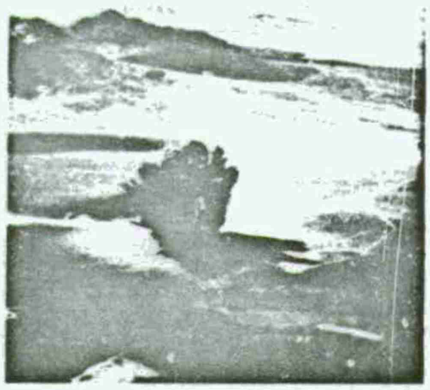


FIG. 23. Detonation Plus 3 Seconds.

FIG. 24. Detonation Plus 5 Seconds.

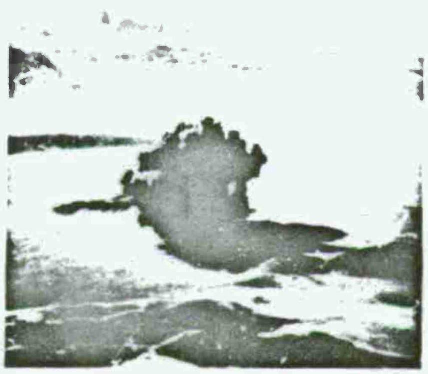


FIG. 25. Detonation Plus 8 Seconds. Note dust puffs raised by fragments hitting the ground, also visible in Fig. 26 through 30.

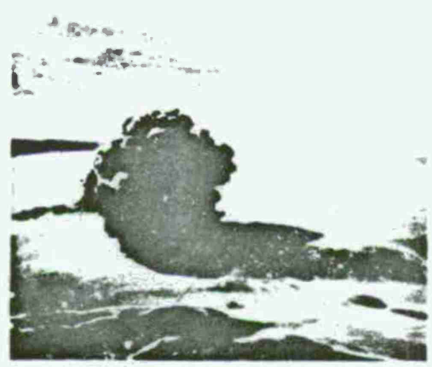


FIG. 26. Detonation Plus 12 Seconds.

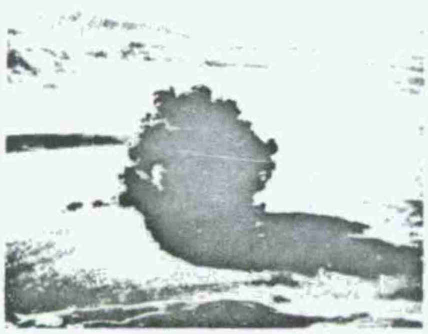


FIG. 27. Detonation Plus 17 Seconds.

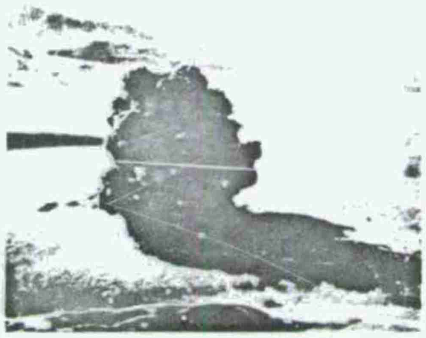


FIG. 28. Detonation Plus 23 Seconds.

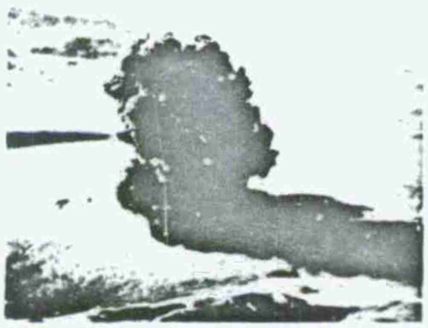


FIG. 29. Detonation Plus 31 Seconds.

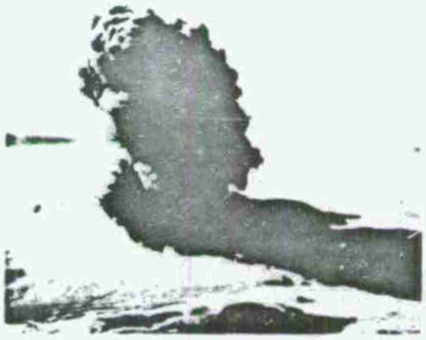


FIG. 30. Detonation Plus 40 Seconds.

explosion or burning. The donor explosion produced the following structural response:

1. The doors were forced inward (Fig. 35). The left door remained attached to the door-frame, but the right door separated and the sheet metal liner was detached from the rest of the door. (Left and right are as viewed from the exterior facing the headwall.)

2. Much earth cover from the donor magazine was thrown into the west igloo (Fig. 36) and also against the headwall and wing walls.

3. A small section of concrete headwall adjacent to the left doorjamb was damaged severely, with complete perforation of a limited area (Fig. 37). This is believed to be the result of impact by a heavy fragment. Heavy fragments of donor curb were found in front of the west igloo (see Fig. 35). One curb fragment 24 feet long was found under the debris piled at the left side. The right side of the headwall experienced minor cracking.

In general, the west igloo condition, except for the damage near the left door joint, was roughly equal to that of the south igloo. The right side of the headwall experienced less damage than any headwall section in any other igloo.

TABLE 1. Summary of Damage Effects.

Acceptor structure and separation distance	Acceptor charge and motor response	Structure response
South igloo, $2.0 \times W^{1/3}$	No explosion or burning.	Doors thrown inward; minor headwall damage.
West igloo, $2.75 \times W^{1/3}$	No explosion or burning.	Doors thrown inward; headwall perforated at one point, but blast effects judged minor.
North igloo, $2.0 \times W^{1/3}$	Four charges burned.	Doors thrown inward and separated, headwall damage from blast more extensive than in south and west igloos.
East igloo, $1.25 \times W^{1/3}$	All charges detonated or exploded.	Acceptor charge reactions caused major damage; only floor, rear wall, wing walls, and outer portions of earth cover remained at initial site.
Northwest concrete-block structure, $2.0 \times W^{1/3}$	Both motors burned.	Structure reduced to debris; some reinforced elements remained tied together.
Northeast concrete-block structure, $2.0 \times W^{1/3}$	No explosion or burning.	Structure reduced to debris; many reinforced elements remained tied together.
B-29 aircraft, 1,800 ft	No acceptor units.	Aircraft skin pierced by fragments at 42 points.

NORTH IGLOO

Four of the eight acceptor charges burned (Fig. 38); the remaining four did not burn or explode. Three of the burned units were from the lower tier of charges, and two of these were from the inside positions behind the door. The fourth burned unit was from an upper inside position. The mechanism that initiated burning could not be determined. The donor explosion resulted in the following structural response:

1. The doors were forced inward and detached from their hinges. Sheet metal door liners were separated.

2. Headwall cracking was much more general than in the south or west igloos. Cracking and inward movement was particularly more evident just inward of the line of attachment to the steel arch, the concrete sill, and concrete floor (Fig. 39 and 40). Despite this more extensive damage, there were only very limited areas of concrete separation, or spalling, from the interior surface of the wall. Together with the nature and position of the separation and with low wall velocities of approximately 35 ft/sec, this limited amount of spalling indicated that the secondary concrete fragments would have presented no serious hazard to ordnance in the igloo. Figure 41 shows the linear motion transducer used to derive the wall velocity.

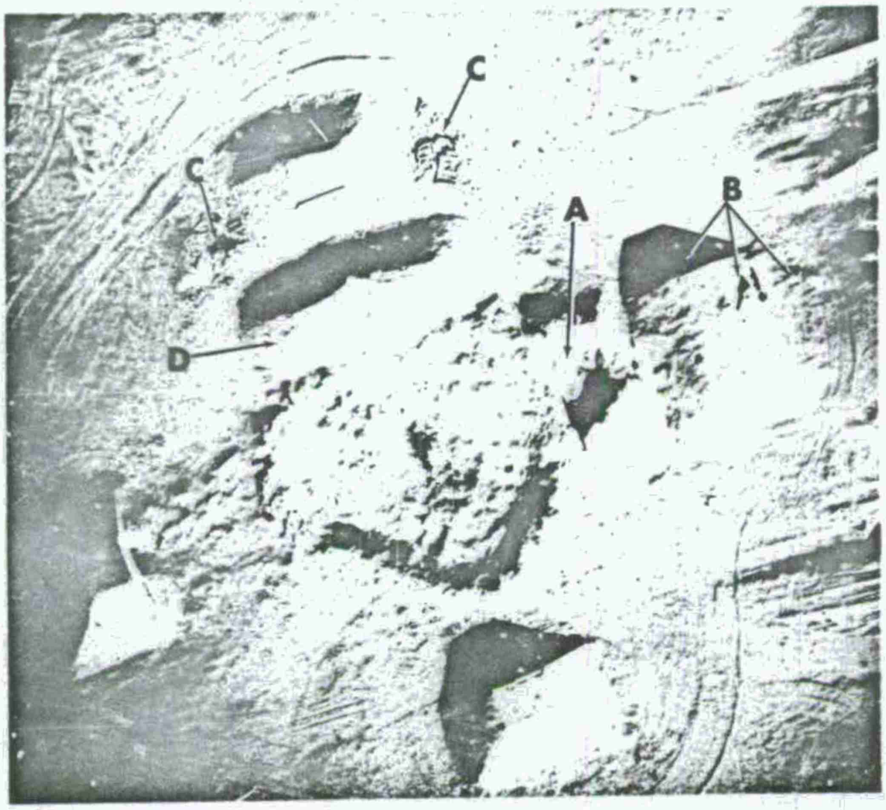


FIG. 31. Aerial View of Test Site After Detonation. Note (A) void in earth cover over remains of east igloo; (B) parts of steel arch of east igloo in front of and on east slope of the 59-foot magazine; (C) collapse pattern of reinforced elements of concrete block structures; and (D) erosion pattern on south slope of earth barricade.

In general, this igloo experienced considerably more overpressure (see later tables) than either the south or west igloo, and the structural response is consistent with this. There was little indication of fragment damage from the donor projectiles or donor structure. Such damage was prevented by the intervening earth embankment, which, though eroded on the donor side, was breached only in a limited region along the top near the extended center line of the donor.

EAST IGLOO

Evidence from high-speed camera records, from fragment pitting of the rear concrete wall, and from fragment perforation of recovered sections of steel arch from this igloo indicates detonation, or a combination of explosion and detonation, of the acceptor units. Probing and partial removal of the earth fill that covered the floor after the test failed to reveal any unexploded acceptors or any large fragments remaining from the eight acceptors contained in the structure. Structural response

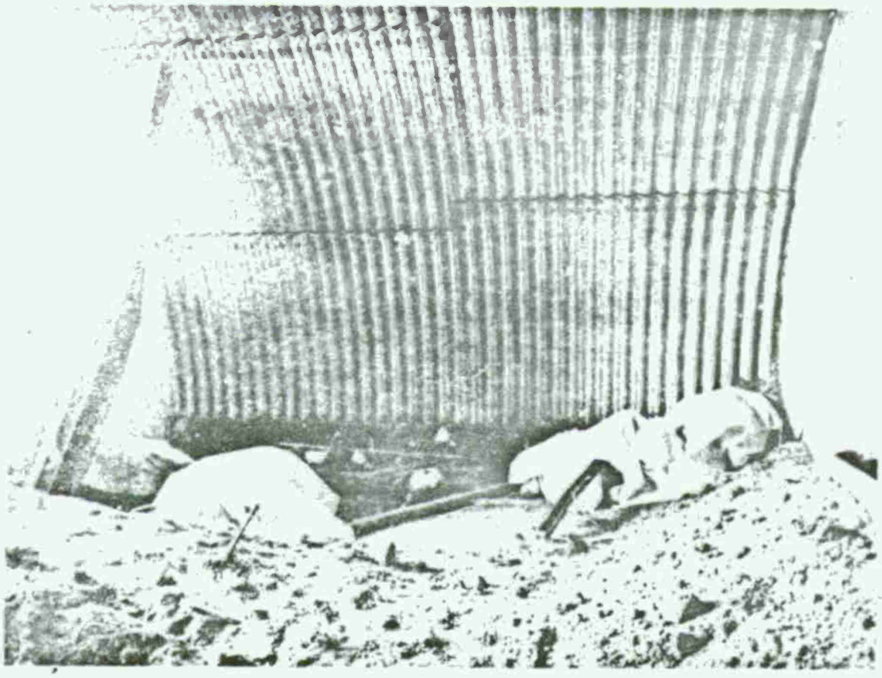


FIG. 32. Interior View of South Igloo.

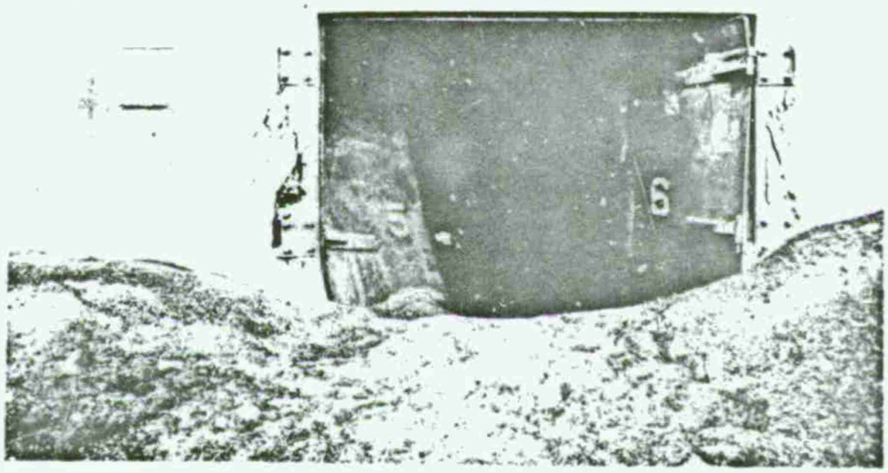


FIG. 33. Headwall and Doorway of South Igloo.

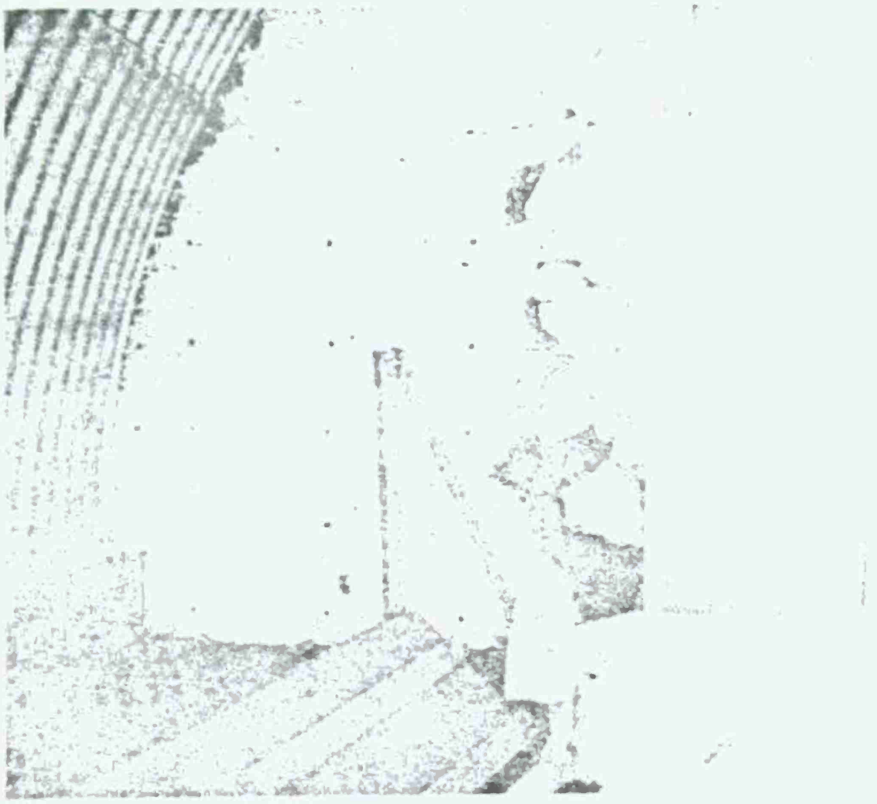


FIG. 34. Interior View of South Igloo Headwall.

FIG. 35. Headwall of West Igloo. Note greater damage to left doorjamb than to right one; this was probably caused by large fragments from the donor magazine, such as those in the foreground.

FIG. 36. Back Wall of West Igloo.

FIG. 37. Heavily Damaged Headwall of West Igloo.

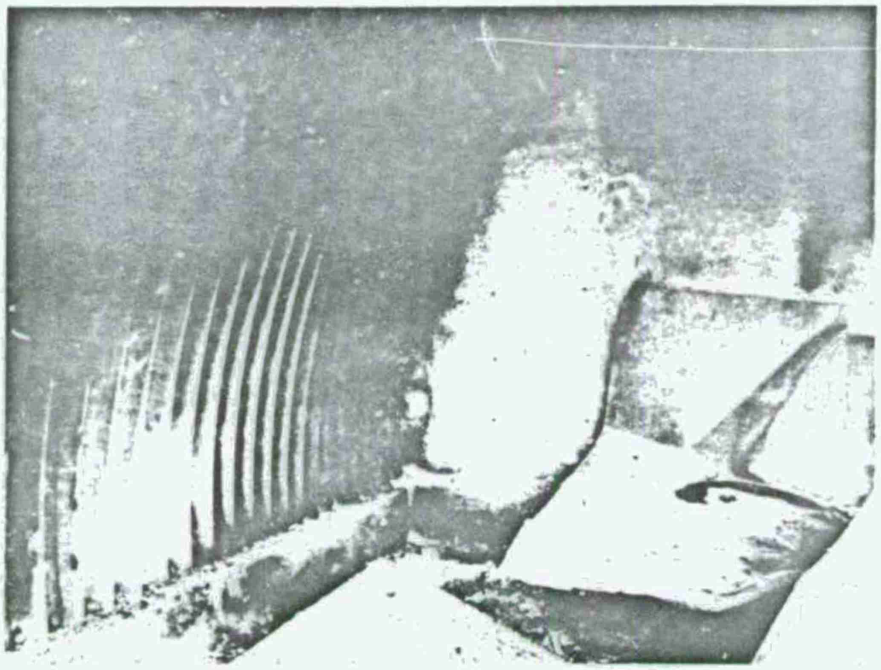


FIG. 38. Left Rear Corner of North Igloo. Scorching is evidence of burning of acceptor charges; circular pattern on wall is imprint of one end of an acceptor charge.

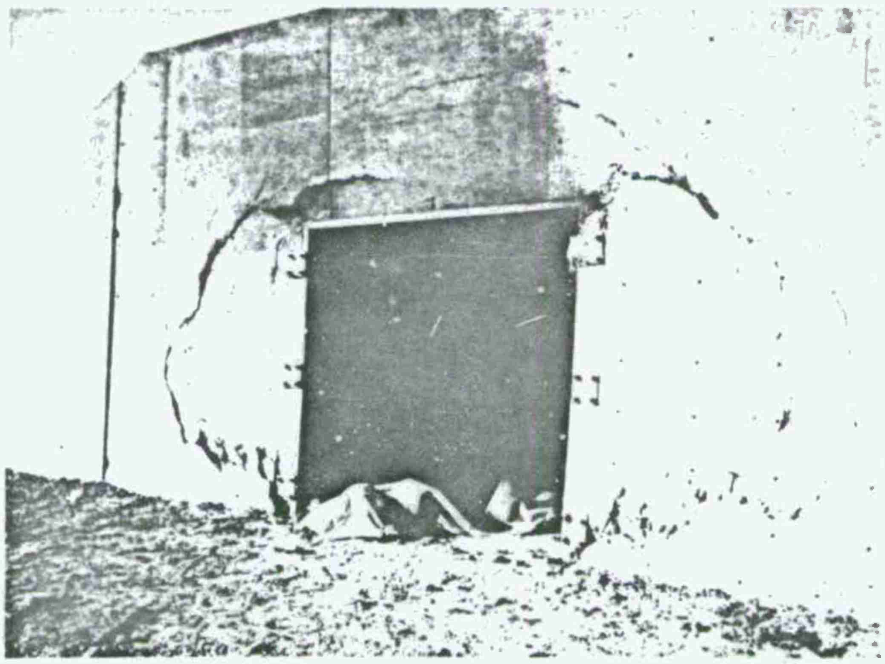


FIG. 39. Headwall of North Igloo. Note crack pattern approximating shape of steel arch.

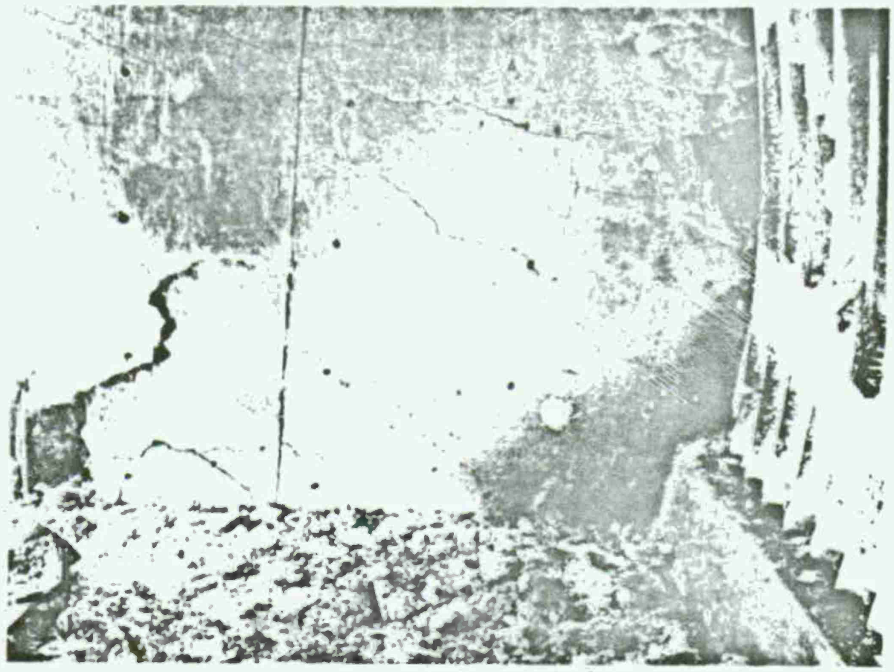


FIG. 40 [illegible] Note [illegible] damage in corner.

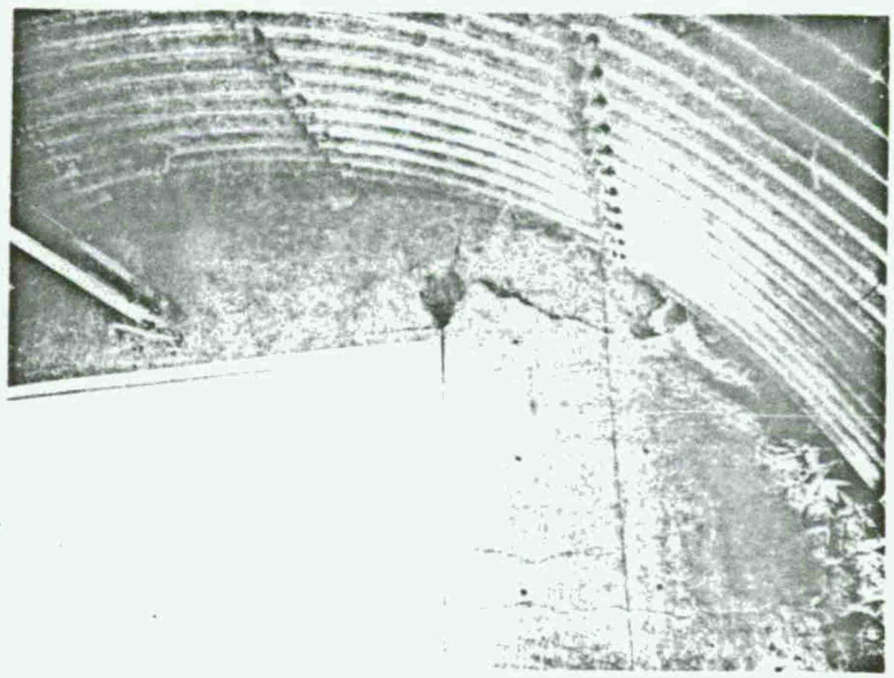


FIG. 41 Upper Headwall of North [illegible] Shown [illegible] and Its Pendulum Mounting

was as follows:

1. No fragments of the steel doors or the concrete headwall, or debris identifiable as such, could be found.

2. The concrete rear wall was severely pitted (Fig. 42) and was thrown backward at the top, coming to rest at an angle several degrees from vertical (Fig. 43).

3. The steel arch was separated into several sections, the largest of which came to rest in front of and on the east slope of the 59-foot-long magazine remaining from a 1963 test. Another piece (Fig. 44) fell in front of the door.

4. The igloo floor was covered with earth.

In general, the extent of damage caused by the donor blast was masked by the subsequent reaction of the acceptor charges within the igloo, so comparisons with the response of other igloos cannot be made. It is apparent that acceptor charge response was much more violent in the east igloo than in the other igloos.

NORTHWEST CONCRETE BLOCK STRUCTURE

The two Class 7 motors, a Polaris second stage and a Minuteman third stage, ignited and burned without undergoing substantial movement from their pretest positions.

The concrete block structure was leveled, with the walls generally collapsing inward from the top. Portions of reinforced vertical cells and the reinforced horizontal bond beams remained tied together although extensively cracked and sheared. Figure 45 shows the remains.

NORTHEAST CONCRETE BLOCK STRUCTURE

The six acceptor charges contained in this structure did not burn or explode. All six were found near the door opening in the north wall of the building.

The structural response was generally similar to that encountered by the other concrete block building (Fig. 46), except that reinforced elements appeared to retain their integrity and relative positions slightly better than in the northwest structure. A direct comparison is not entirely valid because of the motor-burning effects in the northwest pile of debris.

B-29 AIRCRAFT

The aircraft skin was pierced by fragments in 42 places (Fig. 47). Fragments found about the aircraft, which was parked 1,800 feet from the donor magazine, varied in size from small gravel to about 10 pounds in weight (Fig. 48).

FIG. 42. Interior View of Concrete Rear Wall of East Igloo, Showing Acceptor Fragment Impacts.

FIG. 43. Rear Wall of East Igloo, With Part of Steel Wing Wall at Right.

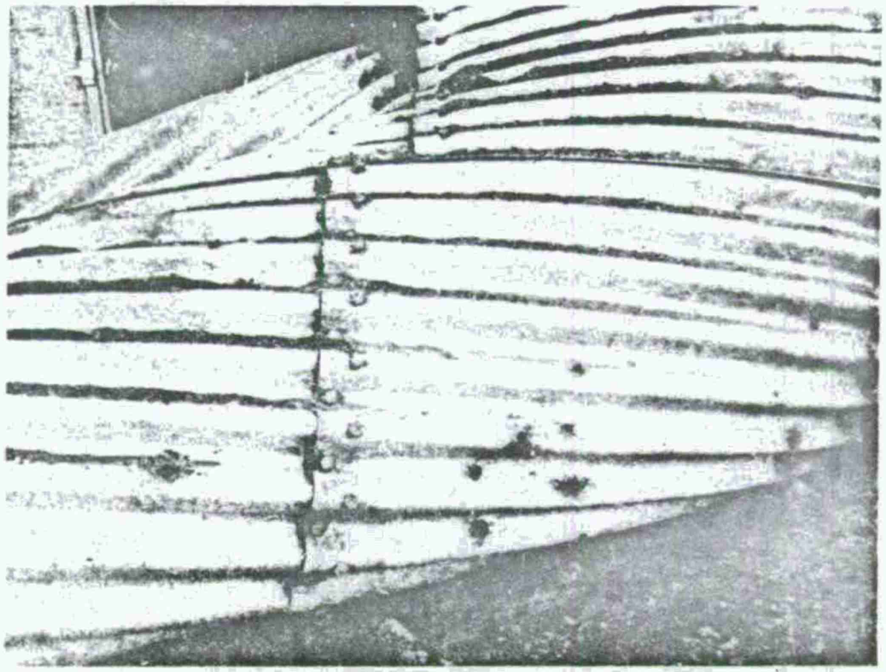


FIG. 44. Part of Steel Arch of East Igloo Lying in Front of Door of 59-Foot Magazine. Note perforations from acceptor fragments.

FIG. 45. Remains of Northwest Concrete Block Structure. Burned out case of Polaris motor is at right; parts of Minuteman motor are at left.

FIG. 46. Remains of Northeast Concrete Block Structure, With Unexploded Acceptor Charges Removed. Note pattern of reinforced vertical and horizontal elements that remained connected in some parts of the walls.

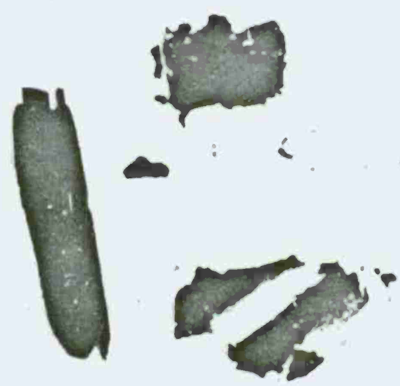


FIG. 47. Typical Fragment Holes in Top of Wing of B-29 Target Aircraft.

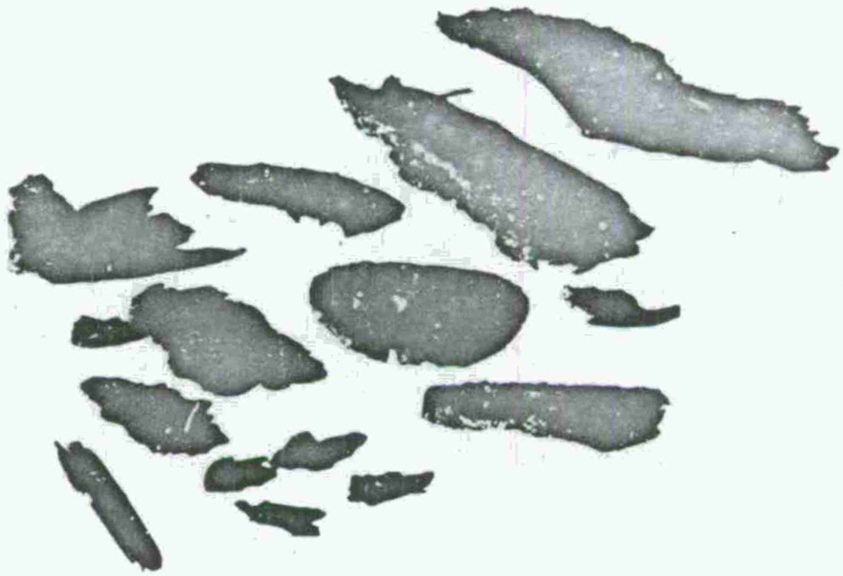


FIG. 48. Projectile Fragments Found at Site of B-29 Aircraft. The largest fragment shown here weighed 10 pounds.

FRAGMENT COLLECTION AND ANALYSIS

FRAGMENT COLLECTION

Before the test, three 5-degree sectors, as shown on Fig. 13, were cleared of vegetation and debris from a prior test, and each sector was divided into cells as described in Table 2. After the test, a truck equipped with an 8-foot-long bar magnet was driven slowly over the area encompassed by each cell. The area was covered once by driving parallel to the main axis of the sector and once by driving at right angles to this axis. The larger fragments collected in each cell, namely, those estimated to weigh 3/4 pound or more, were individually weighed in the field, and the weights were logged. Figure 49 shows three of the larger fragments.

The rest of the fragments from each cell were carried as a group to a central site for screening and weighing. The following screen sizes (in inches) were used: 2 3/4, 1 3/4, 1 1/2, 7/8, 3/4, and 5/8. Fragments retained on each screen were weighed as a group and counted. Estimates of the number of small fragments passing all screens were made by counting small samples and extrapolating.

Pretest planning called for the foot search and hand pickup of fragments from selected 100- by 100-foot areas to supplement data derived from magnet truck

TABLE 2. Cells Used for Fragment Collection by Magnet Truck

Cell no.	Radial distance of cell boundaries from donor magazine center, ft		
	North sector	South sector	West sector
7	500 to 750	500 to 750	500 to 703
6	750 to 1,000	750 to 1,000	703 to 1,000
5	1,000 to 1,250	1,000 to 1,250	1,000 to 1,250
4	1,250 to 1,500	1,250 to 1,500	1,250 to 1,500
3	1,500 to 1,617	1,500 to 2,000	1,500 to 2,000
2	...[a]	...[b]	2,000 to 2,500
1	...[a]	...[b]	2,500 to 3,000

[a] No fragment collection by magnet truck beyond 1,617 feet because of rough, hilly terrain.

[b] No fragment collection by magnet truck beyond 2,000 feet because of soft earth.

FIG. 49. Large Projectile Fragments. A small proportion of the 155-mm projectiles broke into large fragments such as these.

collection, particularly in areas not accessible to the truck because of the terrain. In post-test fragment collection, the pattern of search was varied somewhat from pretest plans to meet field conditions of fragment distribution; in addition, the search was extended to include areas directly adjacent to magnet truck collection sectors as a check on the latter. The search areas were generally 100 feet square; however, 50- by 50-foot areas were used in regions of high fragment density, and two larger areas were also used (see Table 3 and Fig. 13).

The foot searches were conducted thoroughly by two men moving in mutually perpendicular paths. In areas of soft, loose surface earth, all craters, even small ones, were probed for fragments. The craters often yielded metal fragments not visible without probing. In the areas to the west, the craters were more often caused by clods of donor earth cover.

The manual method of fragment collection was considered to be more thorough than magnet collection in areas where the smallest fragments weighed 0.05 pound. At the closer ranges, approximately 1,000 feet or less from the donor, no attempt was made to pick up the very small fragments (0.05 pound and under) by hand.

TABLE 3. Areas Used in Fragment Collection by Hand Pickup.

Size of collection area, ft	Distance from donor center to center of collection area, ft				
	North (356.5 deg)	Southeast (135 deg)	South (174 deg)	West (266.5 deg)	Northwest (330 deg)
50 × 50	1,025 2,018	... ...	... ...	1,025 1,525	... ...
100 × 100	2,850 3,050 3,150 3,250 3,350 3,450	1,850 1,950 2,050 2,150 2,250 2,450	1,000 2,050 2,250 2,450	2,050 2,250 2,450 2,950	2,350 2,650 2,750 2,850 2,950 3,050
100 × 200	...	...	...	2,740	...
100 × 230	...	...	2,950	...	...

FRAGMENT ANALYSIS

In analyzing the fragments, the principal emphasis was placed on producing data that would identify fragment hazards in various regions around the donor igloo by comparison with existing standards. An additional objective was the presentation of data in a manner that would facilitate additional analysis in the event that it was desired to vary either the fragment density criteria or energy level criteria in the standards.

The graphs shown in Fig. 30 through 57 were derived to show the increases in the cumulative number of fragments per 10,000 ft^2 with decreases in fragment weight for each collection cell. The abscissa positions of data points for the larger

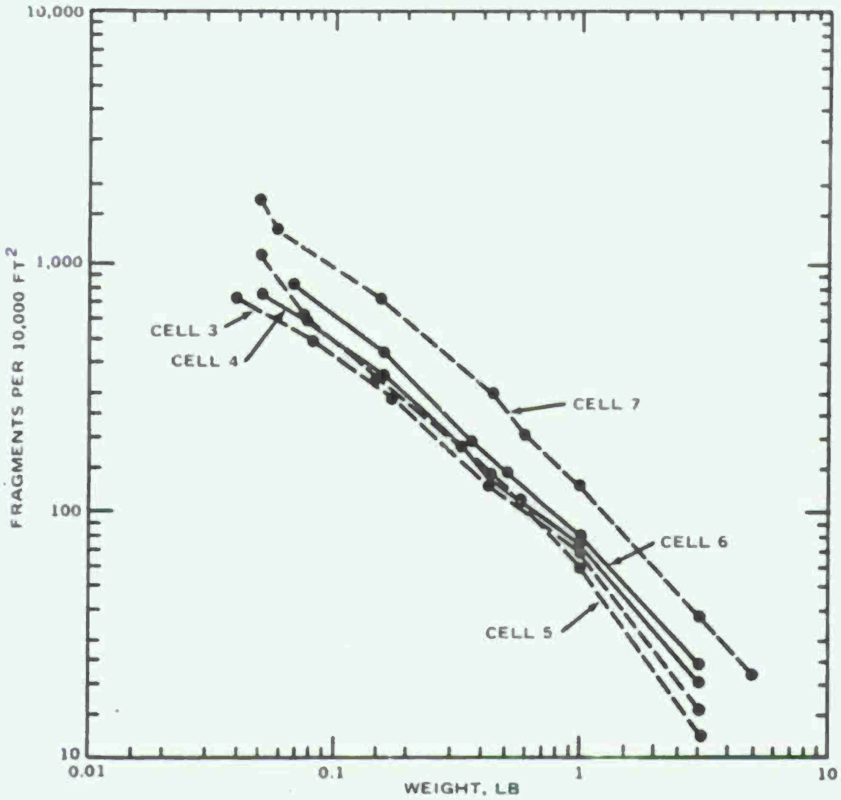


FIG. 50. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Cells in the North Sector (Magnetic Pickup). Rough, hilly terrain prevented magnetic pickup in Cells 1 and 2.

weights, generally 1 pound or more, are based on arbitrary selection and grouping of individually weighed fragments. Abscissa positions of data points of group-weighed fragments, representing retentions on screens, were based on average weights derived for each collection cell. Ranges of average weights were as follows:

Screen size, in	*Weight range, lb*
2 3/4	weighed individually
1 3/4	0.40 to 0.65
1 1/2	0.30 to 0.40
7/8	0.13 to 0.24
3/4	0.06 to 0.11
5/8	0.03 to 0.06

In determining the cumulative number of fragments associated with each weight, it was assumed that half the number of fragments retained on the screen were heavier than the average weight and half were lighter than the average weight; that is, the weight of the median fragment was assumed to be equal to the average

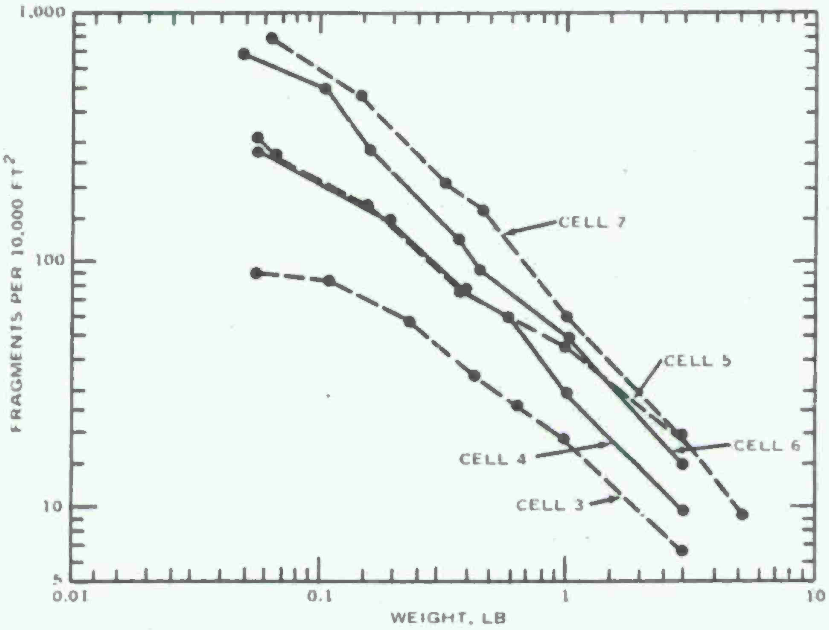


FIG. 51. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Cells in the South Sector (Magnetic Pickup). Cells 1 and 2 were too soft for the truck to operate in.

weight for the group. Based on an analysis of several samples of groups in which fragments were individually weighed, the error introduced by this assumption was considered acceptable.

Implicit in the methods used to determine the cumulative number associated with weight was the assumption that the extreme weight limits for each screen retention group did not extend beyond the average values for adjacent screen sizes. Analyses of the same group samples referred to above showed variations in weight for most screen sizes which extended well past the averages for adjacent screen sizes. The error introduced had the general effect of emphasizing the scattering of data points. With true representation it is believed the data points would have appeared smoother.

In the graphs no attempt was made to differentiate between structural fragments from igloos and 155-mm projectile fragments. However, the basic data from which the graphs were derived does distinguish between the two types of fragments, for fragments which were individually weighed.

Figures 58 through 65 were derived from Fig. 50 through 57, and they show variations in the number of fragments per 10,000 ft^2 for various distances away from the donor magazine. These figures are plotted for fragment weight levels of $\geq$0.125, $\geq$0.28, and $\geq$1.0 pound.

The selection of the 0.28-pound level was based on the following rationale:

1. The present DDESB criterion for hazardous fragments to unprotected personnel stipulates an acceptable density of not more than one per 600 ft^2, a

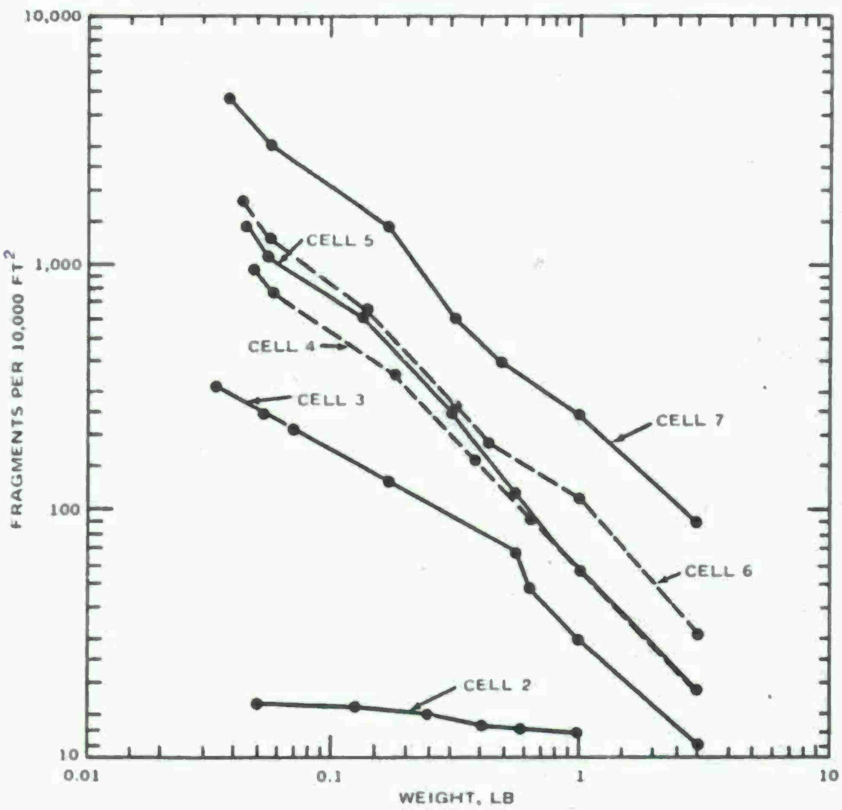


FIG. 52. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Cells in the West Sector (Magnetic Pickup). Data for Cell 1 is off scale in this figure.

hazardous fragment being defined as one having a kinetic energy of 58 ft-lb or greater.

2. The distribution of fragments in this test made it apparent that the safe fragment distance based on the above criterion would be determined by fragments falling at their free-fall terminal velocity. From Fig. 3 of Ref. 2, the value of 0.28 pound was derived as the weight of a 58-ft-lb fragment moving at terminal velocity. Figure 66 shows the limits of fragment hazard for the ESKIMO I test, based on the above standards.

The choice of the 0.125-pound level was somewhat arbitrary, being a bit larger than the 0.08 pound derived from Fig. 3 of Ref. 2 for a fragment with 11 ft-lb of kinetic energy (an energy criterion recommended by some investigators) moving at terminal velocity. However, the 0.125 level does provide data points for a weight level of general interest.

The choice of the 1.0-pound level is again arbitrary, but it does permit comparison of the 0.28-pound level with a much higher level. Furthermore, in this particular test, it demonstrates that the choice of fragment weights and thus

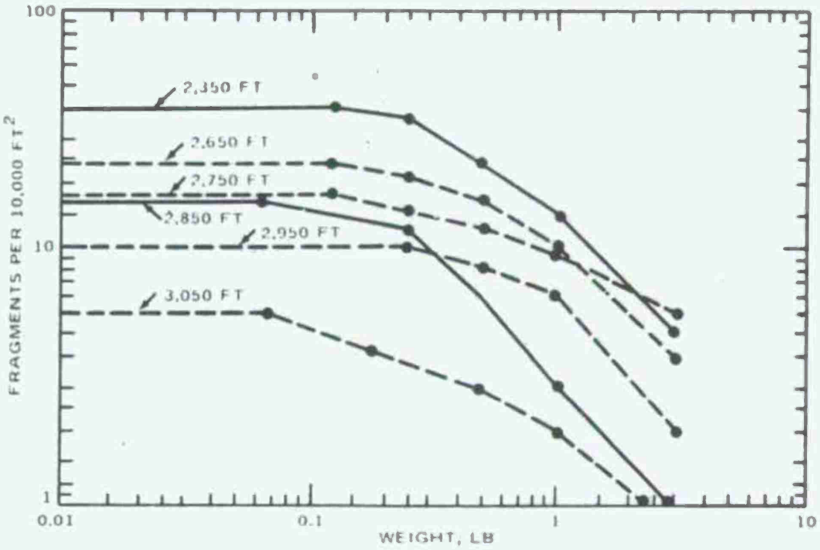


FIG. 53. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Various Northwesterly Distances From the Donor Magazine (Hand Pickup).

indirectly the choice of fragment kinetic energies does not strongly influence the position of the safe distance limits for density values of one hazardous fragment per 600 ft^2 or 16.7 fragments per 10,000 ft^2.

CONCLUSIONS

GENERAL

Based on the results of this test and supporting data from previous tests, DDESB has authorized the following new separation distances for earth-covered steel-arch magazines without intervening barricades:

Face-to-rear orientations: $2.0 \times W^{1/3}$
Face-to-side orientations: $2.75 \times W^{1/3}$

DDESB also adjusted the spacing requirements for face-to-face orientations to $11 \times W^{1/3}$ without an intervening barricade and to $6 \times W^{1/3}$ when a substantial barricade exists between the igloos.

Additionally, as a result of damage incurred by igloo doors and headwalls, DDESB has initiated a test, to be conducted at China Lake, to compare door and headwall designs. The test will use structurally sound portions of ESKIMO I structures. The donor configuration and position will be planned to subject each test

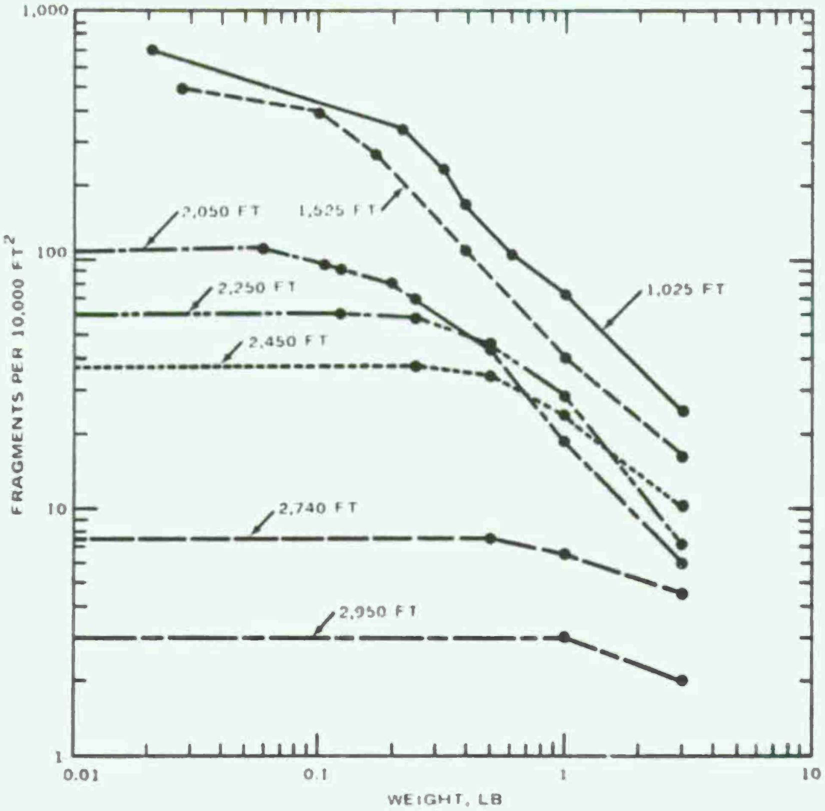


FIG. 54. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Various Westerly Distances From the Donor Magazine (Hand Pickup).

headwall and door to the same blast loading, namely, one approximating that experienced at the south acceptor igloo in the ESKIMO I test.

INSTRUMENTATION DATA

Data from ESKIMO I instrumentation are discussed and tabulated in other sections of this report. The instrumentation data yielded the following basic information:

1. The 16 BRL self-recording mechanical blast gauges placed at 410 to 2,690 feet from the donor in three arrays (north, west, and south) indicated an explosive yield of an unbarricaded stack of about 100,000 pounds of TNT at gauge distances. This is in fair agreement with reductions in yield predicted by Ref. 3.

2. The records from the Kistler piezoelectric blast gauges mounted at ground level near the acceptor igloo headwalls and in the south igloo wing walls showed

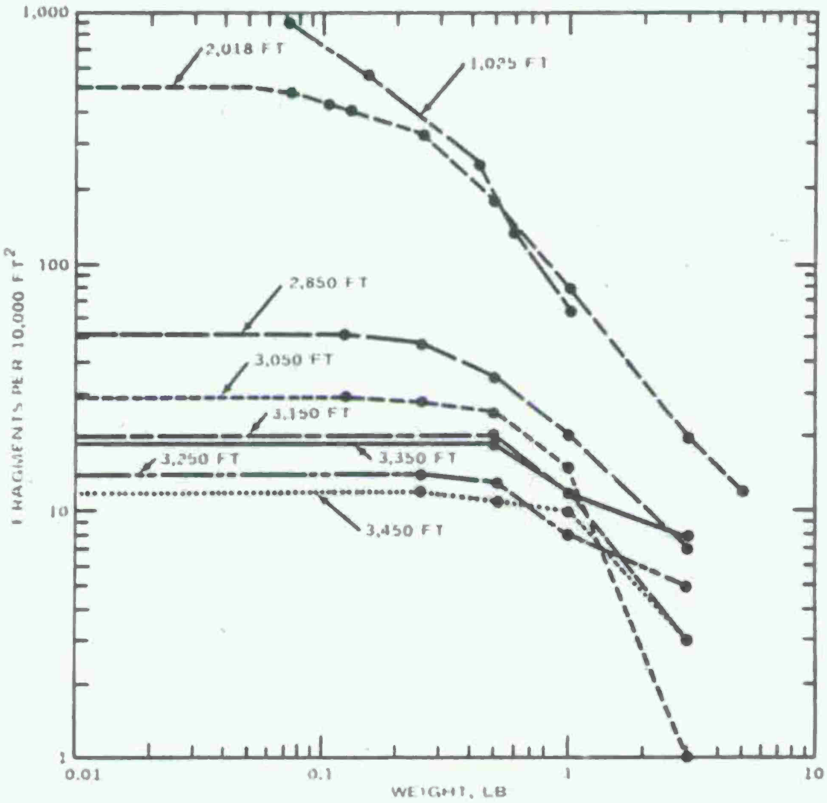


FIG. 55. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Various Northerly Distances From the Donor Magazine (Hand Pickup).

relative pressure/time histories appropriate for their positions and locations. The magnitude of the blast wave, based on these close-in gauges, was highly influenced by the donor magazine structure, so that the blast effect was roughly equal to one from an unbarricaded stack of 30,000 to 35,000 pounds of TNT. The apparent position of the center of the explosion, which was also highly influenced by the donor magazine structure, was 10 to 20 feet north of the headwall of the donor magazine.

3. The following instruments operated properly and provided consistent and usable data: accelerometers mounted on igloo floors; linear motion transducers mounted on interior headwalls above doors; and high-speed motion picture cameras.

In general, the severity of structural damage to the acceptor igloos, as judged by post-test inspection, was consistent with the position and exposure of the acceptor igloos and with the data recorded by instrumentation. The degree of damage was ranked as follows:

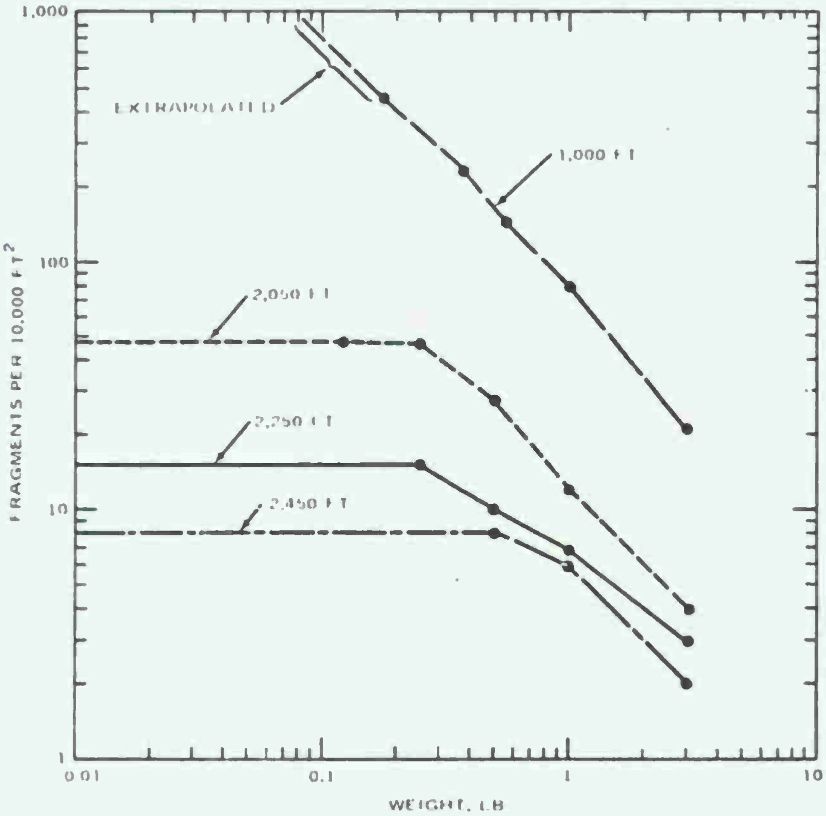


FIG. 56. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Various Southerly Distances From the Donor Magazine (Hand Pickup). The 1,000-foot curve was extrapolated to obtain a 0.125-pound data point for use in calculations.

East igloo, at $1.25 \times W^{1/3}$	Destroyed by explosion of acceptor charges
North igloo, at $2.0 \times W^{1/3}$	Moderate-to-heavy headwall and door damage
South igloo, at $2.0 \times W^{1/3}$	Moderate damage
West igloo, at $2.75 \times W^{1/3}$	Light-to-moderate blast damage and fragment damage at one doorjamb

The instrumentation records showed that the north and east igloos received roughly comparable blast loading and responded in comparable fashion prior to detonation of acceptor charges in the latter.

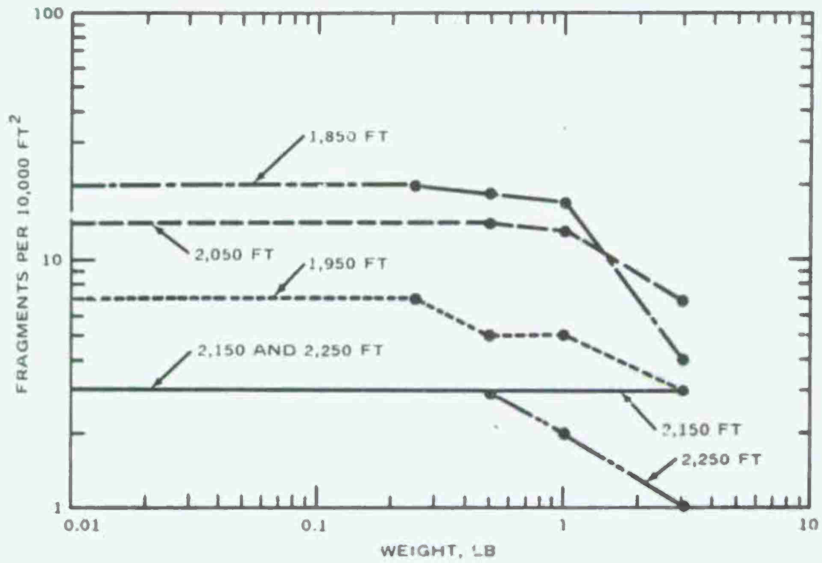


FIG. 57. Cumulative Number of Fragments per 10,000 ft^2 Versus Weight in Pounds for Various Southeasterly Distances From the Donor Magazine (Hand Pickup). The 100- by 100-foot area at 2,450 feet was searched, but no fragments were found in it.

FRAGMENT DATA

Results of fragment collection and analysis are summarized as follows:

1. The limits of fragment hazard, based on an acceptable density of one hazardous fragment per 600 ft^2 of surface area are

North (front) of donor magazine	3,200 feet
West (side) of donor magazine	2,600 feet
South (rear) of donor magazine	2,200 feet

This assumes that a hazardous fragment is one having a kinetic energy of 58 ft-lb or more. Note that the fragment hazard limit forward of the donor magazine is at a distance greater than 2,630 feet, which is the distance for the occurrence of the 1-psi incident overpressure level for 200,000 pounds of unbarricaded TNT, as derived from standard curves.

2. The maximum throw of fragments as observed by field search was as follows:

Projectile fragments north of donor	5,000 feet
Projectile fragments west of donor	3,100 feet
Earth clods west of donor	3,400 feet
Projectile fragments south of donor	3,600 feet

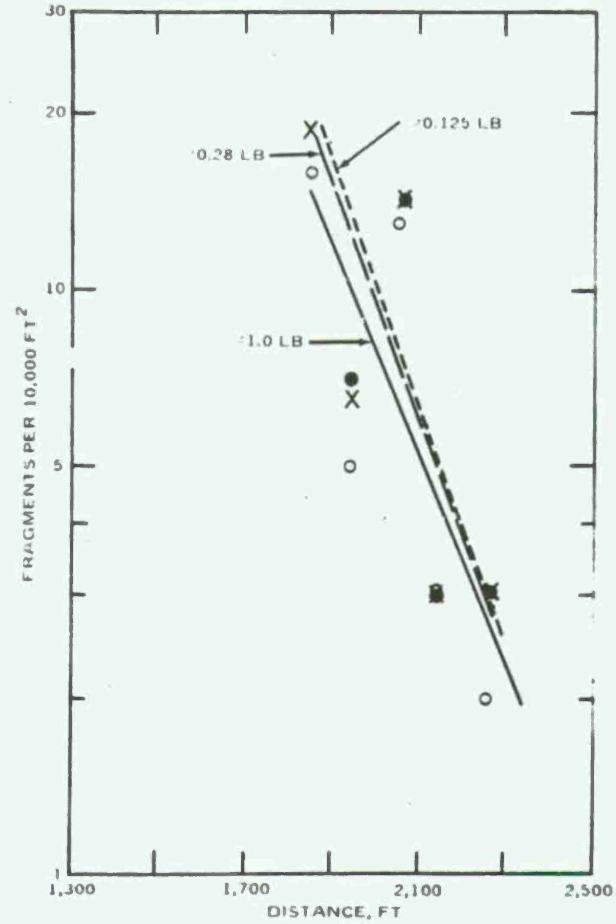


FIG. 58. Number of Fragments per 10,000 ft² Versus Distance Southeast of Donor Magazine (Hand Pickup).

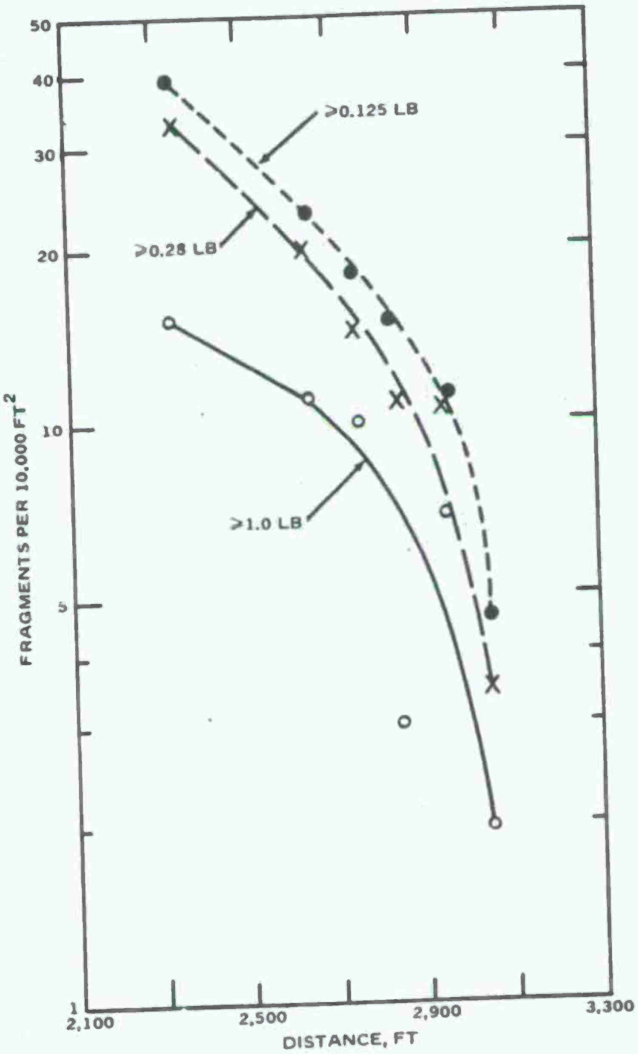


FIG. 59. Number of Fragments per 10,000 ft^2 Versus Distance Northwest of Donor Magazine (Hand Pickup).

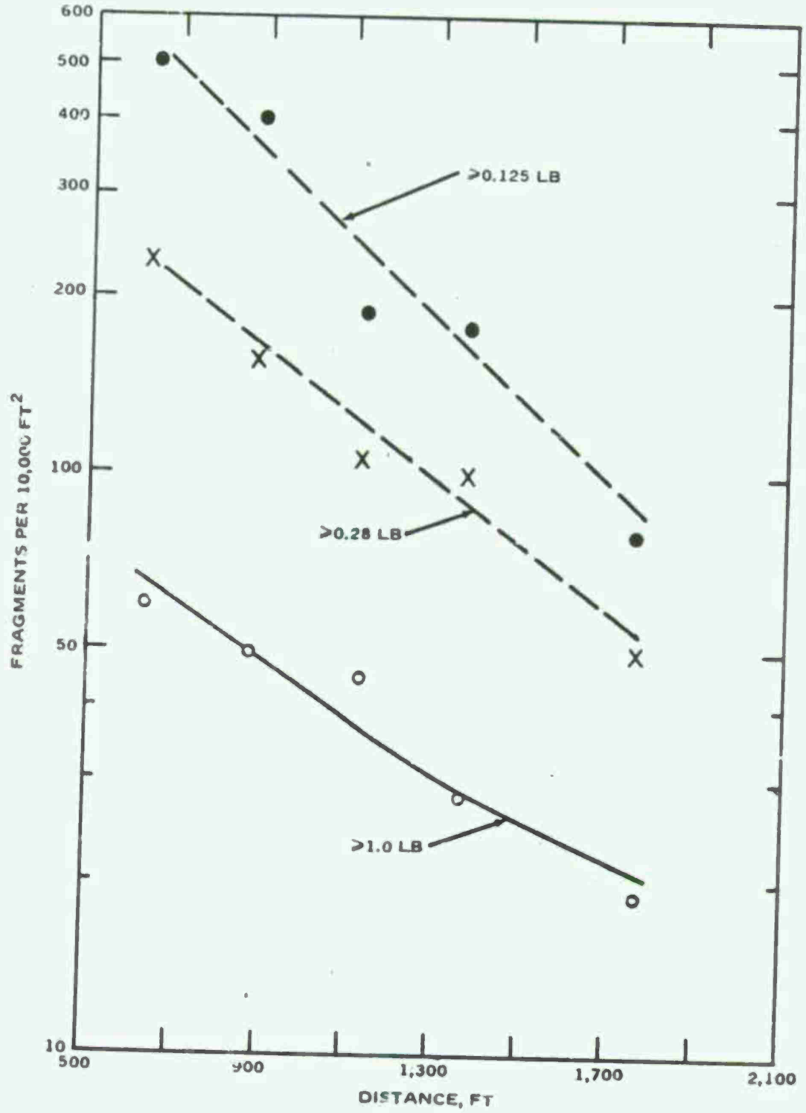


FIG. 60. Number of Fragments per 10,000 ft² Versus Distance South of Donor Magazine (Magnetic Pickup).

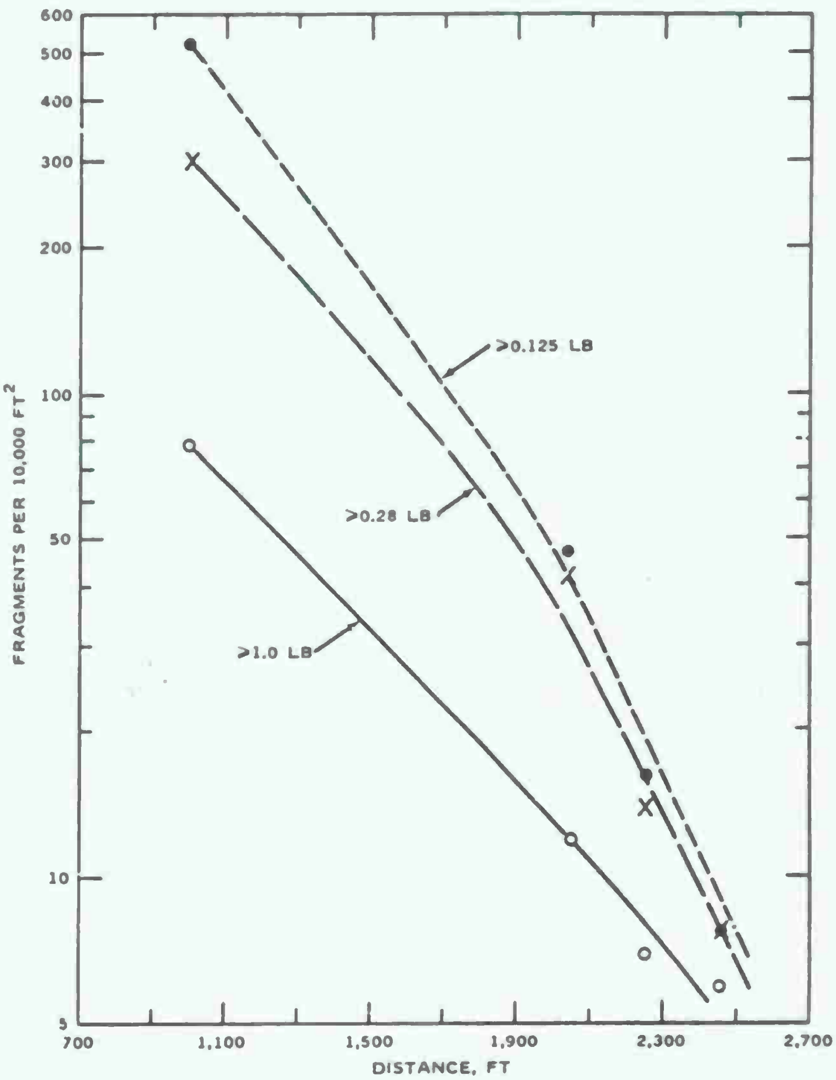


FIG. 61. Number of Fragments per 10,000 ft^2 Versus Distance South of Donor Magazine (Hand Pickup).

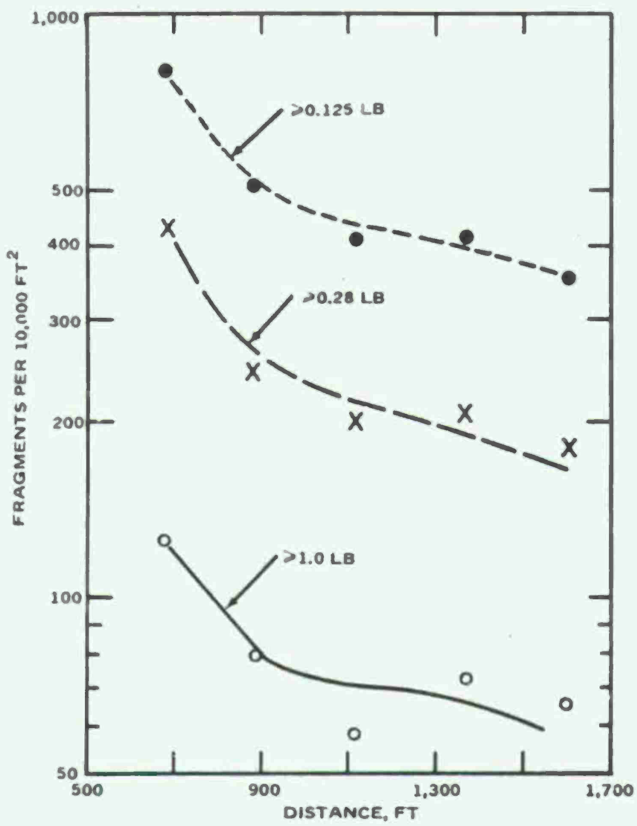


FIG. 62. Number of Fragments per 10,000 ft^2 Versus Distance North of Donor Magazine (Magnetic Pickup).

DATA DERIVED FROM INSTRUMENTATION

EVENT TIMES

With the exception of data derived from the BRL self-recording gages. all data were recorded on a time base: standard IRIG Format B for the motion pictures, and binary coded 1,000-hertz timing for magnetic tape data from Kistler blast gages, linear motion transducers, and accelerometers. Figures 67 and 68 show recordings of instrumentation data; on both of these figures the small timing pulses are milliseconds.

Table 4 summarizes test event times derived from assessment of the various data recorded on a time base. Selection of a zero time was somewhat arbitrary; however, it does correspond to one of three pulses on the zero time record. In addition, zero time coincides with (1) the first occurrence of a substantial fireball

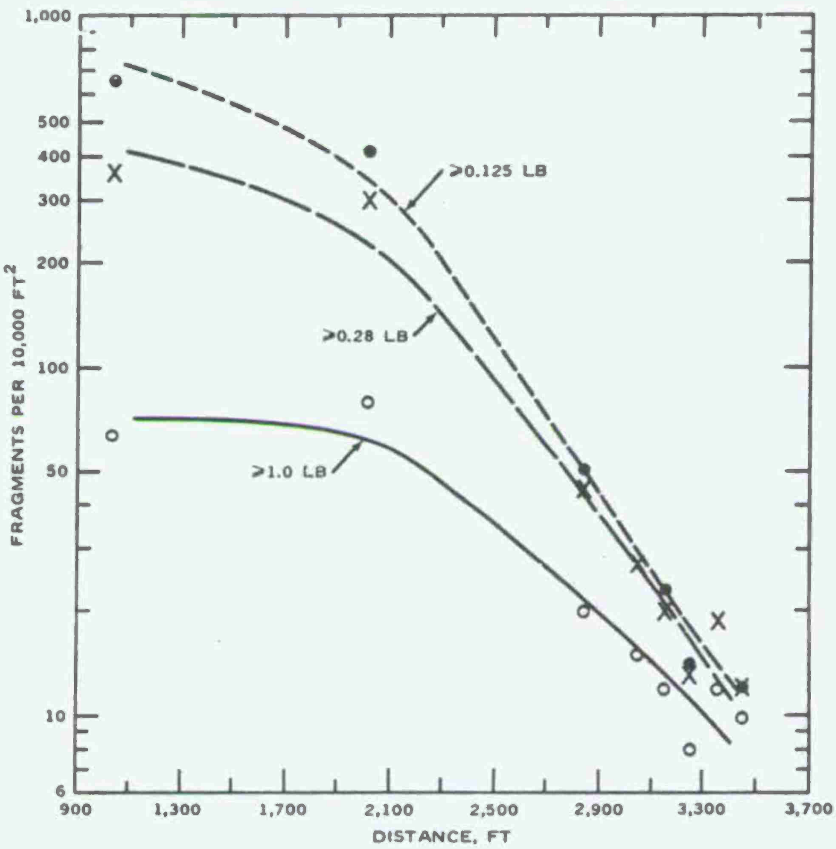


FIG. 63. Number of Fragments per 10,000 ft^2 Versus Distance North of Donor Magazine (Hand Pickup).

just north of the donor magazine, (2) the appearance of a nearly continuous line of initial fireball eruption through the top of the donor earth cover, and (3) first fireball lighting of acceptor igloo headwalls. The pulse on the zero time record was derived from an ionization probe located atop the earth fill at the center of the donor magazine. Note in Table 4 that the main blast wave arrived at blast gauges 2 feet forward of the headwall of the north igloo 6.7 milliseconds before it arrived at a corresponding gauge position at the east igloo, despite the fact that the east igloo was much closer to the center of the donor explosive mass. This is one of many indications of the strong direction influence on the blast exerted by the presence of the donor magazine structure and earth cover.

MOTION PICTURE PHOTOGRAPHY

The test event was recorded photographically by ground-based 16-mm and 35-mm cameras using color film. Film from cameras operating at 1,000 frames per

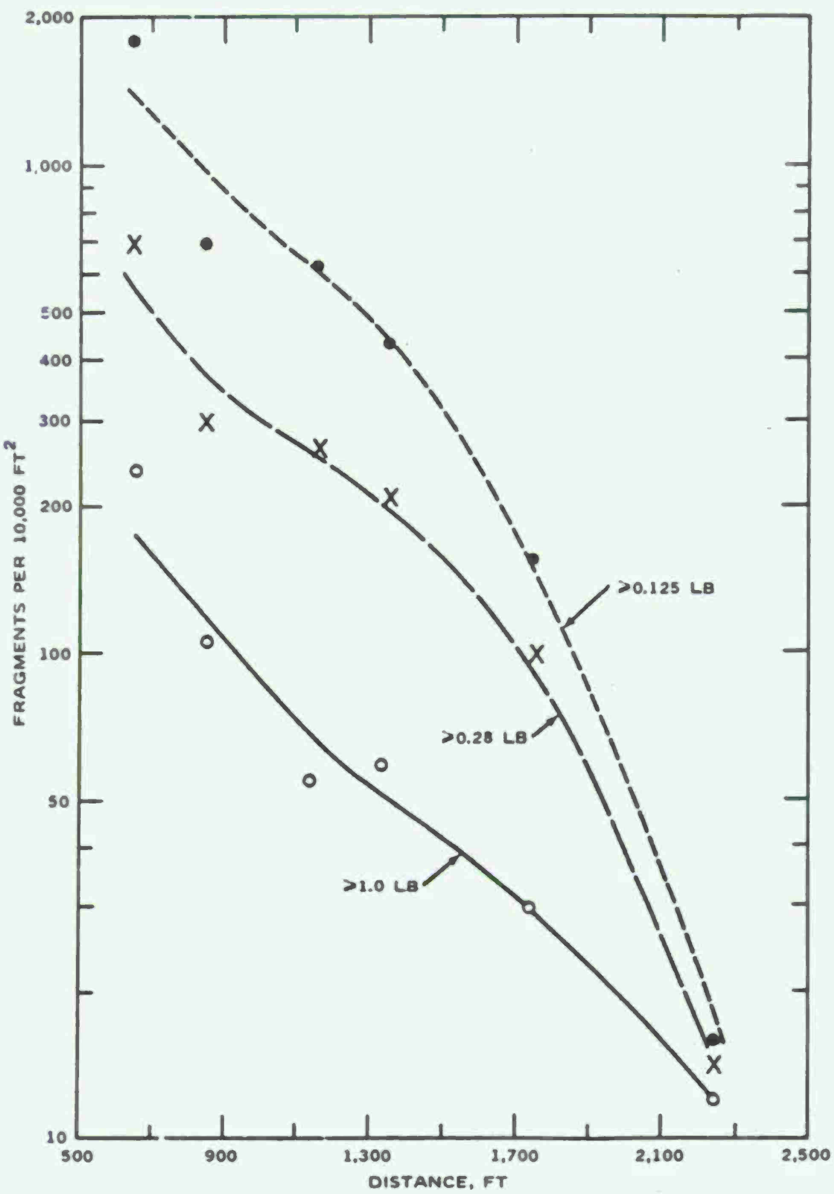


FIG. 64. Number of Fragments per 10,000 ft^2 Versus Distance West of Donor Magazine (Magnetic Pickup).

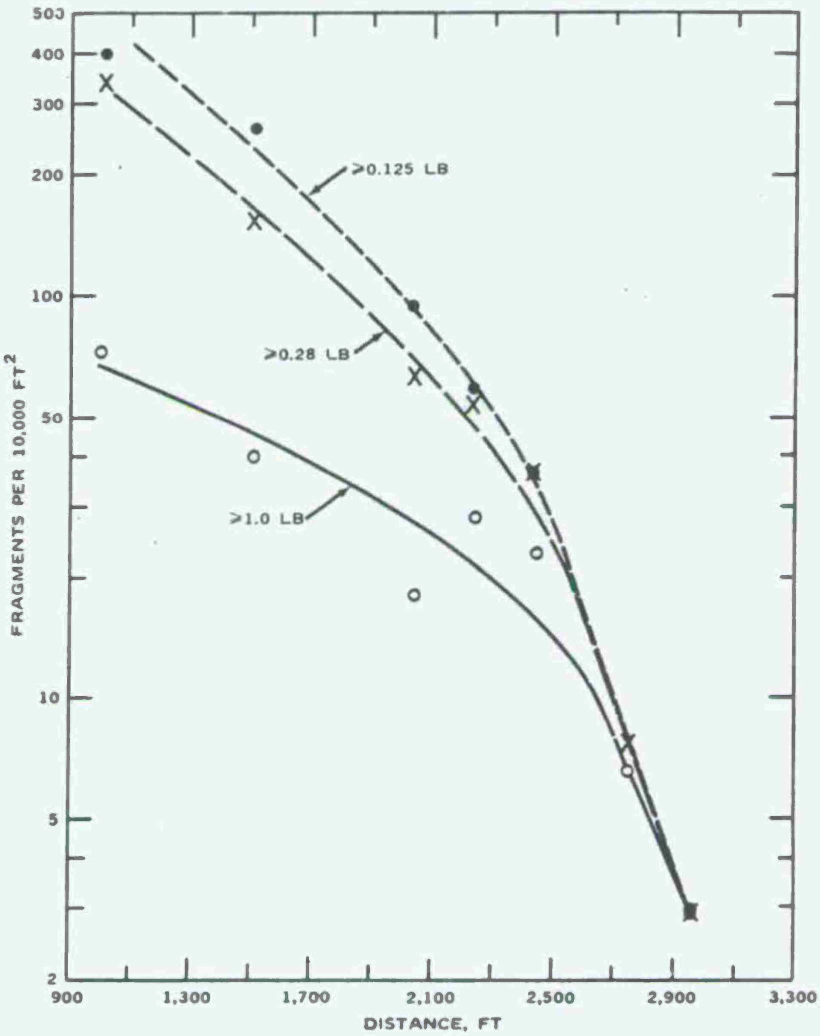


FIG. 65. Number of Fragments per 10,000 ft^2 Versus Distance West of Donor Magazine (Hand Pickup).

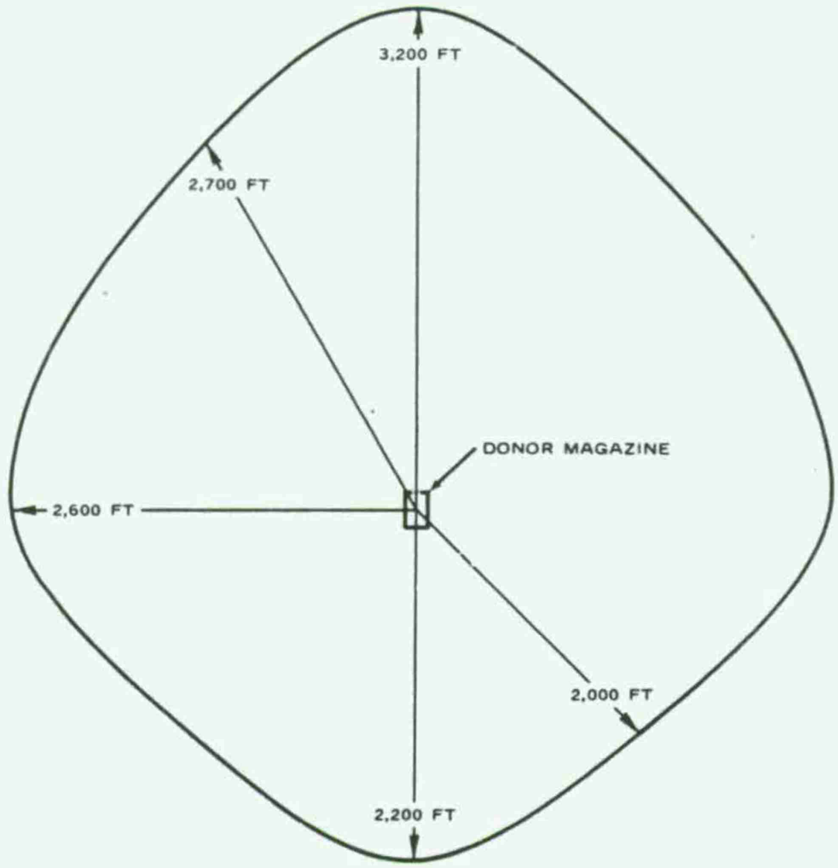


FIG. 66. Limits of Fragment Hazard, Based on Acceptable Density of One Hazardous Fragment per 600 ft^2. A hazardous fragment is defined as one having kinetic energy ≥ 58 ft-lb.

second and less gave an overall picture of the fireball growth and the explusion of debris. Detailed coverage of acceptor igloo headwalls provided good views of blast waves approaching and reflecting from structural surfaces. Waves appeared as multiple and complex at the north, east, and south acceptor igloos.

Coverage of the donor magazine headwall showed initiation and travel of the detonation along the Primacord, followed by emergence of a bright fireball from the door and headwall. Detonation of acceptor charges in the east igloo was recorded as a brillant, intense light typical of detonation photographs.

The timing marks recorded on the high-speed 16-mm film became erratic after emergence of a substantial fireball; however, the timing of observable events as derived from film records agreed well with timing of the same events recorded on tape (if the measured camera speed at or near zero time is assumed to hold throughout the event). The single exception to this is a disagreement between tape and film records concerning the time of detonation of acceptor charges in the east

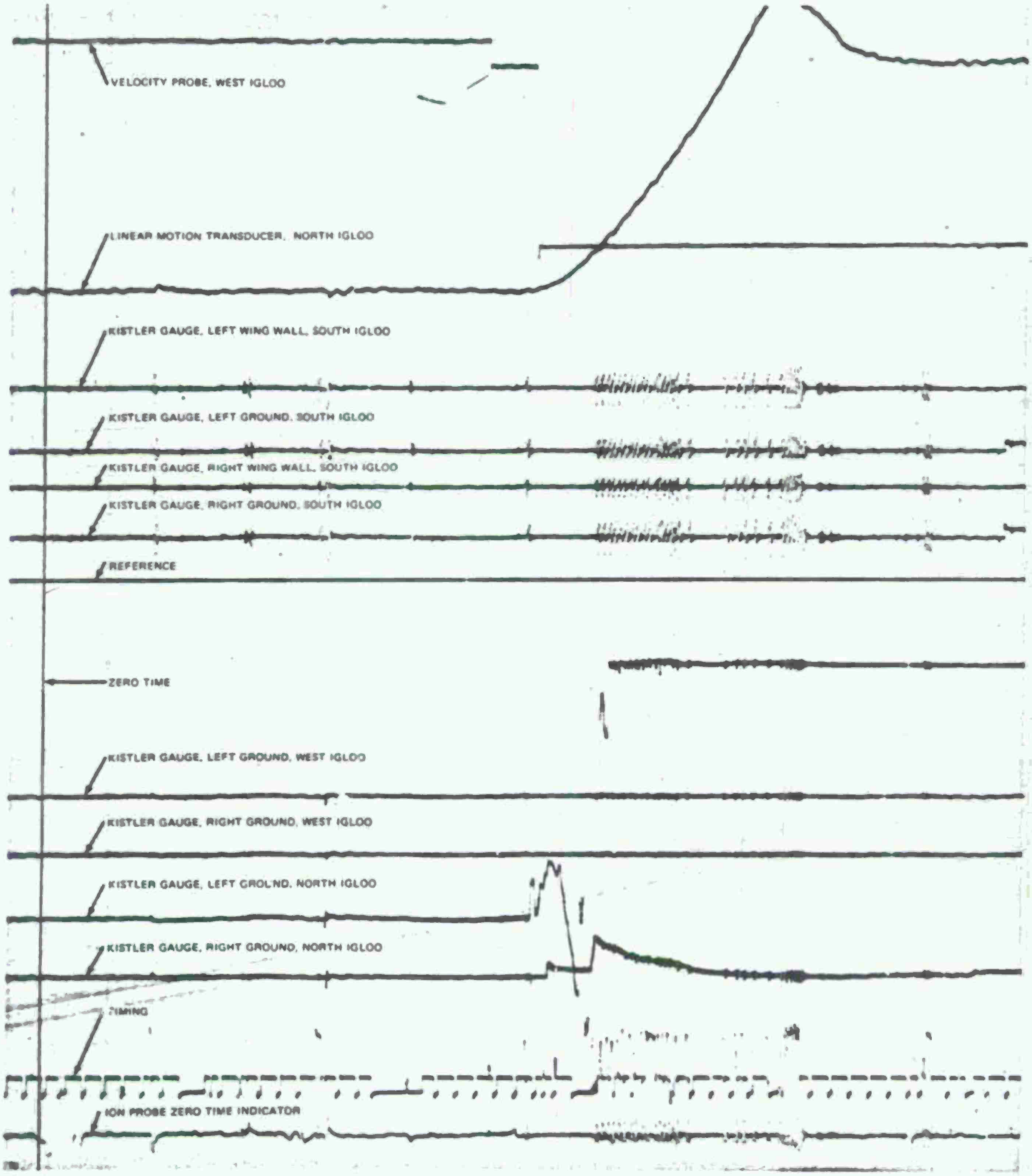
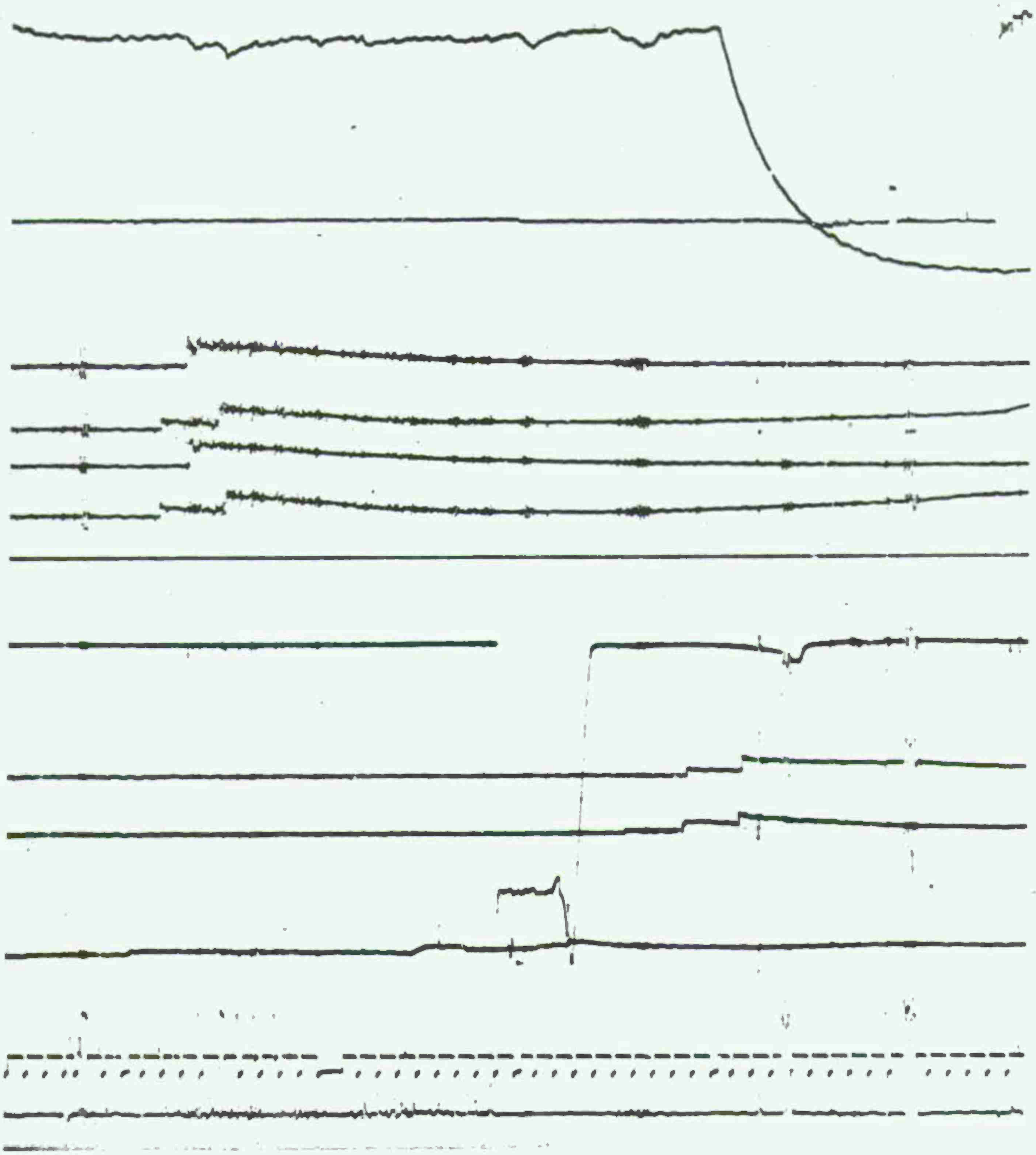
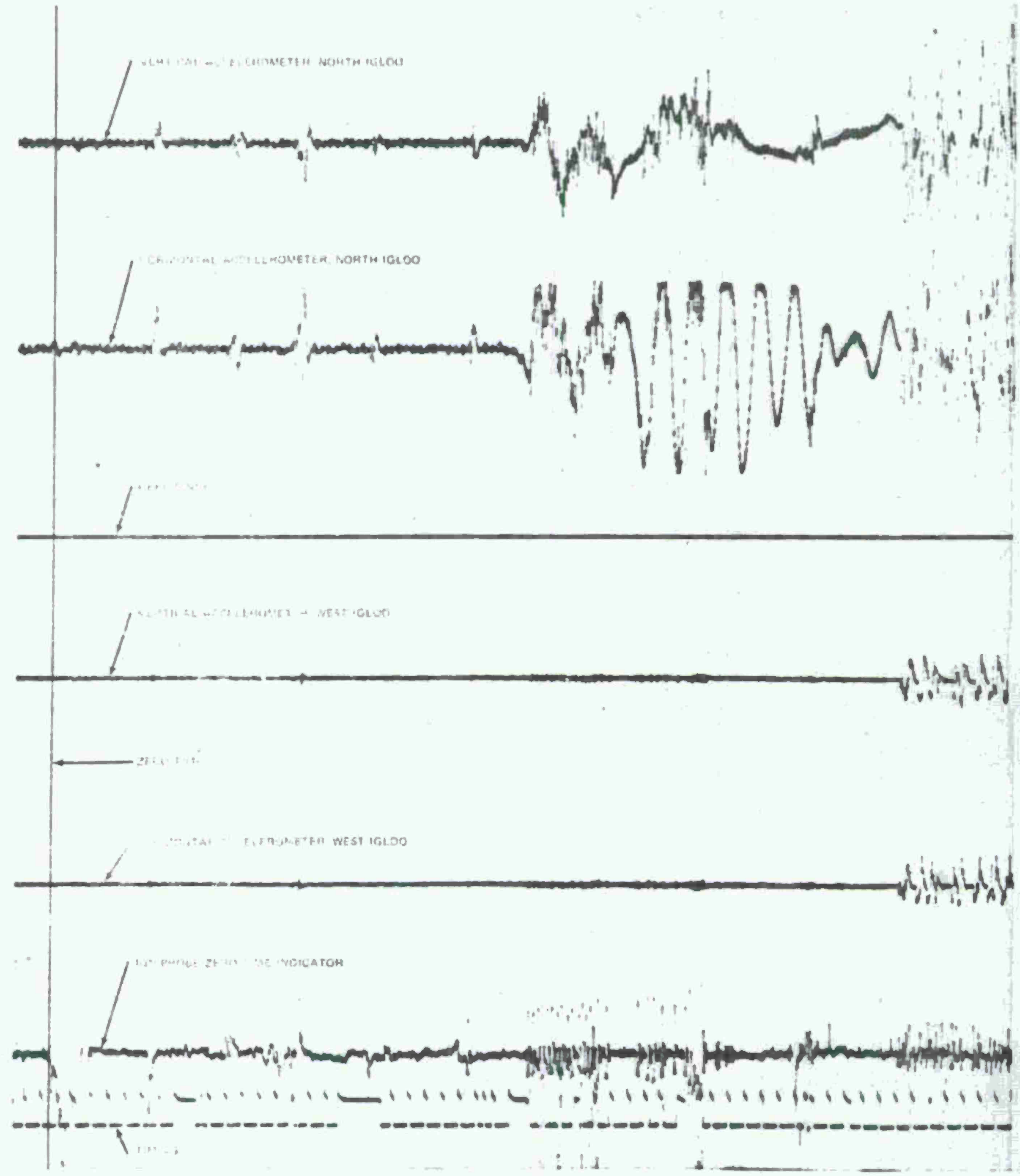


FIG. 67. Instrument Recordings, Prima



ient Recordings. Primarily Kistler Gauges.



NORTH IGLOO
ACCELEROMETER, NORTH IGLOO
WEST IGLOO
WEST IGLOO
INDICATOR

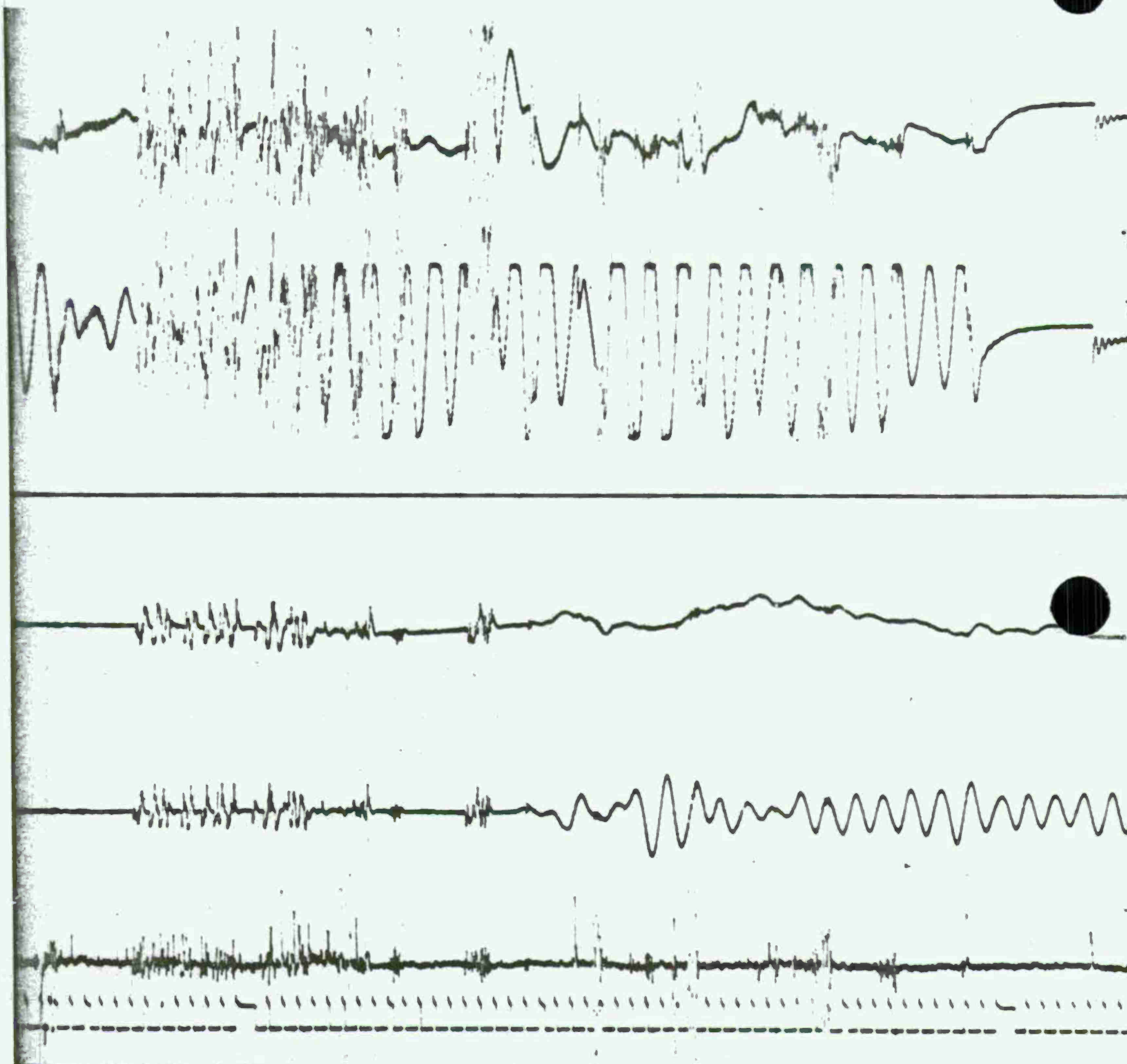
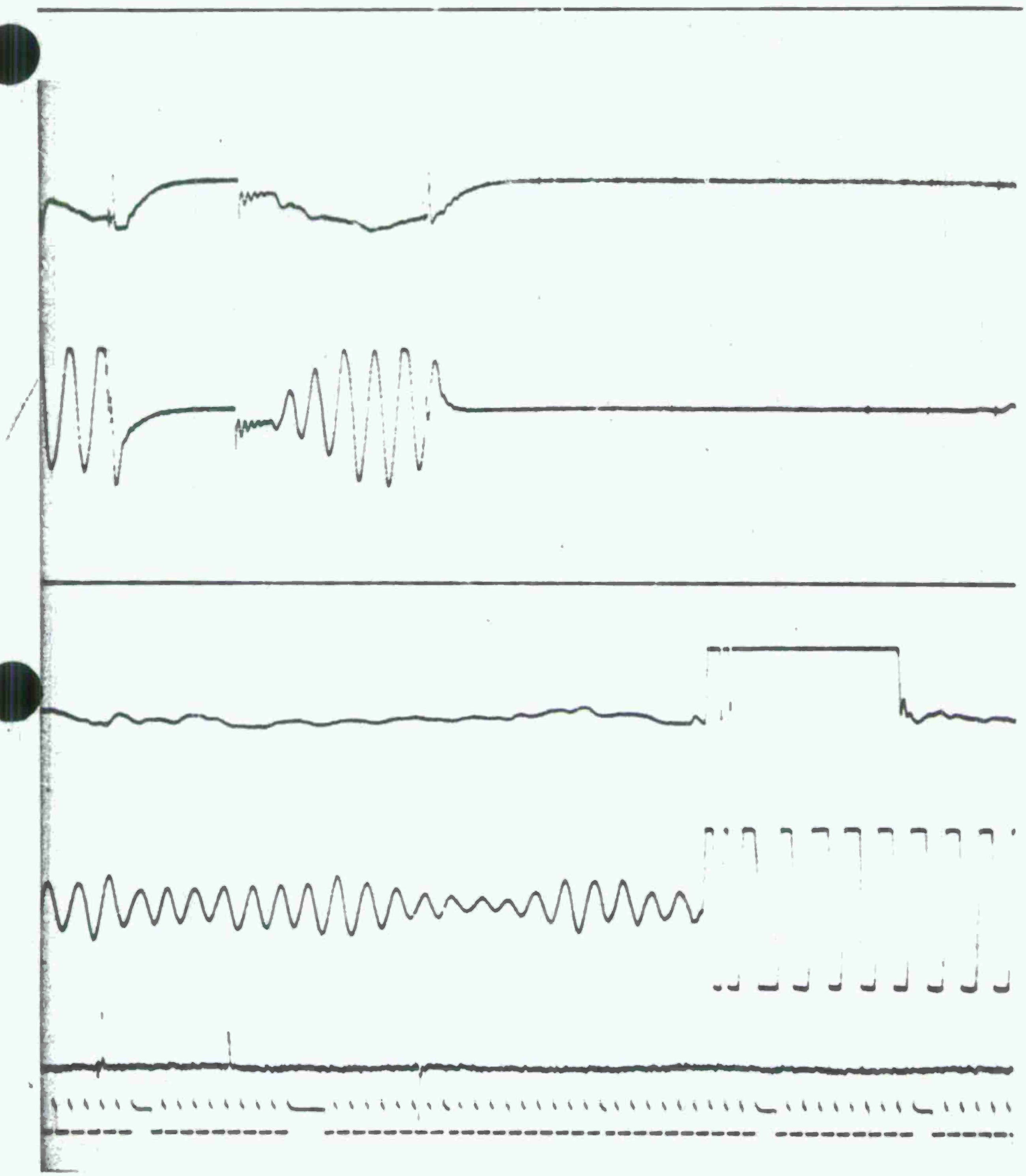


FIG. 68. Instrument Recordings, Primarily Accelerometers

2



3

TABLE 4. Summary of Event Times in Milliseconds.

Times are based on 0.0 ms for fireball eruption as described in the text. Primacord was initiated at −14 ms.

Event	North igloo	East igloo	South igloo	West igloo
First signal from velocity probes at igloo doors	NA	26.2	41.2	23.0
Arrival of main blast at ground Kistler gauges 2 ft in front of igloos	26.2	32.9	49.2	76.0
Arrival of main blast at headwall Kistler gauges	NA	NA	50.7	NA
First wall motion recorded by transducers in headwalls	25.2	33.9	51.1	NA
First floor motion recorded by horiz. and vert. accelerometers	27.7	32.6	54 ± 3	75.6
First floor motion caused by events other than donor blast	. . .[a]	51 to 65[b]	. . .[a]	144.0[c]
Approx. detonation time of acceptor charges in east igloo	NA	51 to 60[d]	NA	NA

[a] No meaningful data obtained.

[b] Record is noisy, but accelerometer channels appear to be driven to saturation in this time frame. Detonation of acceptor charges in east igloo also occurs in this time frame.

[c] Instrumentation channels were driven to saturation shortly after most of this motion, which is believed to be caused by impact of a large section of donor igloo floor curb against west igloo headwall.

[d] Records from accelerometers and linear motion transducer suggest 51 ms. Motion picture records show 60 ms. This discrepancy is discussed in the text.

igloo. To resolve this disagreement it is believed necessary to assume that (1) the camera speed was accelerating rapidly from zero time to the acceptor charge detonation, or (2) the strong signal changes recorded by accelerometers and linear motion transducer channels at approximately 50 milliseconds after zero time were related to events other than acceptor charge detonation—for example, impact of a very large fragment similar to that striking the west igloo.

BLAST GAUGE DATA

General

The blast gauge instrumentation consisted of two basically different types of gauges: (1) BRL self-recording mechanical gauges placed at distances ranging from 410 to 2,690 feet from the donor, as listed in Table 5 and shown in Fig. 14 and (2) Kistler piezoelectric gauges placed at relatively shorter distances, commensurate with their greater frequency-response characteristics, from the donor magazine.

BRL Gauges

Data from the BRL gauges are given in Table 5. The use of $W^{1/3}$ values from this table permits comparison with blast fields from other igloo tests and comparison of front, side, and rear blast levels with standard prediction values for actual or equivalent weights of explosive. From Table 5 the average values of $W^{1/3}$ derived from overpressure and from impulse are

Front 51.1
Side 46.8
Rear 40.4

The average of these three values is 46.1, which gives an effective equivalent weight (W) of 98,000 pounds.

Average values of $W^{1/3}$ similarly derived from the 1963 test using 100,000 pounds of Composition B (Ref. 1) are

Front 43.7
Side 39.6
Rear 32.3

The average of these three values is 38.5, which gives an effective equivalent weight of 57,000 pounds of TNT.

If the derived equivalent weights of the front, side, and rear gauge arrays are compared as a percentage of the derived overall equivalent weights for ESKIMO I and the 1963 test (Table 6), results are consistent with expectations in that the

TABLE 5. Summary of BRL Gauge Data.

Gauge No.[a]	Gauge distance (R) from donor center, ft	Peak overpressure psi		Scale distance (λ_1) derived from overpressure, ft/lb$^{1/3}$	R/λ_1 (or $W_1^{1/3}$) derived, lb$^{1/3}$	Impulse (I), psi-ms		I/R, psi-ms/ft	Scale distance (λ_2) derived from impulse, ft/lb$^{1/3}$	Rλ_2 (or $W_2^{1/3}$) derived, lb$^{1/3}$	Duration of overpressure curve, computer extrap., ms
		Direct reading	Computer extrap.			Direct reading	Computer extrap.				
1N	410	11.8	12.0	8.8	46.6	520	530	1.29	7.6	54.0	148
2N	526	8.89	7.86	10.6	49.6	397	418	0.795	9.8	53.8	162
4N	880	2.88	3.02	20.2	43.5	213	216	0.245	18.0	48.9	182
5N	1,580	1.62	1.47	31.5	50.2	141	152	0.0962	29.0	54.5	236
6N	2,690	0.569	0.75	56.0	48.0	100	107	0.0378	45.0	59.8	299
1S	410	8.04	7.45	10.6	38.7	243	248	0.605	11.2	36.6	95
2S	526	5.83	5.71	13.1	40.2	251	252	0.479	12.6	41.1	123
3S	703	4.50	4.08	15.5	45.2	190	194	0.276	17.0	41.4	135
4S	880	2.57	2.60	22.5	39.1	154	154	0.175	21.6	40.7	147
2W	526	6.03	6.05	13.0	40.7	282	292	0.555	11.8	44.6	127
3W	703	4.55	4.54	15.5	45.4	239	250	0.356	15.0	46.9	144
4W	880	3.25	3.31	19.6	45.0	209	229	0.260	17.5	50.3	158
5W	1,580	1.39	...	37.0	42.6	...	...	...	...	...	...
6W	2,690	0.879	8.86	50.0	53.3	73	78	0.029	53.0	50.7	209

TABLE 6. Comparison of Derived Equivalent Weights for ESKIMO I and 1963 Tests.

Gauge array location	ESKIMO I test		1963 test	
	weight ratio	weight ratio, %	weight ratio	weight ratio, %
Front	$51.1^3/46.1^3$	136	$43.7^3/38.5^3$	148
Side	$46.8^3/46.1^3$	105	$39.6^3/38.5^3$	108
Rear	$40.4^3/46.1^3$	67	$32.3^3/38.5^3$	59

larger overall weight produced more symmetrical front and rear values (136 and 67% versus 148 and 59%).

Figure 69 shows 1-psi overpressure values to the front, side, and rear of the donor magazine, derived from BRL gauge data, and a computed value based on 200,000 pounds of TNT. The three derived values were obtained by using $W^{1/3}$ values derived by averaging the BRL gauge overpressure and impulse values and multiplying by a scaled distance factor of 45 corresponding to a 1-psi overpressure level in standard curves prepared by C. Kingery of BRL (Ref. 4). These values of 2,300, 2,110, and 1,820 feet are slightly higher than those based solely on the 1-psi overpressure levels recorded by the BRL gauges. The computed value was determined without reduction to an equivalent weight; that is, $200{,}000^{1/3} \times 45 = 2{,}630$ feet

The equivalent weight can be calculated from the following formula from Ref. 3:

$$W_{stack} = 1.2WkF$$

where

W_{stack} = equivalent weight of the stack
W = total charge weight of the stack in pounds of TNT
k = attenuation factor for the mode of storage (0.8 for munitions stored in a standard steel-arch earth-covered igloo)
F = factor given by the modified Fano formula to account for the energy expended in breaking up the metal of the weapon case (0.635 for the 155-mm projectile body)

Using these values,

$$W_{stack} = 1.2 \times 200{,}000 \times 0.8 \times 0.635$$
$$= 122{,}000 \text{ pounds}$$

Using this value, $W^{1/3} = 49.5$, and the predicted position of the 1-psi overpressure level would be 49.5×45 or 2,230 feet in all directions from the donor magazine.

The computer assessment of the BRL records produced (1) tabulations of the overpressure and impulse versus time and (2) plots of the data. Figures 70 through 74 show the plotted data for 13 of the 16 BRL gauges. Gauges 3N and 1W did not produce usable records, and gauge 5W showed peak pressure only.

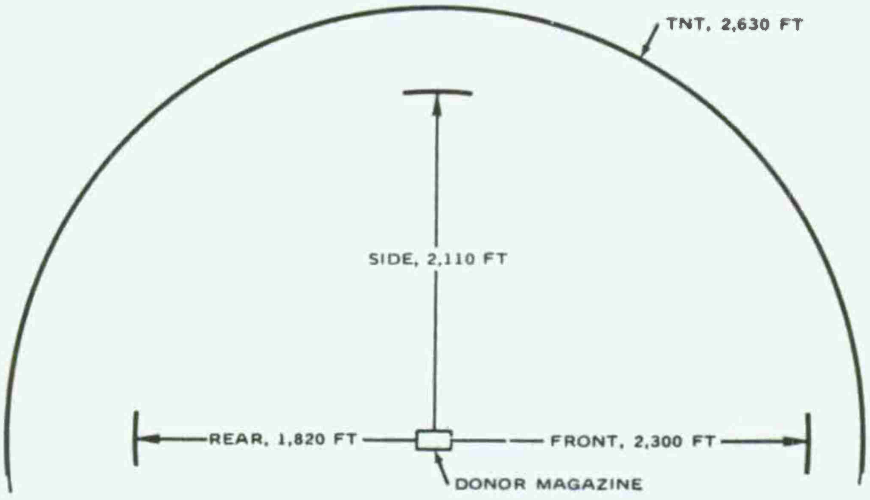


FIG. 69. Comparison of 1-psi Overpressure Distances for ESKIMO I Test With Distance for 200,000 Pounds of Unconfined TNT.

In addition, the computer plotted the first part of the overpressure curve on a semilogarithmic scale and fitted a least squares line to the curve, permitting an extrapolation to zero time for determining the most likely real initial overpressure. Figure 75 shows such a plot. This procedure was designed to reduce the effect of slow response by the BRL gauges at the leading edge of the shock wave and the effect of overshoot and oscillation by the Kistler gauges.

Similarly, the computer plotted the trailing edge of the positive phase of the overpressure curve on a semilogarithmic scale and fitted a straight line to it, permitting extrapolation to the most likely positive-phase duration (Fig. 76). The program also included the computation of impulse based on these extrapolations.

Kistler Gauges

Data from Kistler piezoelectric gauges are presented in Table 7. The data, like the BRL data, reflect the blast directionalization caused by the donor magazine structures. The value of $W^{1/3}$ derived from overpressure is much higher forward of the donor than are those to the rear; however all $W^{1/3}$ values are lower than those derived from BRL gauge data. By an averaging process giving equal weight to incident overpressures recorded in each cardinal direction, the equivalent W derived from the Kistler gauges is 30,000 pounds of TNT, or 30% of the equivalent W derived from the BRL gauge data. The apparent center of the 30,000 pound equivalent W is about 10 feet outside the door of the donor magazine.

There is no clear-cut, evident explanation for the large difference in equivalent $W^{1/3}$ derived from BRL and Kistler gauges. The high-speed 16-mm films showed multiple blast waves appearing at different angles with the ground surface. These were spaced well apart in some instances and close together in others. This multiplicity of blast waves is consistent with phenomena recorded on film showing

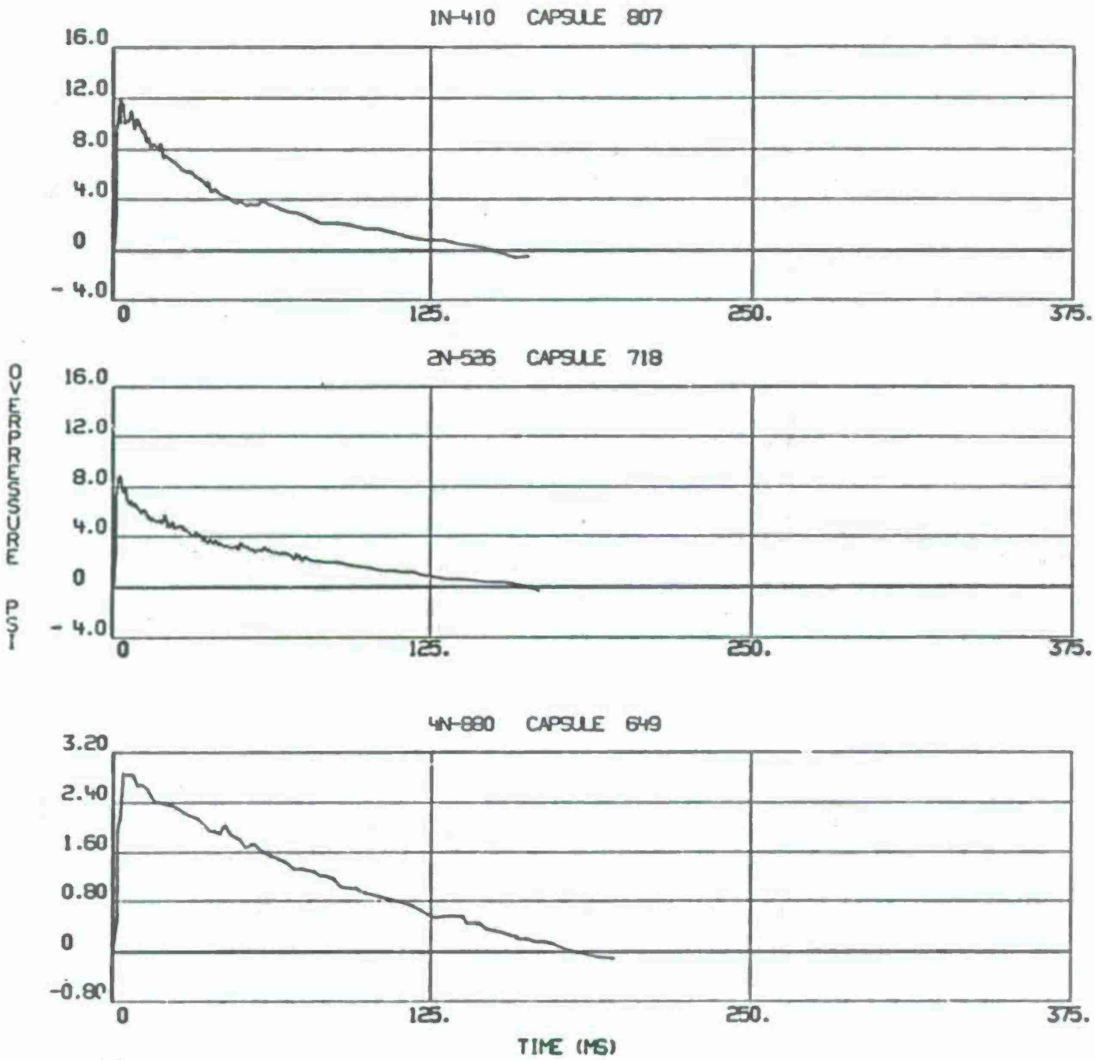


FIG. 70. Data Plots for BRL Gauges 1N, 2N, and 4N.

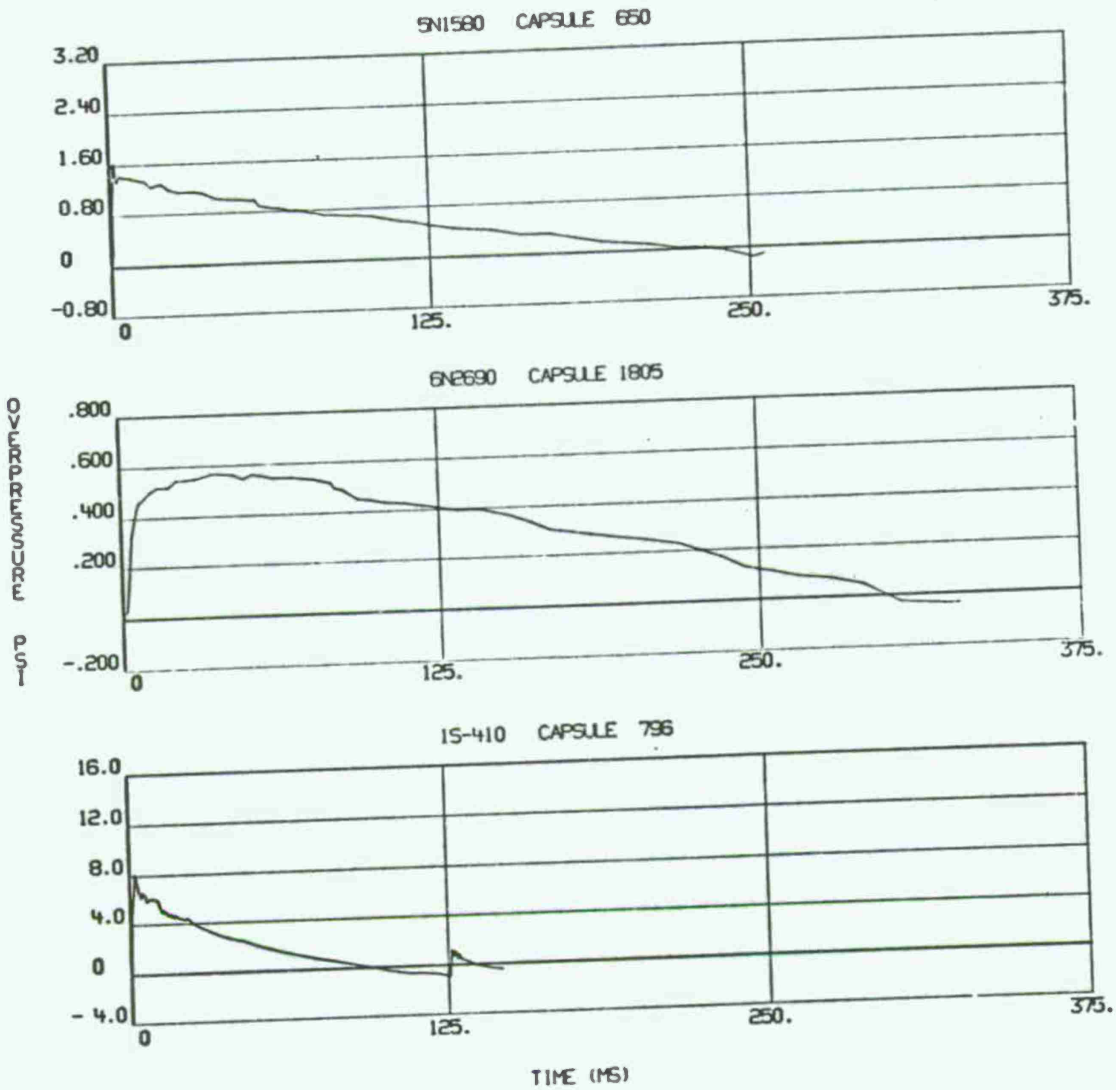


FIG. 71. Data Plots for BRL Gauges 5N, 6N, and 1S.

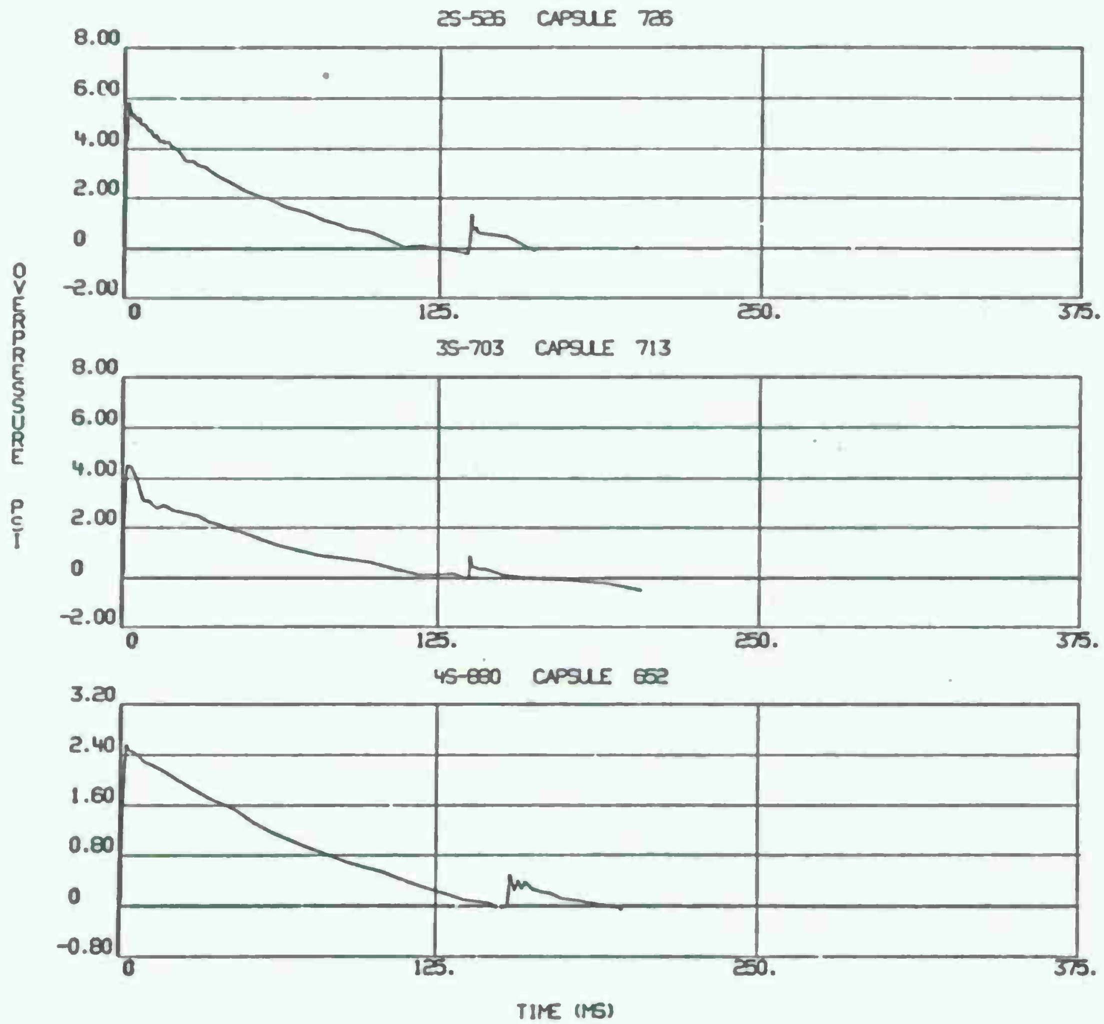


FIG. 72. Data Plots for BRL Gauges 2S, 3S, and 4S.

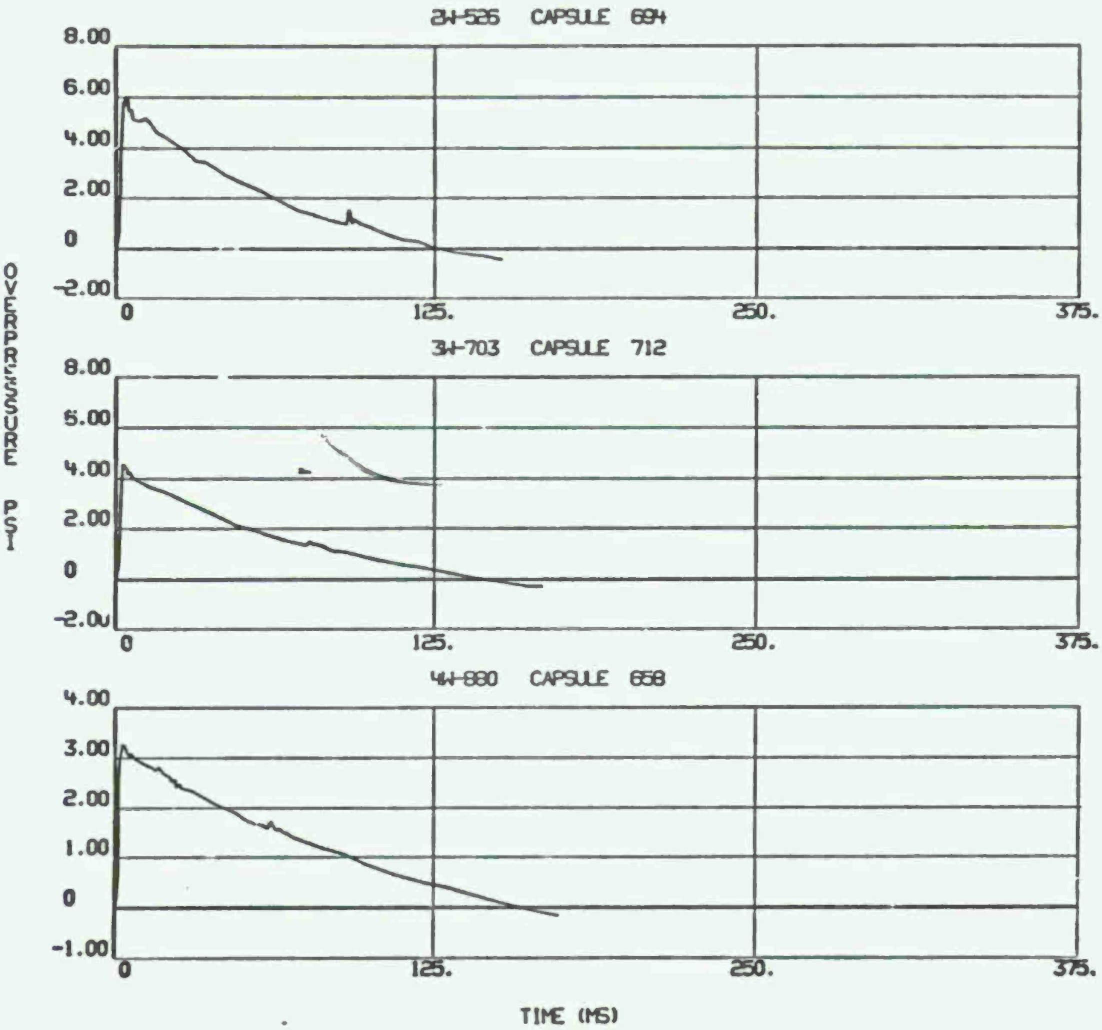


FIG. 73. Data Plots for BRL Gauges 2W, 3W, and 4W.

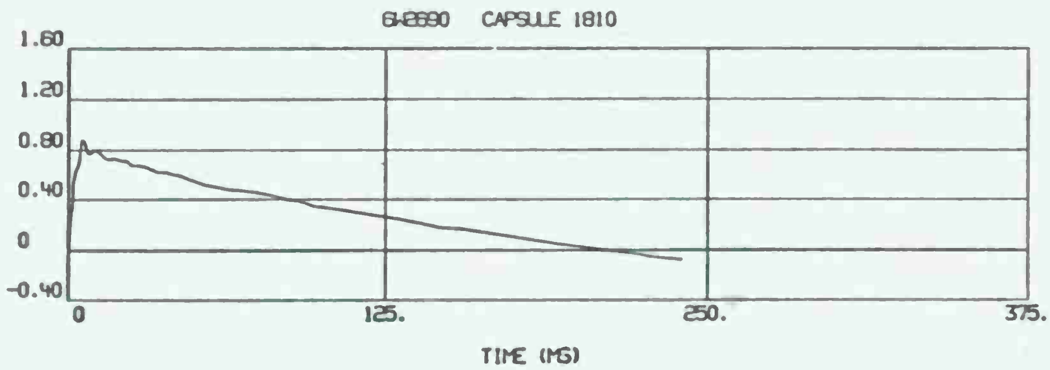


FIG. 74. Data Plot for BRL Gauge 6W.

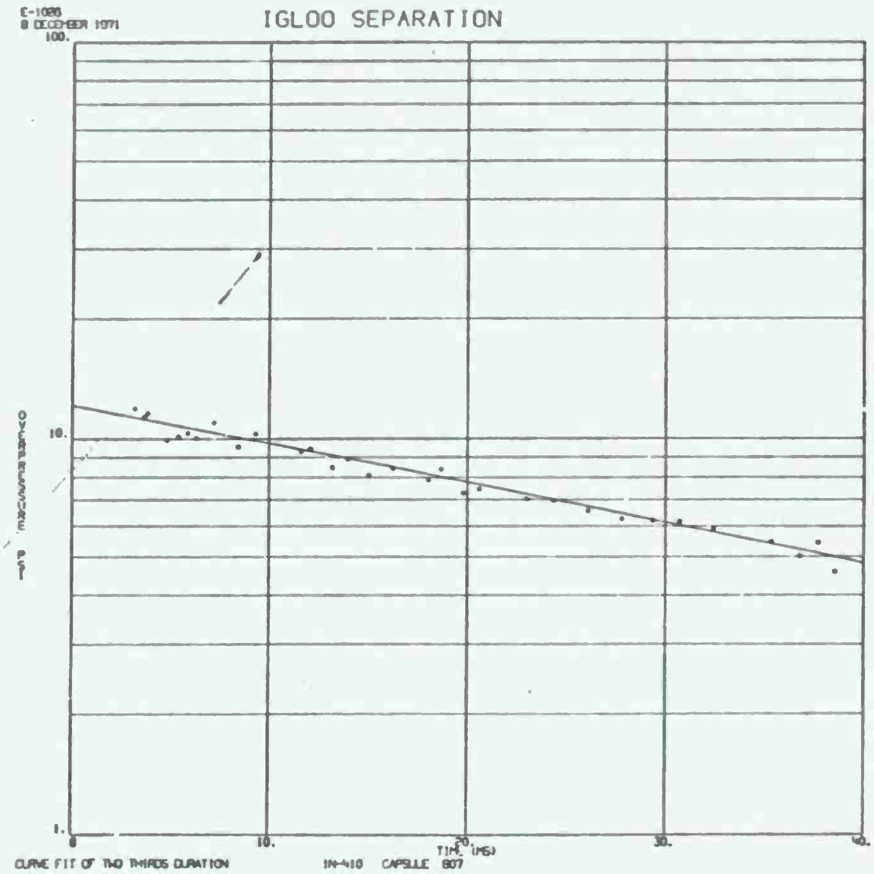


FIG. 75. Computer Plot of First Part of Overpressure Curve From BRL Gauge 1N.

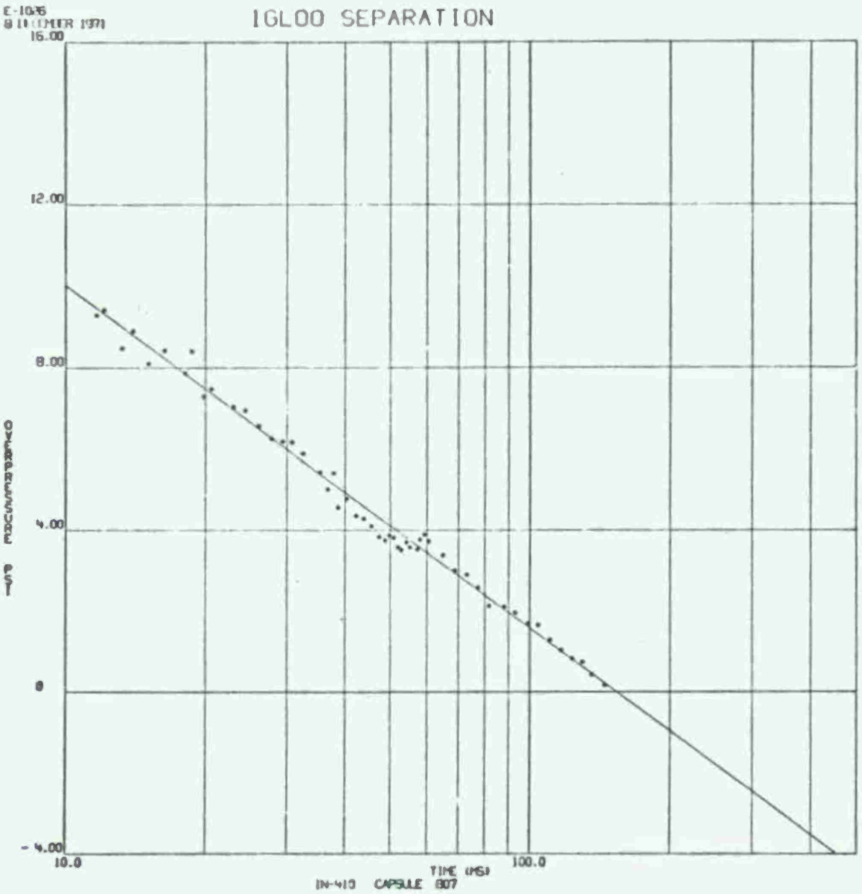


FIG. 76. Computer Plot of Trailing Edge of Overpressure Curve From BRL Gauge 1N.

overall views of the early stages of development of the explosion–namely, that the development of a fireball north of the donor magazine and the development of a fireball in a line atop the donor magazine appear as separate processes. It may be hypothesized that these multiple blast fronts later coalesced as they approached the BRL gauge positions to form a single blast wave typical of that from a point source of about 100,000 pounds of TNT. However, the Kistler gauge records do not support this hypothesis, most gauges having recorded a more-or-less classical initial-peak blast pressure pulse with clearly interpretable reflection by the igloo headwall. There are additional signals on the records, particularly at the north and east gauge sites, that may have resulted from a blast wave or waves, but the traces are not consistent with the others.

The differences between near (Kistler) and distant (BRL) gauges are not believed to result from instrument error or calibration error; they are believed to be representative of a real condition. Model tests reported Ref. 5 show similar results.

TABLE 7. Summary of Kistler Piezoelectric Gauge Data.

Gauge station[a]	Gauge distance (R) from donor center, ft	Peak overpressure, psi		Impulse, psi-ms		Duration of overpressure curve, computer extrap., ms	λ_1, derived from std. curve for incident overpressure, ft/lb$^{1/3}$	R/λ_1 (or $W_1^{1/3}$), derived from overpressure, lb$^{1/3}$	ID/R,[b] psi-ms/ft	λ_2 derived[b] from std. curve for I/R, ft/lb$^{1/3}$	R/λ_2 (or $W_2^{1/3}$) derived[b] from ID, lb$^{1/3}$
		Incident	Reflected	Measured (I)	Derived[b] incident component (ID)						
N, r.g.	145	75	238	768	...	12.5	3.8	38.1	...	...	...
N, l.g.	145	No record[c]	...	...	...	...	...	...	...	...	...
W, r.g.	172	38	68	585	...	31.5	5.1	33.8	...	...	...
W, l.g.	172	25	64	...[d]	...	40.2	6.2	27.9	...	...	...
S, r.g.	145	33	61	545	...	26.7	5.5	26.3	...	...	...
S, l.g.	145	33	61	693	...	28.0	6.0	24.1	...	...	...
E, r.g.	84	27	...	...	...	...	...	...	...	...	...
E, l.g.	84	No record[c] 150	250	1,010	...	...[e]	2.8	30.0	...	...	...
S, r.w.	147	None	76	705	258	79.7	6.1	23.0	1.75	6.2	23.9
S, l.w.	147	None	72	641	244	27.1	6.1	22.7	1.66	6.4	23.0

[a] N, W, S, and E refer to the north, west, south, and east igloos; r. and l. refer to right and left positions; g. and w. refer to ground and wall locations.
[b] Derived only for the wing wall locations in the south igloo.
[c] Gauge did not record peak overpressure; hence no calculations can be made.
[d] Data not reliable.
[e] Not computed; unreliable data.

MOTION INSTRUMENTATION

Linear motion transducers positioned to measure movement of the concrete headwall above the center of the north, east, and south acceptor igloo doorways recorded data from which motion values listed in Table 8 were derived. The data for the north and east igloos were very similar for the first 3 inches of movement, which represents the limit of movement tolerated by the transducers and the limit of calibration.

Attempts were made to measure door movement with probes of varying length mounted on a vertical post behind the door and seated against microswitches. These were not successful, probably because the microswitches were activated by forces other than door motion. The times of initial motion sensed by the probes are shown in Table 4.

Accelerometer data, given in Table 9, are consistent in timing with blast wave arrival. Events later than blast wave arrival and of equal or greater significance are discussed in the Remarks column of this table.

STATIC HEADWALL MEASUREMENTS

Before the test, survey monuments were set to define a vertical plane 3 feet in front of each acceptor igloo headwall, and distances were measured from these planes to selected points on the headwalls. After the test, these distances were again measured, along with a number of additional distances not previously surveyed. Since pretest measurements showed that the walls deviated from a true vertical plane by ±0.05 feet, all of these additional distances are subject to that much error. The permanent changes in position of the three remaining (north, south, and west) headwalls are shown by isopleths in Fig. 77, 78, and 79.

TABLE 8. Summary of Linear Motion Transducer Data.

Location of headwall transducer	Max. velocity, ft/sec	Av. velocity from initial motion to peak excursion, ft/sec	Time from initiation motion to max. velocity, ms	Av. acceleration from initial motion to max. velocity, *g*
North igloo	29.8	20.0	8.1	114
East igloo	29.5	18.5	8.0	114
South igloo	27.9	13.3	14.4	60

TABLE 9. Summary of Accelerometer Data.

Accelerometers were located on center lines of igloo floors, near the front.

Location of accelerometer	Type of motion sensed	Max. acceleration as a direct result of donor blast, g	Approx. frequency of accelerations as a direct result of donor blast, Hz	Remarks concerning acceleration record not directly resulting from donor blast
North igloo	Horizontal Vertical	10.3[a] 16.0	490 Not measured[b]	At approximately 32 ms after main blast arrival at the headwall, a second series of motions was recorded by the vertical accelerometer channel, with a maximum of 16.4 g. The horizontal channel was again saturated at 10.3 g.
East igloo	Horizontal Vertical	33.0 20.0	545 Not measured[b]	The record was noisy; however, both channels appeared to be saturated intermittently, with motion beginning approximately 17 ms after arrival of the main blast wave.
South igloo	Horizontal Vertical	6.3 2.0	500 Not measured[b]	No remarks.
West igloo	Horizontal Vertical	5.5 4.0	533 Not measured[b]	Both channels were saturated by motion beginning 68 ms after motion resulting directly from the donor blast.

[a] Channel was driven to saturation at 10.3 g.

[b] Too few cycles registered to obtain a measurement.

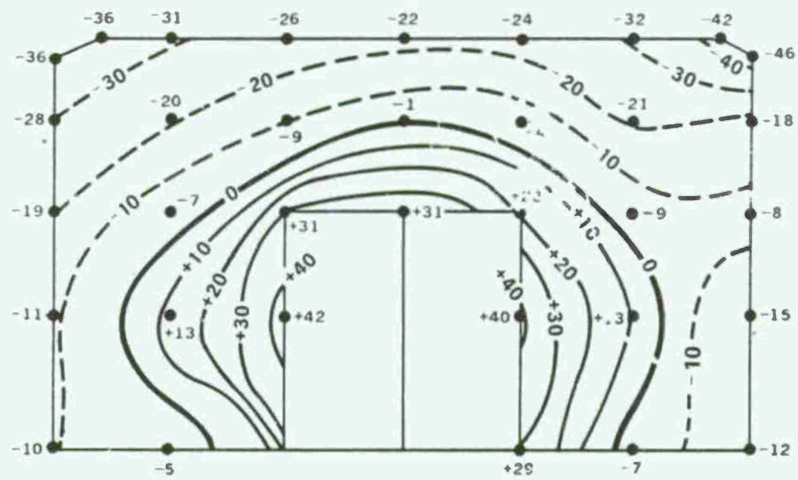


FIG. 77. Movement of Headwall of North Acceptor Igloo. A plus value shows movement away from the donor magazine; a minus value shows movement tow:rd. The units are in hundredths of feet.

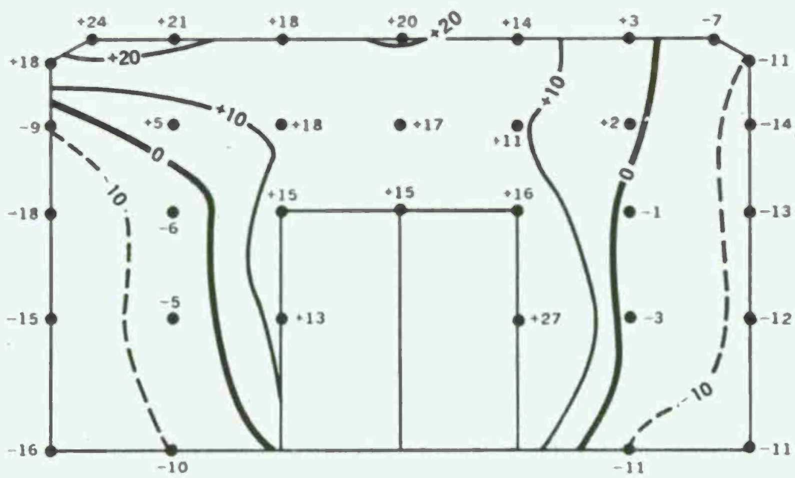


FIG. 78. Movement of Headwall of South Acceptor Igloo. A plus value shows movement away from the donor magazine; a minus value shows movement toward. The units are in hundredths of feet.

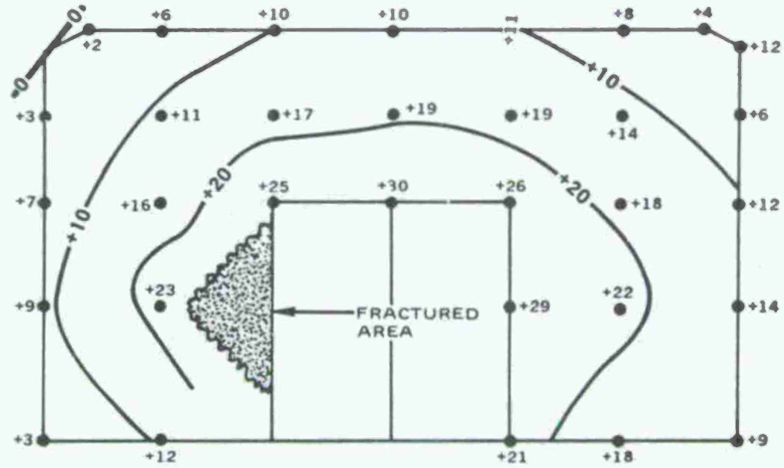


FIG. 79. Movement of Headwall of West Acceptor Igloo. Plus values show movement away from donor magazine; one point (upper left) showed no movement. The units are in hundredths of feet.

Note that the headwalls appear to have responded in different ways at each of the three sites measured. It is apparent from visual observation and from examination of the measurement data at the north and south sites that the steel arch acted as a reaction line resisting headwall movement. The steel arch yielded somewhat but, curiously, this effect was more pronounced at the south igloo, where measured movement at the top of the arch was 2.5 to 3 inches.

The movement shown in Fig. 77, 78, and 79 does not represent the maximum motion experienced by the headwalls. For example, there was a space approximately 0.2 feet wide between the back of the south headwall and the earth cover at the top left corner and a similar space 0.1 feet wide at the top right corner indicating movement greater than the permanent displacement. Similar but less marked evidence of earth cover compression was seen at the other acceptor igloos. This earth cover disturbance at headwalls may be seen in an overhead photograph (Fig. 31).

Appendix A

INTERIOR BLAST PRESSURES OF ACCEPTOR MAGAZINES: ESKIMO I

by

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November 1972

This appendix contains extracts from the above report, with only Fig. 1, 5, 6, and 7 being reproduced herein. The omitted text and figures are essentially duplications of material contained in the main body of the basic report (TP 5430).

INTERIOR BLAST PRESSURES OF ACCEPTOR MAGAZINES: ESKIMO I

ABSTRACT

This report describes the measurement of dynamic pressure-time histories within earth-covered, steel-arch acceptor magazines which were subjected to overpressures produced by the detonation of a central donor magazine containing 200,000 pounds of TNT cast in M101 155 mm projectiles.

Shockwave arrival times were monitored at the headwalls of four inwardfacing acceptors located at scaled distances of 1.25 $W^{1/3}$ (Head to Side), 2.00 $W^{1/3}$ (Head to Head with intermediate barricade), 2.00 $W^{1/3}$ (Head to Rear), and 2.75 $W^{1/3}$ (Head to Side). Equivalent explosive weight values are derived as functions of time and direction for near-field conditions, based on exterior arrival time data as well as negative phase amplitudes of experimentally observed pressure profiles inside the acceptor "igloos."

Since the test arrangement represented worst-case orientation for internal damage to adjacent magazines, some obvious safety aspects concerning potential personnel and equipment hazards are discussed with suggested improvements.

INTRODUCTION

The Department of Defense Explosives Safety Board is engaged in a program to more accurately determine the minimum safe separation distance between magazines storing explosives. This distance is the least which will provide assurance that an explosion in one magazine will not propagate to another although the second magazine and possibly its contents might be extensively damaged. Of particular interest to the AEC was the determination of air shock levels within the adjacent magazines to assess probable personnel effects and equipment damage. Previous tests (1) have demonstrated that earth-covered steel-arch igloo magazines can be safely spaced side to side at a distance in feet determined by 1.25 $W^{1/3}$ in which W is the weight in pounds of the high explosive in storage. However, little information has been developed which will indicate the minimum safe distance between the concrete headwall of the magazine and the earth covered side, rear or barricaded headwall of another magazine. To determine the minimum safe separation distances when the headwall faces the donor explosion the Department of Defense Explosives Safety Board sponsored the Eskimo I Test.

DISCUSSION

TEST ARRANGEMENT

A plan view of the test arrangement complete with AEC instrument locations is shown in Fig. 1.

INSTRUMENTATION

The pressure transducers used for the test were Kulite type XTS-190 (3). These are miniature strain gage type transducers containing a silicon diaphragm on which a Wheatstone bridge has been diffusion bonded. Each transducer had a small reference tube emerging from its back side which was sealed at an atmospheric pressure of 936 millibars such that each transducer read differential pressure.

An array of 3 transducers was located centrally in each of the four acceptor igloos. These were positioned on a stand 2 feet above the floor and were directed to read head-on, side-on, and rear-on pressures within a 1-1/2 inch radius of each other. Each of the head-on gages in the acceptor igloos were fitted with Kulite type M shields, which are small perforated screens used to resist particle impingement in severe environments.

Each pressure transducer station was fitted for calibrations using pressurized dry nitrogen.

Individual transducers were mounted near ground level, centrally inside each concrete blockhouse and 2 feet outside the forward wall of each blockhouse. These were for side-on pressure measurement only.

Five shock motion detectors (pressure-activated switches) were installed for measuring arrival times. One was mounted on each acceptor igloo headwall and one was positioned on the top center of the donor igloo to obtain a zero time reference point.

The record/reproduce instrumentation system was located in an instrument barricade approximately 1,000 feet west of the donor igloo. The signal monitoring system included differential amplifiers driving a magnetic tape recorder and an oscillograph. The transducers were connected through long underground control cables which entered a 2" conduit at the rear of each acceptor igloo and emerged in the floor at the center of the igloo. A simplified block diagram of the record/reproduce instrumentation system is shown in Fig. 5.

The calibration procedure consisted of pressurizing each gage incrementally at its location; i.e., through the long control cables, the longest of which was 1,475 feet, and monitoring the output voltage at the instrument barricade. Each input channel was then calibrated by inserting known voltage steps to ascertain the deflection sensitivity of each channel. Three complete calibration runs were made on all of the gages, the final run being made just prior to the test. Since the instrument barricade was not manned during the test, the equipment functions were remotely programmed from a control center located approximately 6 miles away.

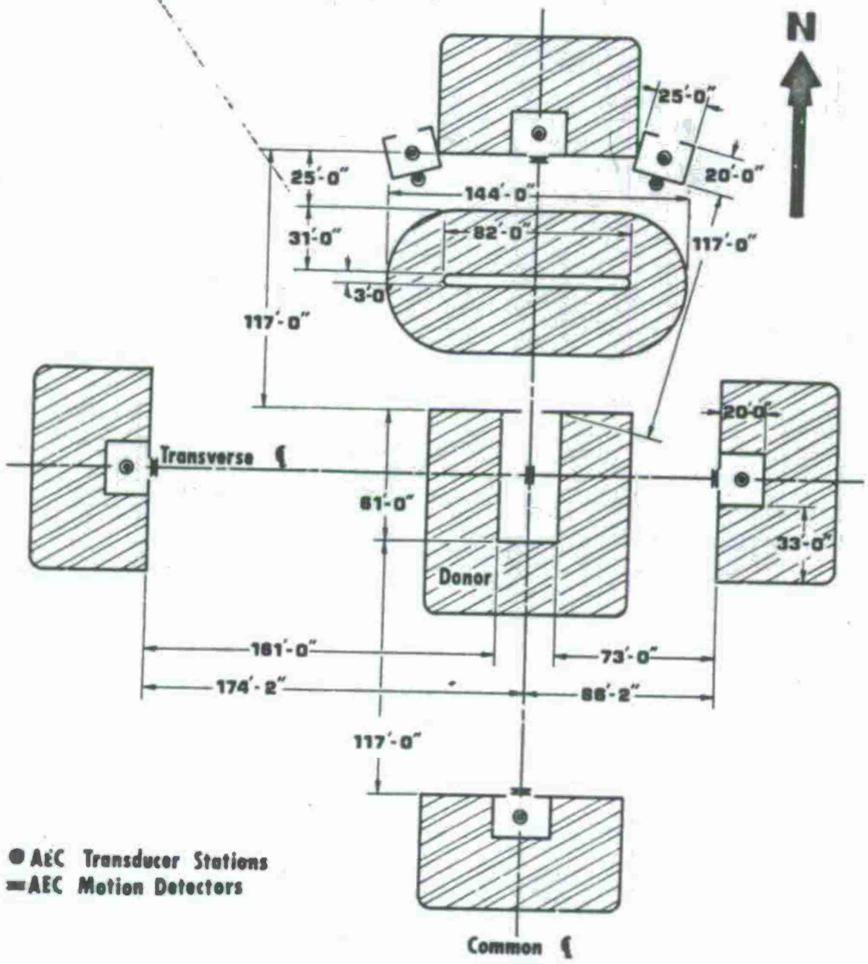


FIG. 1

Plan View Of Eskimo I Test

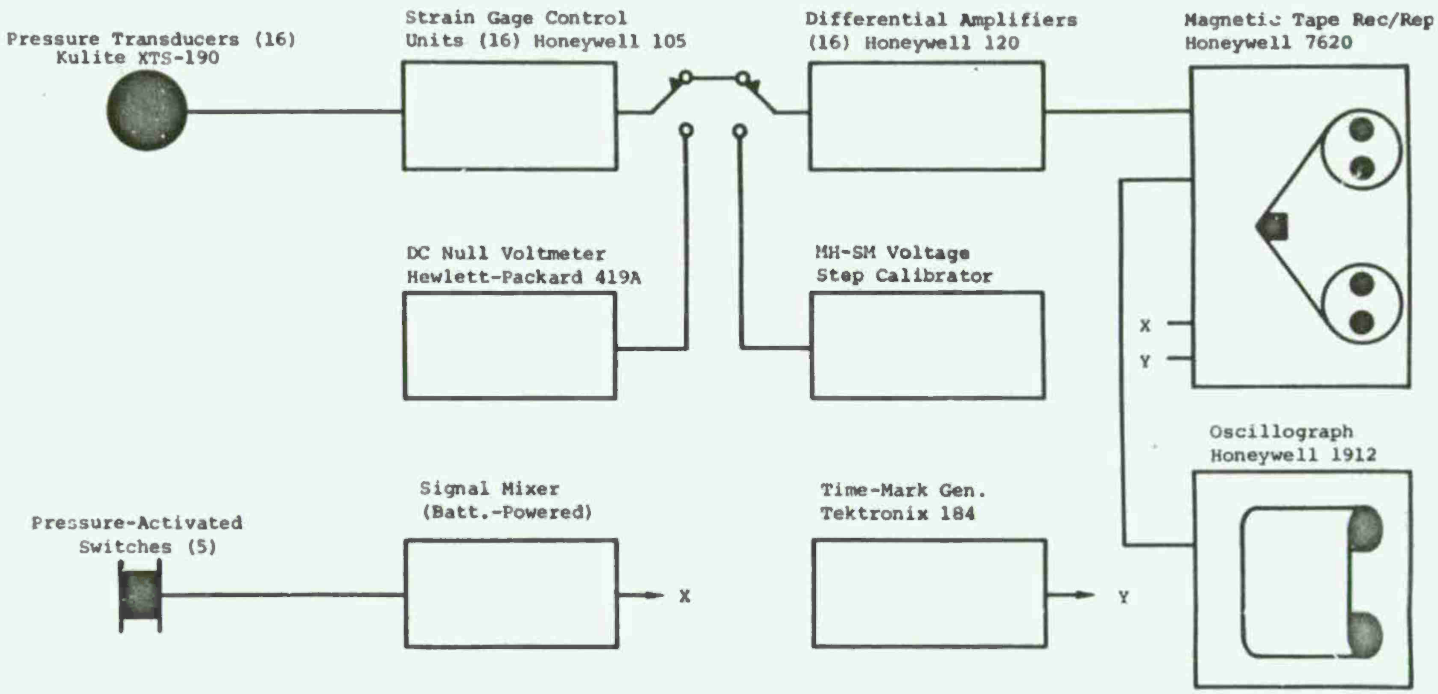


Fig. 5. Block Diagram of Record-Reproduce Instrumentation

PRESSURE MEASUREMENTS

Of the 16 transducers installed, two were scratched prior to the test; one had an open bridge circuit and the other a ruptured diaphragm. One of these was located outside the northwest blockhouse and the other was located inside the north acceptor igloo, rear-on. The remaining exterior pressure gage was located at a scaling factor of 2.0 $W^{1/3}$ to achieve correlation with NWC pressure data.

Due to the test configuration and manner of donor detonation the emerging shockwaves were directional, thereby complicating data correlation (measurement of a zero time reference was valid only in the direction measured). Actually, the test was designed to produce heavy fragmentation (more than 1 million pounds of steel was fragmented by the donor) for comparison with previous tests using bulk explosives and did not lend itself well to prediction of expected overpressures.

Calculations made for a single M101 round in the donor stack, based on an approximative model using a casing weight to charge weight ratio of 5 to 1, yielded blast wave production efficiencies as low as 50 percent ($W^{1/3} = 46$). However, pressure enhancement due to reflections and interactions from adjacent rounds would tend to increase this efficiency number. Moreover, pressure estimations were further complicated by the initiation geometry of the donor, directional effects due to donor configuration, charge weight to structure volume ratio, and response or failure time of the doors and headwalls of the acceptor magazines. Therefore, selection of pressure ranges for transducers was weighed to worst-case conditions.

One external pressure measurement was obtained near the NE blockhouse and interior pressures were monitored for each acceptor igloo and the NW blockhouse. Selected pressure-time profiles are shown in Fig. 6 and the reduced data is given in Table 1.

TEST RESULTS

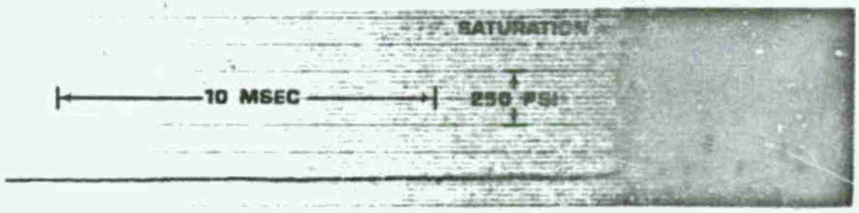
Preliminary NWC data (4) indicate that the donor blast was equivalent to a cubicle-confined detonation (5) of 100,000 pounds of TNT ($W^{1/3} = 46.5$) from far-field, BRL pressure gage measurements. Directionally, the effective $W^{1/3}$ approximated values were 51,47, and 41 for front, side, and rear of the donor, respectively. NWC near-field pressure data, measured in the acceptor igloo complex, show reduced effective $W^{1/3}$ values ranging from approximately 23 to 38.

AEC data also exhibits near-field anomalies, at least for the positive phase portion of the blast. Effective $W^{1/3}$ values computed from near-field negative phase amplitudes were in closer agreement with far-field measurements. Presumably, the mechanisms affecting positive phase characteristics were no longer contributing factors during negative phase, i.e., breeching of the donor magazine, rupture of acceptor doors, etc.

A mach stem with a triple point height several feet above ground level was observed in the high-speed camera views of the shockwave approaching the south acceptor igloo. This suggested that near-field positive phase effects were more associated with that of an air burst rather than a surface burst; therefore, effective

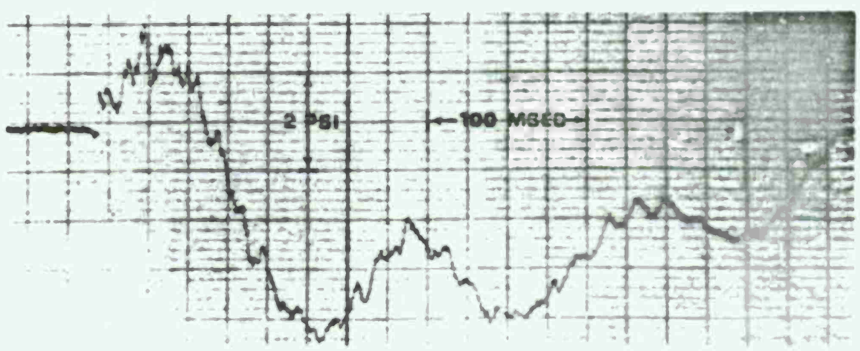
A. Interior of [illegible] Blockhouse

Interior of [illegible] Tube



Interior of [illegible] Tube

Interior of [illegible] Tube



Interior of West [illegible]

[illegible]

Table I. Eskimo I Test Data

Ambient Conditions: 936 mbars, 55 F

Location	Distance to Headwall (ft)	Shock Arrival [a] @ Headwall (msec)	Distance to Transducers (ft)	Shock Arrival [a] @ Transducers (msec)	Transducer Orientation	Peak Positive Overpressure (psi)	Positive Phase Duration (msec)	Negative Phase Duration (msec)
N Acceptor	117	23.1	127	27.3	Head-On Side-On Rear-On	31.2 14.8 --	89	276
E Acceptor	73	7.7/10.5 [b]	83	33.9/43.6/44.7 [c]	Head-On Side-On Rear-On	8/303 Saturation Saturation Saturation	Acceptor Units Detonated Transducers Destroyed	
S Acceptor	117	41.0	127	51.6	Head-On Side-On Rear-On	9.2 8.3 7.9	66	373
W Acceptor	161	69.6	171	78.9	Head-On Side-On Rear-On	2.2 2.2 2.3	68	405
NE Concrete Block Magazine	117	25.5 (Calc.)	115	24.3/26.7 [d]	Side-On (Outside)	85.4/187.8 [d]	16	37
NW Concrete Block Magazine	117	--	127	31.9	Side-On (Inside)	59.5	Transducer Destroyed After 10 msec	

[a] *Arrival Time Referenced to Motion Detector Atop Donor Igloo*

[b] *Double Pulse Recorded on E Acceptor Channel; Considered Unreliable*

[c] *Arrival Times and Pressures are Shown for Leakage Pressure, Peak Positive Pressure Preceding Saturation and Saturation, Respectively; Saturation Levels were ~ 700 psi for the Head-On Gage and 350 psi for the Side-On and Rear-On Gages*

[d] *Arrival Time and Peak Positive Pressure for Both Incident and Reflected Waves are Listed*

$W^{1/3}$ values were computed for both air and surface bursts for comparison. Apparently, a combination of the characteristics of both types of bursts affected near-field measurements, depending on direction from the donor. Effective $W^{1/3}$ calculations from arrival time and negative phase data, corrected to sea level, are given in Table II.

These data are plotted in Fig. 7 with scaled curves taken from Fig. 4-12 of Reference 5.

The calculations based on arrival times are subject to inherent directional errors of as much as 5 ms... Attempts to correct the measured arrival time for each direction, using NWC high-speed camera views of the donor breeching sequence, yielded effective cube-root weights which were still substantially lower than far-field results.

The high-speed camera records showed that first light emerged from the doors of the donor igloo about 5 msecs prior to ground shock activity near the zero time motion detector atop the earthen fill of the donor. The reference time is thus off-set from the first eruption of the detonation, but is assumed to be representative of the finite time required from detonation of the first rounds to essentially complete detonation of the entire stack. According to high-speed camera data, approximately 9 msecs elapsed from the first light eruption at the front of the donor to the last of a sequence of gas ventings which progressed along the top of the earthen fill toward the rear of the donor.

The time off-set discussed above is not critical for evaluation of far-field measurements but is of importance for interpretation and correlation of near-field results, i.e., those measurements taken near the acceptor igloos. For example, all effective cube-root explosive weights estimated from near-field positive phase measurements (listed in Table I) are smaller than the average value of 46.5 estimated from far-field results. Effective weights, estimated from time of arrival data, were obtained by selecting values of effective cube-root weight such that calculated points for scaled arrival time and distance agree with the idealized, scaled time of arrival curve of Fig. 7. Effective explosive weights were also estimated from results of the external transducer located at the base of the northeast con te magazine. The recorded side-on pressure (85.4 psi) corresponds to an effective cube-root weight of 41 and the arrival time to 35 $W^{1/3}$ for a surface burst; 46 $W^{1/3}$ and 41 $W^{1/3}$, respectively, for an air burst.

Effective weight calculations based on near-field measurements are not intended to conclusively determine donor charge. They do, however, indicate that blast conditions experienced by the igloos were not as intense as might be expected from far-field measurements.

OPERATIONAL SAFETY ASPECTS

Predictions of biological effects (6) and equipment damage are strongly dependent on the test configuration. Due to early blast door failures and resulting line of sight propagation of fireball, blast wave, and debris, Eskimo I represents a worst-case condition for potential damage to acceptor igloo interiors. For example,

Table II. Eskimo I Test Data, Converted to Sea Level

Location	Distance[a] to Headwall (ft)	Shock Arrival at Headwalls (msec)	Effective[b] Cube-Root Weight-Surface Burst ($W_{EFF}^{1/3}$ Pos Phase)	Effective[c] Cube-Root Weight-Air Burst ($W_{EFF}^{1/3}$ Pos Phase)	Distance to[a] Transducers (ft)	Peak Negative Pressure (psi)	Effective[d] Cube-Root Weight-($W_{EFF}^{1/3}$ Neg Phase)
N Acceptor Igloo	144	27.2[e]	38	45	153	-11.3	57
E Acceptor Igloo	84	--	--			--	--
S Acceptor Igloo	144	40.0	21	30	153	-10.1	51
W Acceptor Igloo	170	67.7	16	23	179	- 4.8	36
NE Concrete Block Magazine	144	29.6[e]	35	41	142	-12.1	59
NW Concrete Block Magazine	14[illegible]	--	--		153	--	--

[a] *Converted distance referenced to center of donor*

[b] *Effective cube-root calculations based on converted arrival times, assuming ideal surface burst*

[c] *Effective cube-root calculations based on converted arrival time, assuming ideal air burst*

[d] *Effective cube-root calculations based on converted, peak negative pressures*

[e] *Time off-set approximately 4.9 msec due to detonation asymmetry*

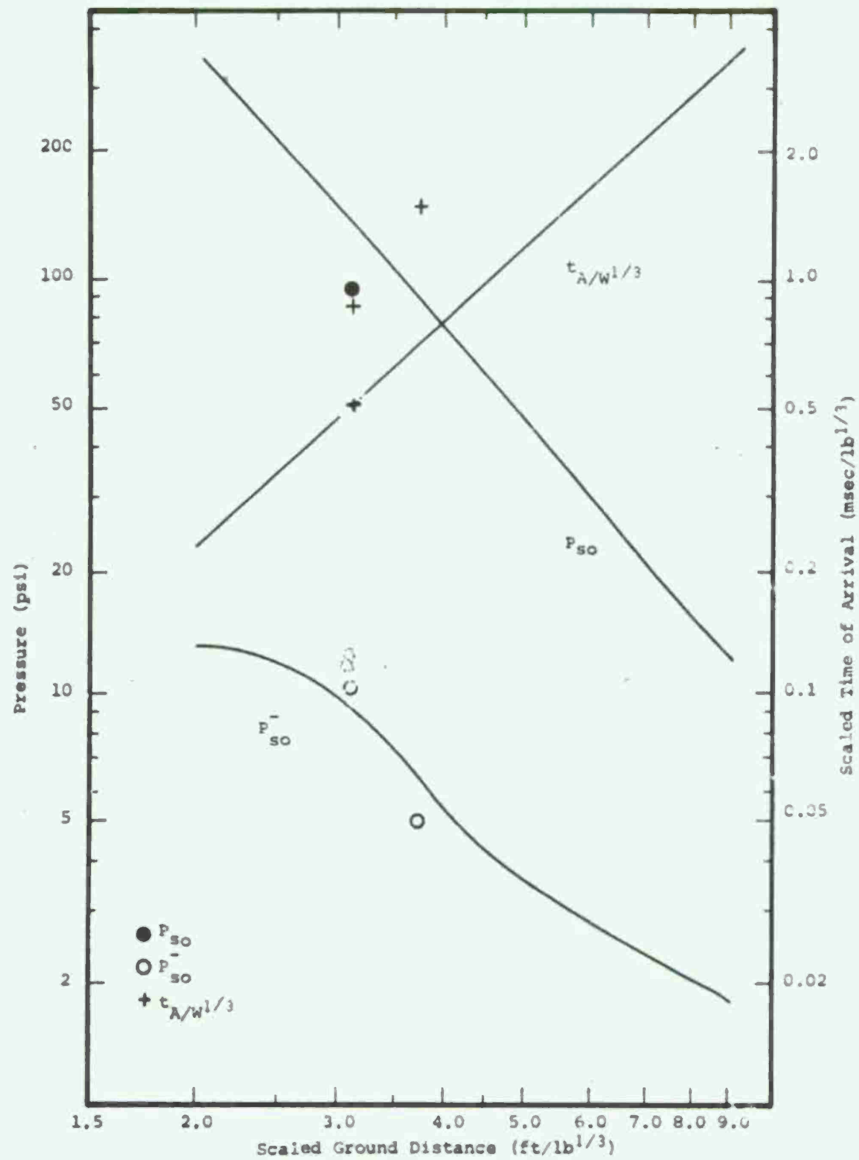


Fig. 7. Comparison of Converted Eskimo I Data with Ideal Surface Burst Curves

increasing the pressure-resistance of blast doors and observing side-on orientations between igloos, coupled with the additional protection provided by the earthen fill, would probably negate debris damage and reduce fireball produced effects within adjacent igloos.

Since the instrumentation described here only provides interior pressure-time information, the discussion of probable interior effects will, henceforth, be restricted to blast produced damage and obvious conclusions derived from post-test examination. Further, for purposes of discussion, the pressure transducers used to instrument the igloos will be defined as "delicate instruments."

Tentative criteria for biological effects are given in Ref. 6, where effects of blast and shock are subdivided into three categories termed primary, secondary, and tertiary. Primary effects, those directly due to applied pressure, encompass both positive and negative phases. However, effects resulting from the negative phase have not been established. Criteria for biological damage in Ref. 6 are based on "fast-rising" long-duration pressure-time histories. Except for the east igloo, the overpressures observed were classed as "slow-rising", effecting a decrease in potential biological damage for a given peak overpressure. For example, even though the probability of personnel injury from overpressures was below threshold for the west and south igloos, survival would still have been unlikely due to debris.

Only four undamaged transducers were recovered. These transducers were mounted side-on and rear-on in the south igloo, rear-on in the west igloo, and side-on in front of the northeast concrete magazine. All other transducers were either destroyed or rendered partially inoperable. The probability of extensive equipment damage was thus at least 50 percent in the south and west igloos and close to 100 percent within the remaining structures.

CONCLUSIONS

Anomalies in near-field measurements are not fully understood, but appear to be caused by complex shockwave diffractions from the donor configuration. The apparent close agreement between effective cube-root weights computed from near-field negative phase amplitudes and far-field positive overpressure measurements indicates that the negative phase was less dependent on initial geometry.

Orientation of magazines within a storage complex is equally as important as their spacing. From the standpoint of operating personnel safety, adjacent igloos within a complex should be ideally arranged such that no line-of-sight path exists between any igloo and the doors of another. Reinforcement of magazine blast doors would enhance safing of stored explosives and equipment in closed magazines, but this would afford little more protection for operating personnel under present operating conditions: Typically, the doors of an occupied igloo are left open due to inadequate light and/or ventilation or to transfer material in or out. Therefore, lethal overpressures might be experienced within an occupied igloo, regardless of orientation, under current quantity-distance guidelines. Nevertheless, closed doors with people inside similar operational (not storage) structures is a possibility; and a variety of items whose protection is important are stored in closed-door igloos.

The second and third order effects of acceleration and flying debris were dominant features of the Eskimo I test arrangement and rendered the south and west acceptor igloos–with closed doors–unsafe for potential occupants or materiel, although they could be deemed marginally "safe", considering overpressure levels alone.

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Appendix B

AN ANALYSIS OF ESKIMO I TEST IMAGERY

by

Reconnaissance Applications Section
RADC/IRRC
Reconnaissance Branch
Rome Air Development Center
Griffiss Air Force Base, New York 13440
January 1972

This appendix contains unclassified extracts from the above Confidential report. Although the extracts mention two figures (5A & B and 6A & B), they are not reproduced herein because the text and Table 1 are considered sufficiently descriptive.

For reasons of safety, the aircraft flyovers in this operation were delayed until approximately 20 minutes after detonation, which permitted the fragments to cool somewhat before measurements were made, thus reducing temperature differentials between fragments and backgrounds.

AN ANALYSIS OF ESKIMO I TEST IMAGERY

1. PURPOSE: To determine the extent to which steel and concrete fragments can be discriminated from the background and counted over a more extensive area than is practicable by mechanical means.

2. BACKGROUND: Test conducted on 8 December 1971, consisting of the simultaneous detonation of 200,000 pounds of high explosive 155mm projectiles contained within a donor igloo. Fragments of steel and concrete were predicted to be 100°F-150°F hotter than the background and scattered throughout a 3,000 ft. radius circle.

3. SENSOR COVERAGE: The following sensor coverage was available for evaluation.

KC-1B, black and white, pre-explosion
KC-1B, IR color, pre-explosion
RS-10C, IR, pre- and post-explosion
KA-56, black and white, pre- and post-explosion
AN/AAD-5, IR, pre- and post-explosion

4. ANALYSIS:

c. Pre-explosion AAD-5 imagery was taken at 940 ft. AGL. Post-explosion AAD-5 imagery was taken at 840 ft. AGL. The fragment dispersal contained in the latter was readily apparent.

d. Figures 5A and 5B illustrate the methodology employed for the analysis and were accomplished on post-explosion AAD-5 imagery taken at 2,520′ and 2,450′ AGL, respectively. With no reference to precisely locate compass headings, line A was established from the center of the donor igloo extending through the northward cleared sector. Assuming this base line to be 0°, the other represented lines were established at 30° intervals and alphabetically identified in a clockwise direction. Squares representing 100′ X 100′ ground distance were then established at 500′ radial distances and numerically identified from the center, i.e., A1 = 500′; A2 = 1,000′; A3 = 1,500′, etc. The established 100′ square locations were then transferred to lower altitude (approximately 1,000′), larger scale, post-explosion AAD-5 imagery for actual fragment assessment.

e. Table 1, Fragment Dispersal, and Figures 6A and 6B show the number of fragments identified for each 100′ square identified in Figures 5A and 5B. The additional squares, other than those depicted in Figures 5A and 5B, are included because they were covered on the larger scale (low altitude) imagery. They fall on the same radial lines, again at 500′ intervals. Lack of squares up to the 3,000′ radius is due to incomplete low altitude imagery coverage.

TABLE 1. FRAGMENT DISPERSAL

SEGMENT	NEAREST ADAS RADAR ALTITUDE	# FRAGMENTS	SEGMENT	NEAREST ADAS RADAR ALTITUDE	# FRAGMENTS	SEGMENT	NEAREST ADAS RADAR ALTITUDE	# FRAGMENTS	SEGMENT	NEAREST ADAS RADAR ALTITUDE	# FRAGMENTS
A1	1000	132							I8	980	0
A2	1080	21									
A3	1080	26	D1	1000	31	G1	900	90			
A4	1240	10	*D2	1000	34	G2	900	53	J1	1000	79
A5	1240	14	D3	1000	10	G3	980	60	J2	1000	42
A6	1240	4	D4	1000	12	G4	980	21	J3	1140	18
			D5	1000	3				J4	1140	18
			D6	1000	0				*J5	1140	10
			D7	1000	0				J6	1140	0
B1	1000	67							J7	1140	0
B2	1000	62				H1	900	36			
B3	1080	9				H2	900	36	K1	1000	71
B4	1080	4	E1	900	22	H3	980	17	K2	1000	20
B5	1240	7	E2	900	28	H4	980	2	K3	1090	26
B6	1240	3	E3	900	23	H5	980	14	K4	1090	13
B7	1240	0	E4	900	8				K5	1090	6
			E5	980	0				K6	1090	0
									L1	1000	102
C1	1000	61				I1		30	L2	1080	5
C2	1000	9				I2	900	0	L3	1080	18
C3	1000	9	F1	900	32	I3	900	23	L4	1080	8
C4	1080	0	F2	900	96	I4	900	15	L5	1370	1
C5	1080	0	F3	980	58	I5	900	3	L6	1370	0
C6	1080	1	F4	980	10	I6	980	2	L7	1370	0
C7	980	0	F5	980	3	I7	980	0			

*100′ square not in exact location depicted on Figure 5A, due to ADAS chamber displacement.

f. All fragments were counted from the original AAD-5 negative at 15 times magnification. Fragment size and composition could not be determined. Vegetation precluded the location of many fragments. In addition, system gain settings were apparently such that detail in areas of extreme temperatures, either hot or cold, cannot be differentiated. Lack of complete pre-explosion coverage precluded actual point-to-point comparisons in many instances. Fragment count in cleared areas vs. uncleared areas indicates that some fragments could have been buried in the earth and their thermal signature lost.

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Two 16-mm motion picture films (TMP 357 and TMP 364) of the ESKIMO I test are available and can be lent to authorized requesters. TMP 357 is confidential, formerly restricted data; it runs for 17 minutes. TMP 364 is unclassified and runs for 15 minutes. Both have optical sound tracks. Address requests to the Naval Weapons Center, Code 7506, China Lake, CA 93555.

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	Department of Defense Explosives Safety Board Washington, DC 20314

13. ABSTRACT

In a fully instrumented test in December 1971 at China Lake, Calif., 200,000 pounds of TNT explosive contained in 155-mm projectiles were detonated simultaneously in an earth-covered magazine surrounded by four earth-covered igloos placed at various distances from the donor magazine. The principal objective was to evaluate magazine spacing. Based on data from this and previous tests, the Department of Defense Explosives Safety Board reduced the separation distances for earth-covered steel-arch magazines to 2.0 X $W^{1/3}$ for face-to-rear orientations and 2.75 X $W^{1/3}$ for face-to-side orientations. The report contains data on fragment sizes and distribution, igloo damage and structural motion, and blast pressures at the site.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
ESKIMO I						
Magazine Safe-Separation Distance						
Blast Overpressure Measurement						
Fragment Distribution and Density Resulting From Magazine Explosion						
Magazine Safety						
Magazine Explosion						

ABSTRACT CARD

Naval Weapons Center

ESKIMO I Magazine Separation Test, by Frederick H. Weals. China Lake, Calif., NWC, April 1973. 84 pp. (NWC TP 5430, publication UNCLASSIFIED.)

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