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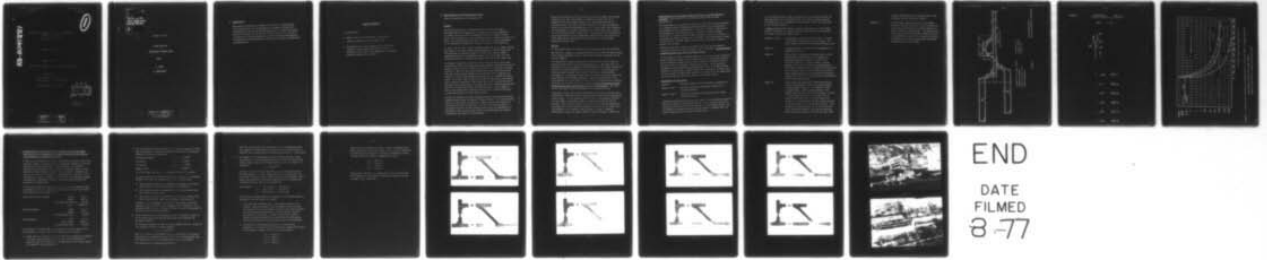
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MODEL TESTS ON UNDERGROUND STORAGE SITES. PART I. (MODELLUNTERS--ETC(II))  
MAR 76 G GUERKE, G SCHEKLINSKI

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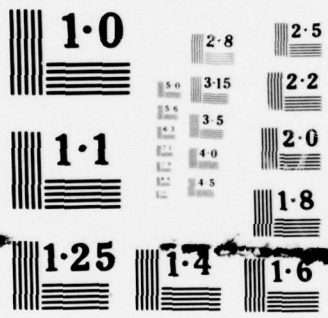
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NATIONAL BUREAU OF STANDARDS  
MICROCOPY RESOLUTION TEST CHART

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Modelluntersuchungen zur unterirdischen  
Munitionslagerung  
Erster Teilbericht

Bericht E 3/76

Auftraggeber:

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Report E 3/76

MODEL TESTS ON  
UNDERGROUND STORAGE SITES

PART I

G. GÜRKE

G. SCHEKLINSKI

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1. Introduction

This report describes the February 1976 state of investigations on the scaled model of an underground two-chamber storage site. Recommendations are given for the assessment of quantity distances. This is to provide for any data so far available to be considered in drafting the German manual (ZDv 34/250) "Unterirdische Lagerung von Munition und Explosivstoffen" (Underground Storage of Ammunition and Explosives).

TABLE OF CONTENTS

1. Introduction
2. Model tests on the two-chamber storage site  
State of evaluation as of February 1976
3. Recommendations, based on model test results and  
contained in the manual ZDv 34/250, which are  
provided for guidance in the assessment of quantity  
distances against blast effects

## 2. Model Tests on Two-chamber Storage Sites

State of Evaluation as of February 1976

### General

The Ernst-Mach-Institut's responsibilities include the task of investigating blast propagation in tunnels and in the neighborhood of tunnel exits for various configurations of two-chamber storage sites. In particular it is the institute's aim to assess the protective effect of a self-closing block which would close the main passageway of an underground storage site in case of an accidental explosion.

In case of an accident, there is high overpressure in the tunnel system resulting in a hazardous blast wave propagating from the tunnel exit. The heavy gas jet emanating from the tunnel exit causes a highly asymmetrical pressure propagation outside the tunnel exit, with the preferred direction generally coinciding with that of the blast wave.

According to applicable protective rules the distance at which peak overpressure of the blast wave resulting from mass detonation of stored material remains within 50 mbars is determined as "inhabited building distance". The fact that blast effects extend substantially further than any other damaging effects such as ground shock, fragments and debris is a major disadvantage in the planning of underground storage sites. At a total load of 300 tons of TNT equivalent in a two-chamber site a quantity-distance of 1050 meters has to be observed because of the blast wave propagating in the blast direction, whereas ground shock calls for a quantity-distance of 450 meters only. For a number of years, trials have been conducted with devices to enable a reduction of quantity-distances for air shock effects.

During 1970 through 1973 NDCS (Norwegian Defence Construction Service) conducted model tests, designated "Operation Block", on a self-closing block in a one-chamber storage site, which produced good results on the effects of blast propagation. In 1973, in Trängslet/Sweden, a prototype test with the same configuration proved the possibility of producing a self-closing block capable of withstanding the enormous acceleration and impact on the abutment.

Since the configuration with the self-closing block inside the storage chamber of the type investigated in "Operation Block" will not be adopted for the two-chamber storage site, Ernst-Mach-Institut is conducting model tests with the block located in the main passageway. Series of silhouette photographs were taken in the shock tube revealing the functioning of the self-closing block. Trial blasts were carried out in a steel-pipe model scaled 1:50. Applying the laws of similitude frequently investigated for comparable configurations, the results of model tests can be transferred to the conditions of a full-scale ammunition storage site.

### Results

At the present state of evaluation the following results are provided:

The series of silhouette photographs have revealed that the self-closing block becomes effective only at high loading density conditions in the storage chamber.

At detonations of small charges the closing reaction of the block is relatively slow and a blast wave can get outside. The same effect is obtained by the use of simple blast obstructions (e.g. bypass tunnels and narrows) at loading densities of up to  $10 \text{ kg m}^{-3}$ . At detonations of loading densities higher than  $10 \text{ kg m}^{-3}$  the blast velocity hardly increases due to gasdynamic block effects, whereas the block closes ever more rapidly due to higher pressures. With the configuration under investigation the blast effect outside decreases drastically at loading densities of more than  $10 \text{ kg m}^{-3}$ . In no case does the distance of the 50-mbar isobar exceed 300 meters in the venting direction. The blast effect thus stays inside the hazardous zone for ground shock.

Comparative trials using TNT and Composition B explosive revealed that Composition B explosive produces substantially higher peak overpressures in the tunnel. At the loading densities under investigation, however, the high oxygen deficiency of TNT is largely compensated by after-burning. With the same loading densities for both TNT and Composition B explosive an almost identical impulse is observed at the tunnel exit, with Composition B, however, peak pressure is higher. Pressure distribution outside is almost identical for either type of explosive.

Consideration of an explosive charge equivalent does not seem to be necessary. This portion of the evaluation effort has not been completed yet.

For detonations of an explosive charge of  $Q = 100$  tons of TNT equivalent in a storage chamber (loading density  $28.5 \text{ kg/m}^3$ ) the following data are obtained for the closing block: a block of a mass  $M = 300$  tons is accelerated by a mean pressure of  $P = 125$  bars. After a closing travel of  $X = 6$  meters covered within a closing time of  $t = 150$  ms it has gained an impact velocity of  $v = 300$  km/h. The total kinetic energy of the block  $E = 1000$  MJ (Mega Joule) must be neutralized on impact against the abutment.

During the prototype trials in Trängslet the block was successfully tested with twice that impact energy, e.g.  $E = 2000$  MJ. An appropriately designed closing block would withstand the load.

In the light of various considerations and the results of the "Operation Block" prototype trials it can be agreed that the model tests provide safe estimation coverage for the area of hazardous blastwave effects. The whole stock is unlikely to detonate en masse. In an explosive storage site wall roughness values are higher than in a model causing substantial attenuation. Broken terrain and vegetation, in most cases the wood outside in particular, result in attenuation of the blast wave, a fact that was not taken into account in the model tests.

#### Explanation of the Figures

- Figure 1                      Schematic layout of the two-chamber storage site.
- Figure 2 thru 5              Series of silhouette photographs taken at low loading densities.
- Figure 6 thru 9              Series of silhouette photographs taken at high loading densities.

Silhouette photographs were taken of a model in the Ernst-Mach-Institut shock tube using a Cranz-Schardin Camera. The closing block can be seen as a black rectangle at left in front of the bypass tunnel. The two smaller rectangles with the circular cutouts originate from the model's holding fixture within the shock tube.

At low loading density levels the shock-wave can be seen entering the main passageway and the bypass tunnel, then getting outside through the bypass while the closing block has travelled about one third only of the closing distance.

At high loading density levels, however, acceleration of the closing block is sufficient to close the bypass tunnel before the shock wave can travel through the bypass tunnel.

Figures 10 and 11      Photographs of the model scaled 1:46.7. Volumes of the two storage chambers are identical. The blast chamber has been constructed with heavy walls.

Figure 12              Schematic layout of the model and arrangement of measurement points.

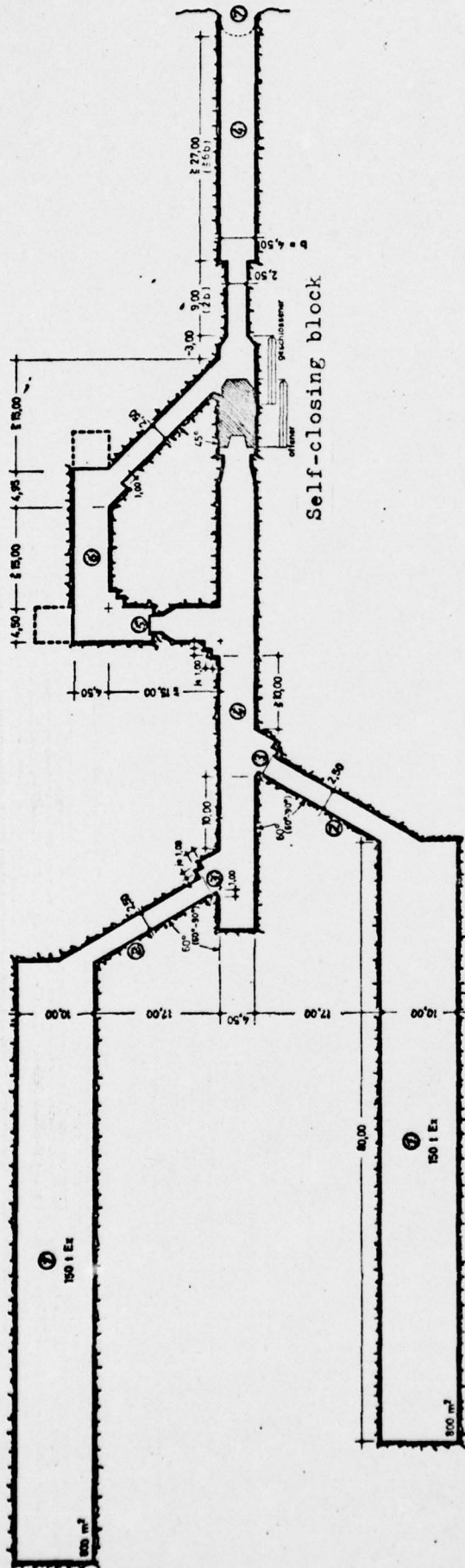
Figure 13              Figure shows overpressure-versus-distance profile proceeding in blast direction (0 degrees) as demonstrated by the example of a load of  $Q = 100$  tons of TNT in a storage chamber, loading density  $28.5 \text{ kg m}^{-3}$ , for various configurations. The 50 mbar isobar distance decreases from 810 meters for a straight tunnel to 540 meters for a blocked main passageway with access provided by the bypass tunnel, and further to 175 meters for a configuration with a self-closing block.

Figure 14              The 50 mbar isobar distance (inhabited building distance) is plotted against the loading density in the 0-degree direction for different tunnel configurations. The shielding effects of the bypass tunnel and the shaft are indicated. Further it can be seen that the self-closing block is almost ineffective up to a loading density of  $10 \text{ kg m}^{-3}$ . The shock wave can get outside through the bypass before it is closed by the block. Only at major loading densities and if accelerated by ever increasing pressures does the self-closing block close fast enough to cut off the shock wave

running outside through the bypass tunnel, thus producing its full protective effect.

Figure 15

In this figure again the trace of the 50-mbar isobar in front of the tunnel exit is plotted for a load of  $Q = 100$  tons in a storage chamber for three different configurations. The bypass tunnel alone (with the main passageway closed) provides a considerable reduction in the quantity distance. The effect of the self-closing block shows most conspicuously in this diagram.



- 1 Ammunition storage chamber
- 2 Branch passageway
- 3 Fire protection door
- 4 Main passageway
- 5 Pressure door
- 6 Bypass tunnel
- 7 Tunnel exit

Self-closing block  
for a two-chamber storage site

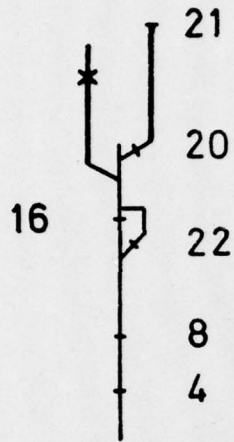
Figure 1

FIGURE 12

INSTRUMENTATION

MODEL III

SCALE 1 : 46,7



- |   |       |       |
|---|-------|-------|
|   | PROBE | 140 m |
| • | A 1   | 275 m |
| • | A 2   | 375 m |
| • | A 3   | 475 m |
| • | A 4   | 575 m |
| • | A 5   | 675 m |

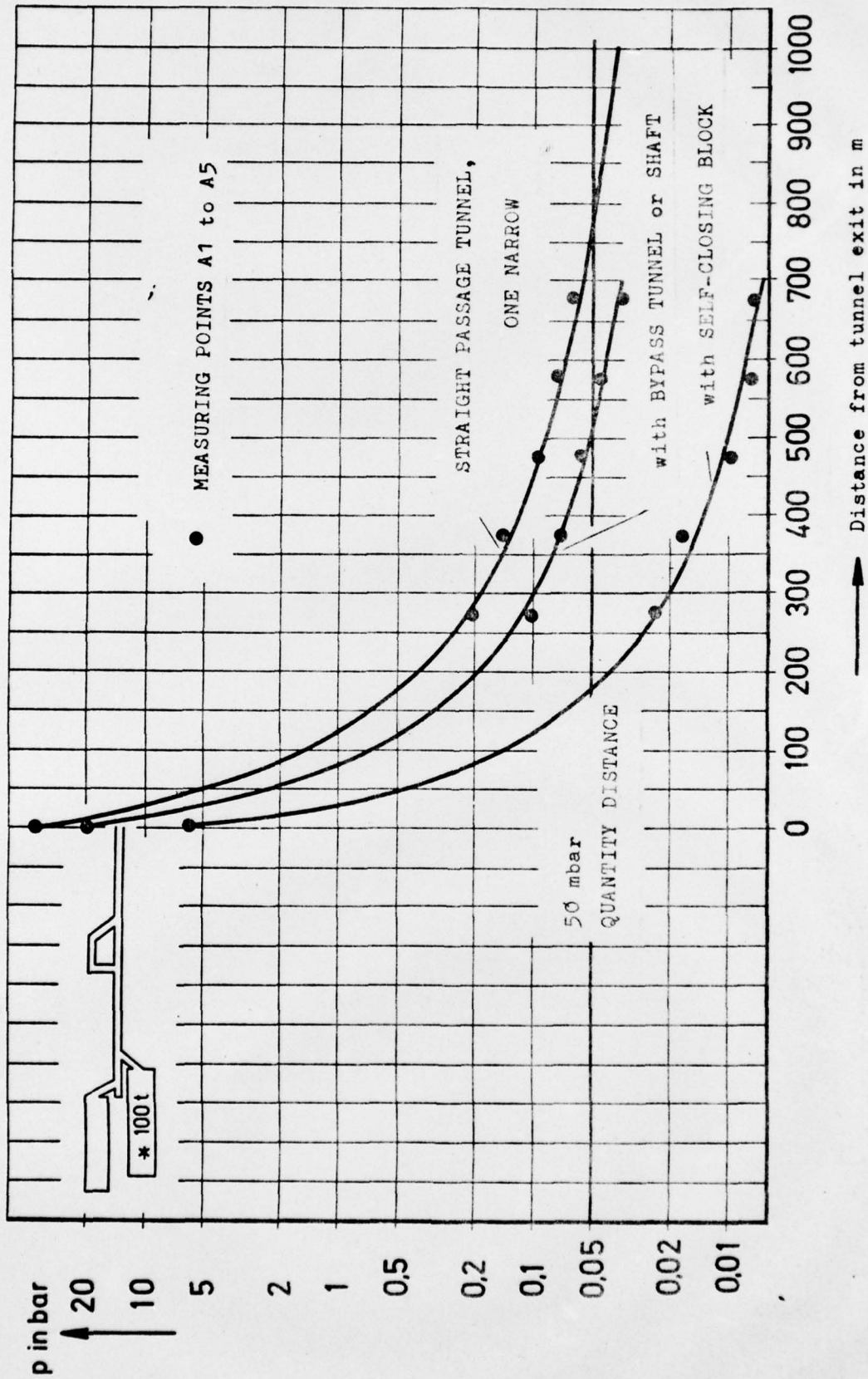


FIGURE 13 Pressure versus distance in the neighborhood of the tunnel exit in 0-degree direction

Load quantity 100t in one storage chamber

Chamber volume 3500 m<sup>3</sup>, loading density 28,6 kgm<sup>-3</sup>

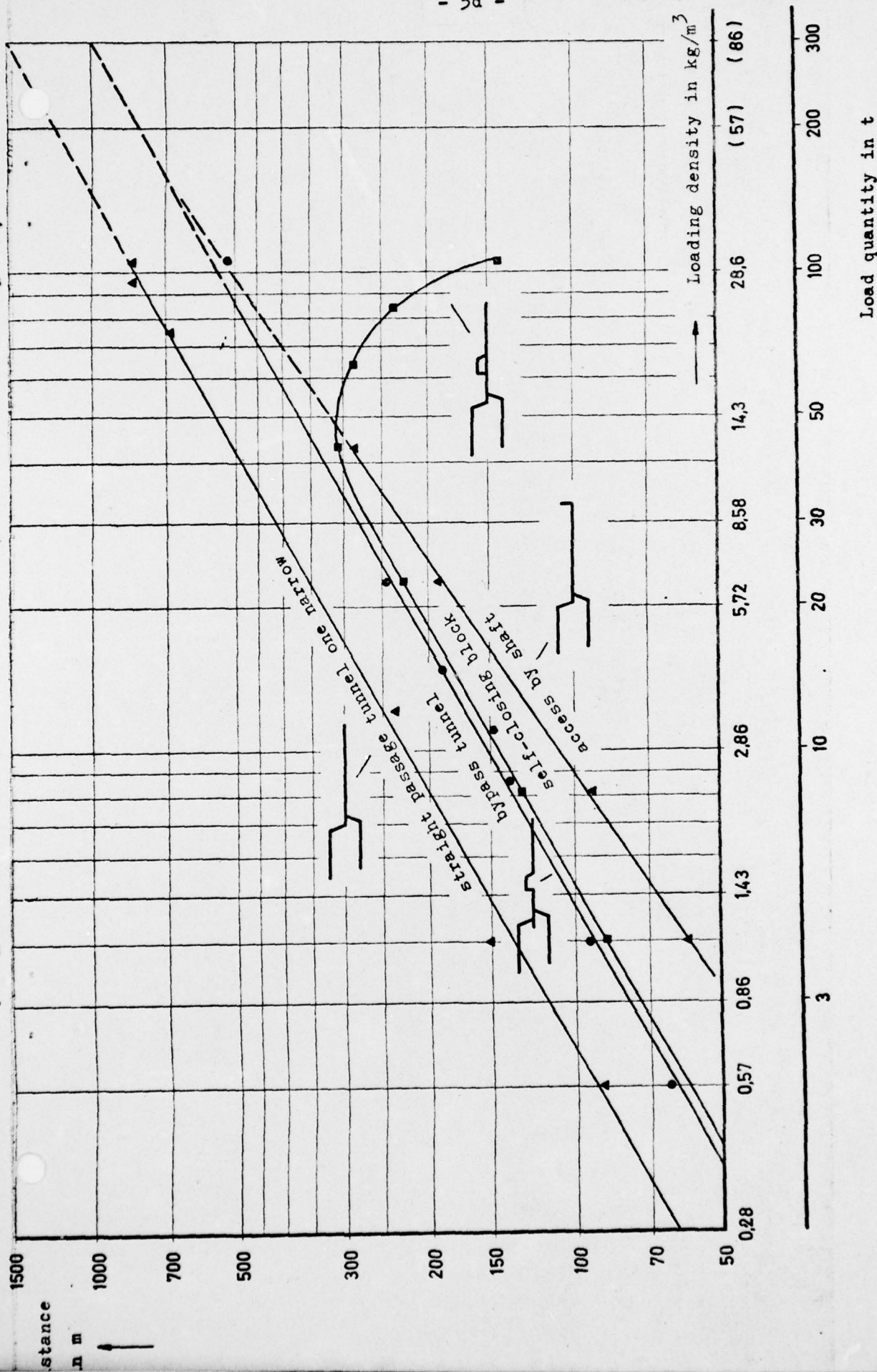


FIGURE 14 Distance of the 50 mbar isobars (quantity distance) in 0-degree direction for various tunnel configurations  
 Detonation in a storage chamber, chamber volume 3500 m<sup>3</sup>

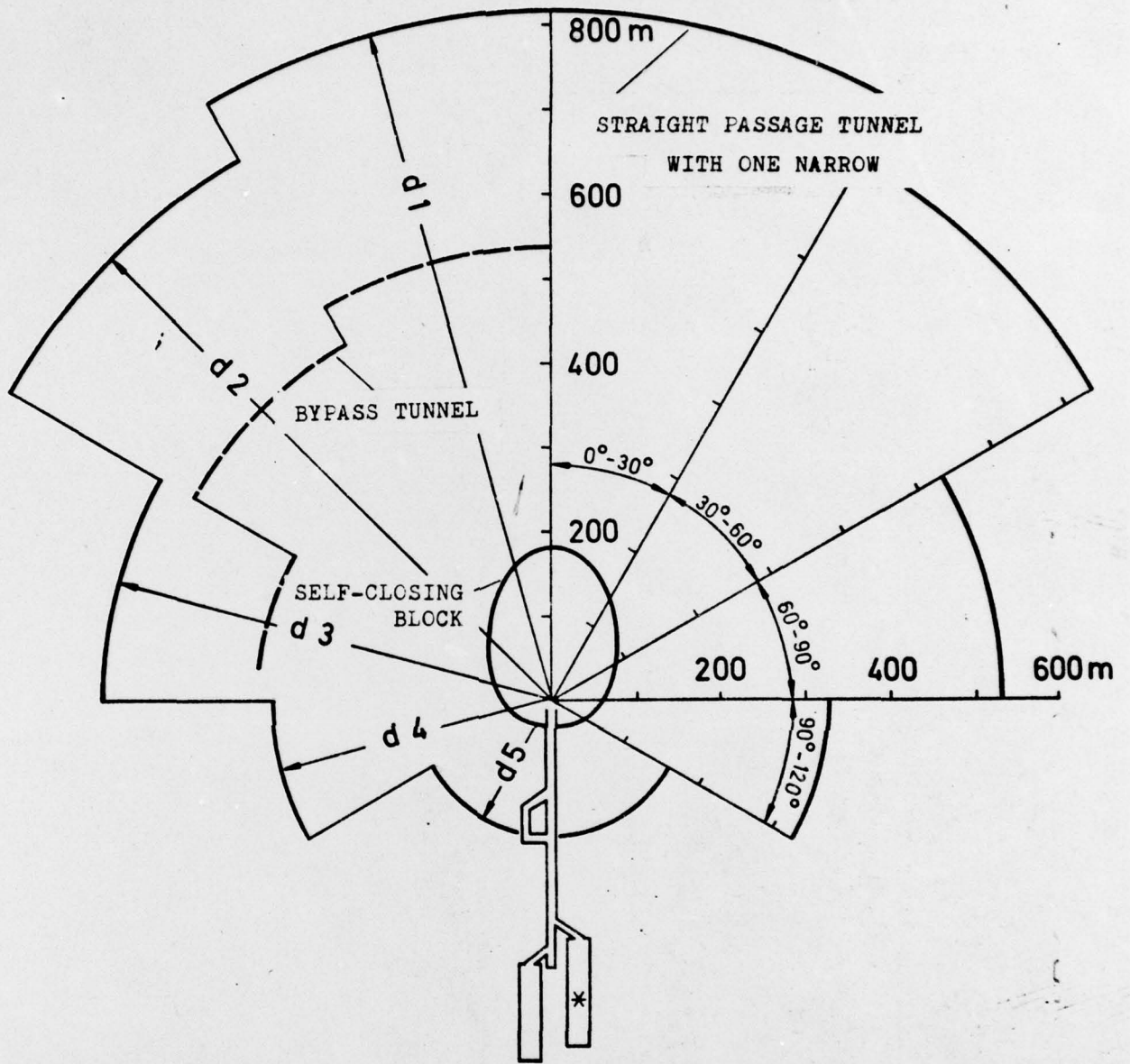


FIGURE 15 TWO-CHAMBER STORAGE SITE - ISOBARS 50 mbar

Load quantity 100 t in one storage chamber

Chamber volume 3500 m<sup>3</sup>, loading density 28,6 kg · m<sup>-3</sup>

3. Recommendations, Based on Model Test Results, by the Ernst-Mach-Institut for the Assessment of Quantity Distances for Blast Effects to be Included in the Manual ZDv 34/250

It has not been possible to provide universally acceptable rules (e.g. formulae, tables) for the assessment of quantity distances to protect underground storage sites against blast effects. The specific geometric configuration of the storage site (chamber volumes, tunnel lengths and cross sections, obstructions, quantity of chambers) and the type of storage (load quantity, loading density) can be of major significance. Because of this, the NATO draft on underground storage recommends the performance of model tests with models of specific geometrical configurations.

The Ernst-Mach-Institut model scaled 1:50, in all its geometric data corresponds to the two-chamber storage site of figure 3 of the draft manual ZDv 34/250 (dated May 1975):

Ammunition storage chambers:	width	10.0 m
	length	80.0 m
	cross-sectional area (q)	43.5 m <sup>2</sup>
	volume	3500.0 m <sup>3</sup>
Branch passageway	width	2.5 m
	length	18.0 m
	cross-sectional area	7.25 m <sup>2</sup>
Main passageway	width	4.5 m
	total length	100.0 m
	cross-sectional area	13.25 m <sup>2</sup>

At the moment (February 1976), evaluation of the model tests is not yet completed. However, the following results are in hand:

- 1) Tests with two different explosives (TNT and Composition B) resulted in almost equal blastwaves outside, even though Composition B produced distinctly higher peak overpressures in the tunnel system for identical loading densities.

- 2) For the inhabited building distance  $d_1$ , Group IV objects (50 mbar peak overpressure), plotted in the blast direction, the following empirical formulae are obtained:

straight passageway	$d_1 = 1.6 Q^{0.56}$
one narrow	$d_1 = 1.3 Q^{0.56}$
two narrows	$d_1 = 1.1 Q^{0.56}$
bypass tunnel	$d_1 = 0.85 Q^{0.56}$

( $Q$  = load quantity in kg;  $d_1$  = quantity distance in meters.)

In this connection the results of the test series on a two-chamber storage site model are complemented by the following data:

- The quantity distance for a straight passageway, which has no obstructions, is taken as the reference magnitude  $S$ .
- The quantity distance is reduced to  $0.8 S$  by one narrow (one half cross-sectional area).
- The quantity distance is reduced to  $0.7 S$  by two narrows (one half cross-sectional area each, staggered configuration).

(Reference: G. Fredrikson, A. Jenssen; Underground Ammunition Storages, NDCS, No. 59/70, 1970, diagrams 5.5.2 B and 6.6 A, for pressures higher than  $p = 20$  bars at tunnel exit and load quantities of more than 30 tons respectively.)

- 3) After installation of a self-closing block (according to figure 12 of the draft manual ZDv 34/250) model tests have produced the following results:

For quantity distances at load quantities smaller than  $Q = 35,000$  kg the following empirical formula applies:

$$d_1 = 0.85 Q^{0.56}$$

With  $Q = 35,000$  kg, the distance of  $d_1 = 300$  meters is attained. With larger load quantities blast effects on the surroundings even decrease because the self-closing block closes very rapidly.

The results can be summarized as follows:

With the self-closing block installed in the contemplated manner, the inhabited building distance plotted in the blast direction  $d_1$  (50 mbar peak overpressure) in no case will exceed  $d_1 = 300$  meters.

- 4) In support of the alternative solution "access through a shaft" (see figure 11), the following function was found for the 50 mbar isobar, plotted against the longitudinal axis of the tunnel ( $d_1$ -direction):

$$r = 0.25 Q^{0.66}$$

As long as the directional dependence of this configuration has not been measured, a circle drawn around the shaft opening with the radius  $r$  as the quantity distance should be determined. Given large load quantities, this will create relatively unfavourable conditions for this specific configuration.

For example:

$r = 316$ m	for $Q = 50\ 000$ kg
$r = 652$ m	for $Q = 150\ 000$ kg
$r = 1030$ m	for $Q = 300\ 000$ kg

The following recommendations could assist in providing clarity of arrangement for the manual ZDv 34/250:

1. All tests were performed using a two-chamber storage site. However, results regarding the one-chamber storage site are not expected to be significantly different from those produced by the two-chamber installation, so that the same quantity distances may be applied. In this conjunction, however, special care must be applied to ensure that the appropriate loading densities (load quantity per volume) are determined.
2. The measure of directional dependence of the quantity distances in front of the tunnel exit (draft manual ZDv 34/250) is determined in table 4 by the following formulae:

$$d_2 = 0.90 d_1$$

$$d_3 = 0.66 d_1$$

$$d_4 = 0.42 d_1$$

$$d_5 = 0.24 d_1$$

These have been measured on certain tunnel configurations by NDCS (Fredrikson and Jenssen, 1970). This could be simplified by expressing the measure of directional dependence in more or less rounded-off figures, something like this:

$$d 2 = 0.90 d 1$$

$$d 3 = 0.65 d 1$$

$$d 4 = 0.30 d 1$$

$$d 5 = 0.20 d 1$$

NDCS trials conducted at a later stage (1972) in connection with "Operation Block" showed directional dependence values to support this suggestion.

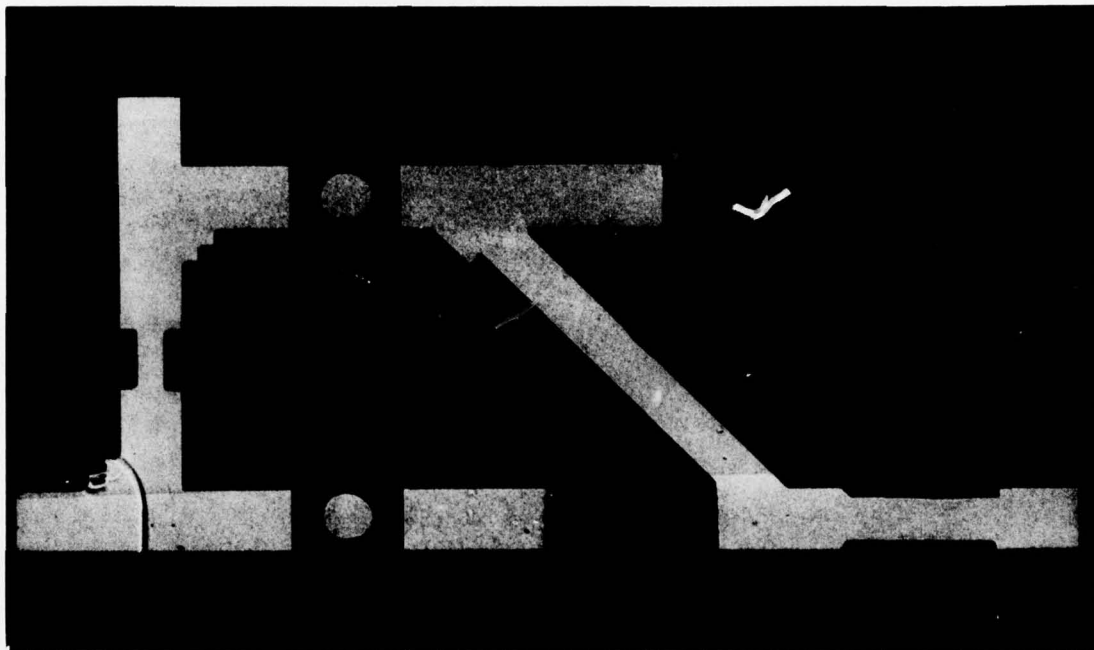


Figure 2

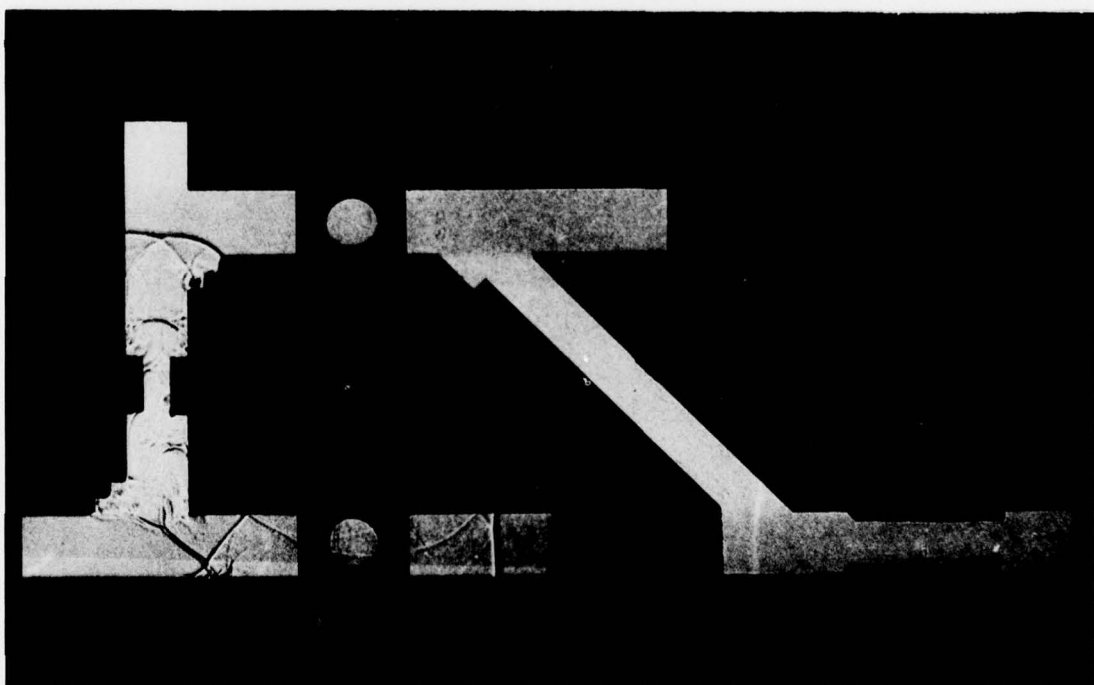


Figure 3

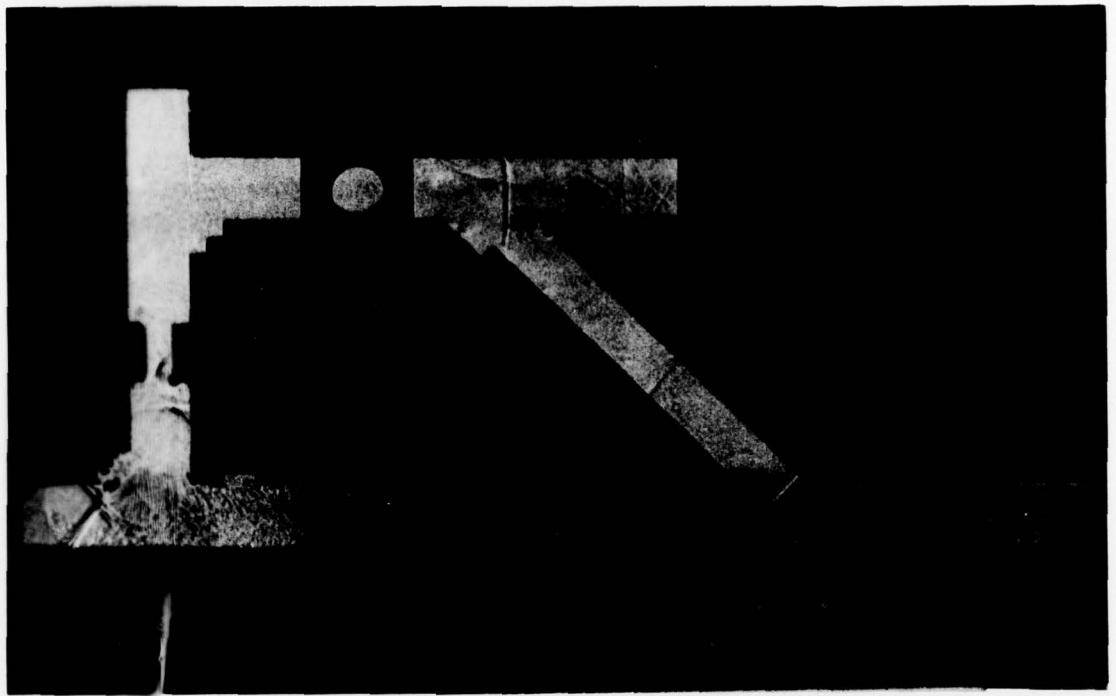


Figure 4

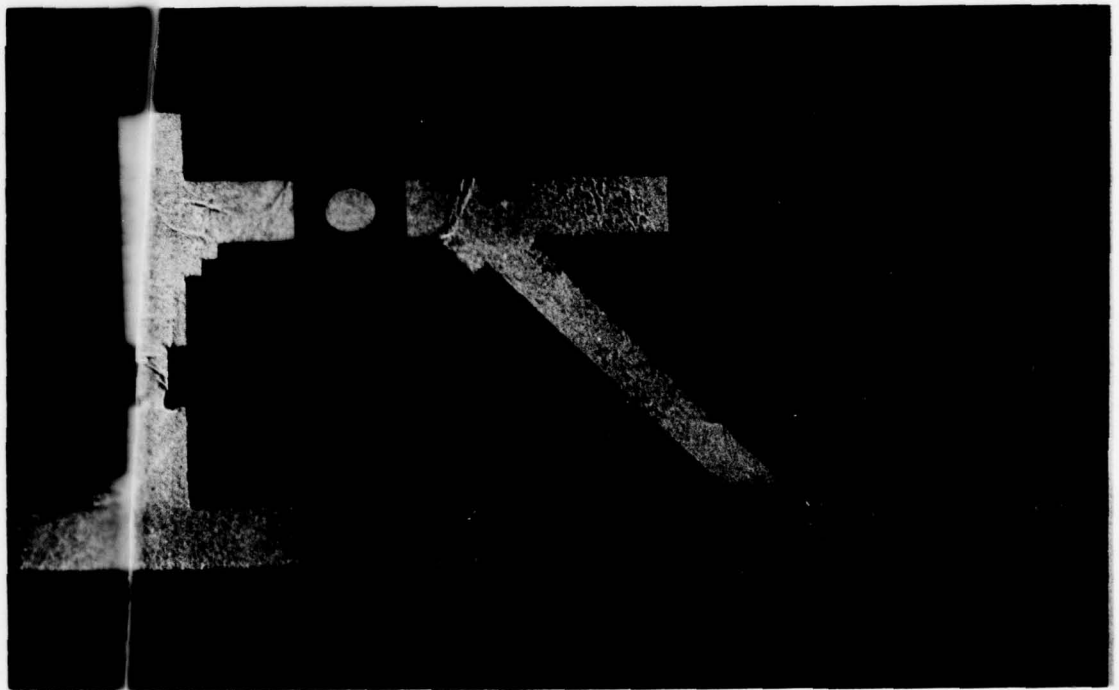


Figure 5

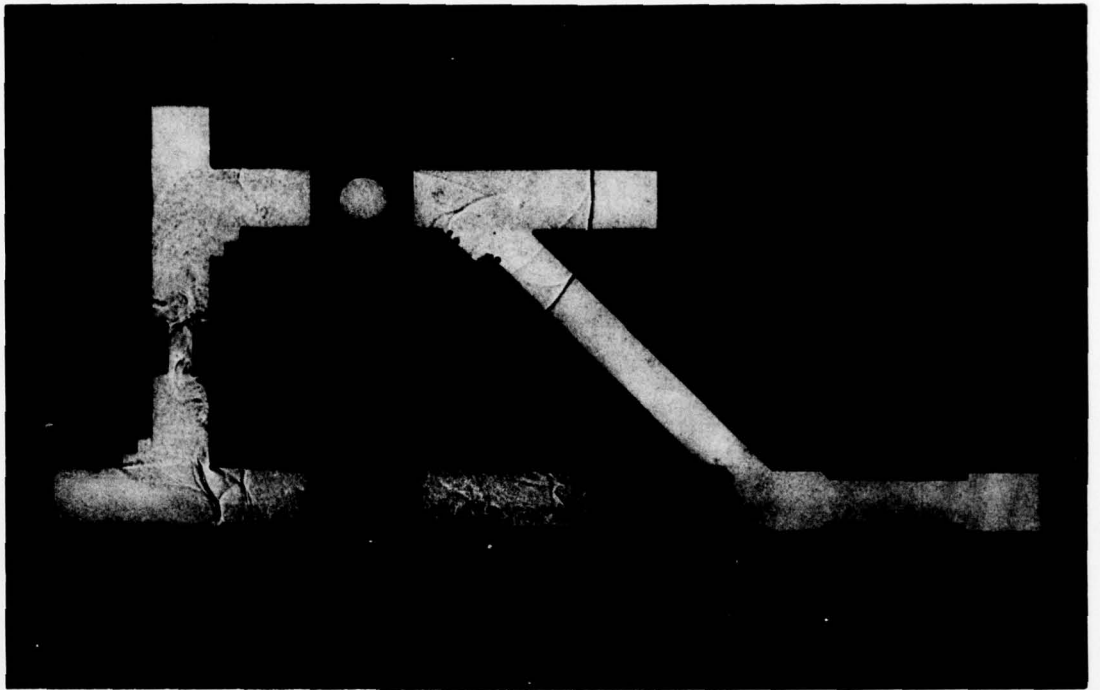


Figure 6

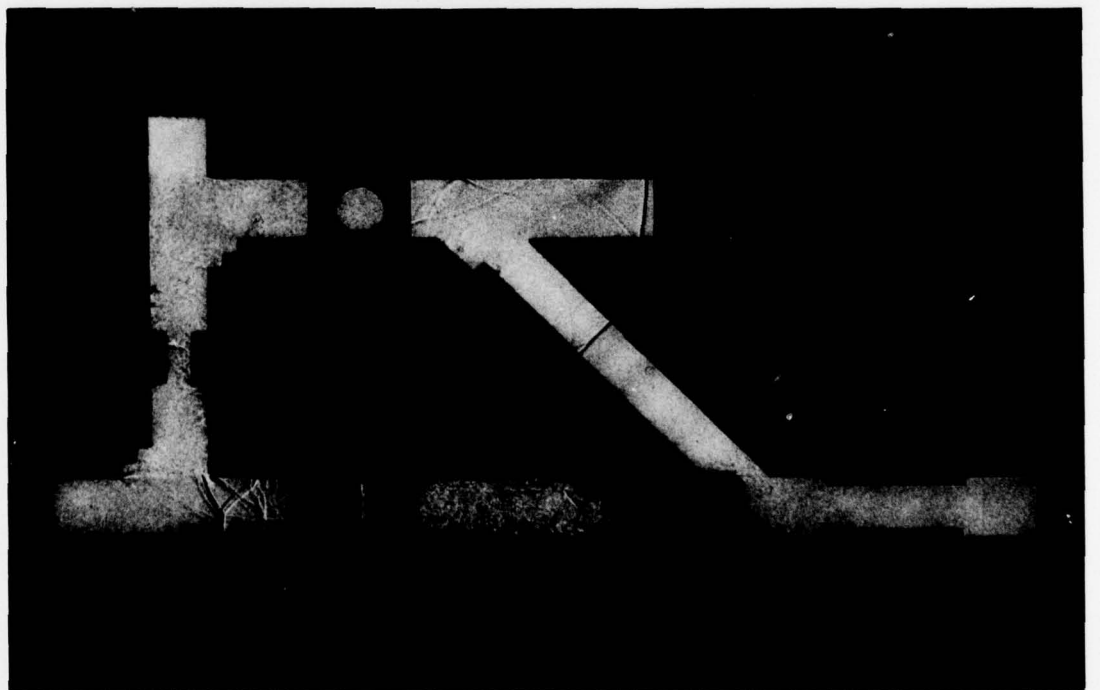


Figure 7

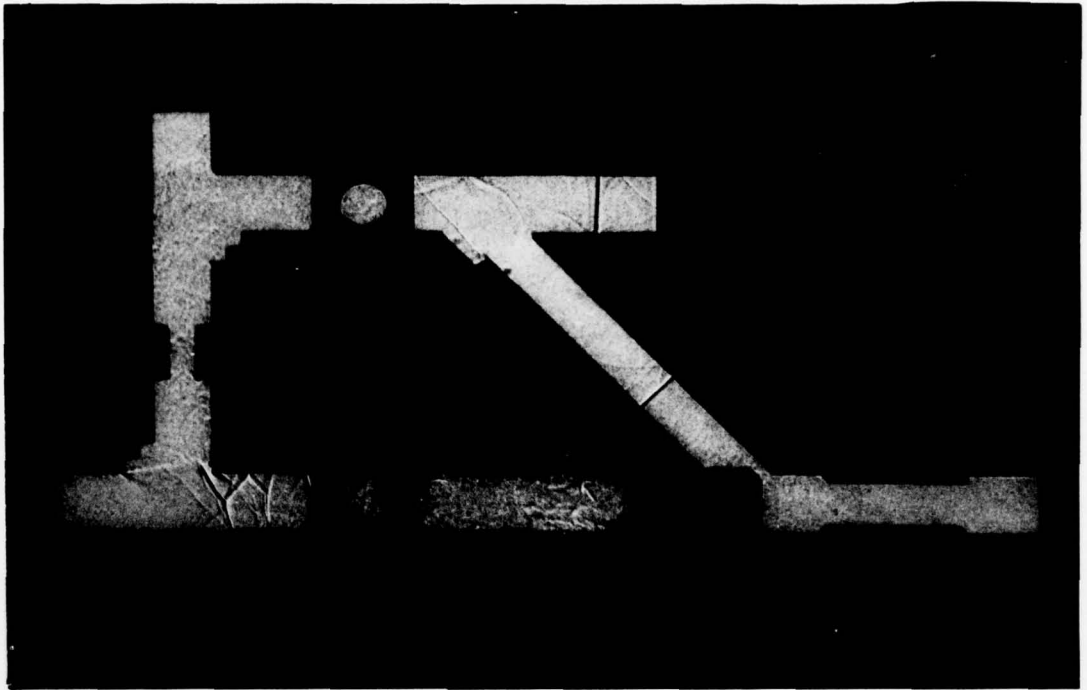


Figure 8

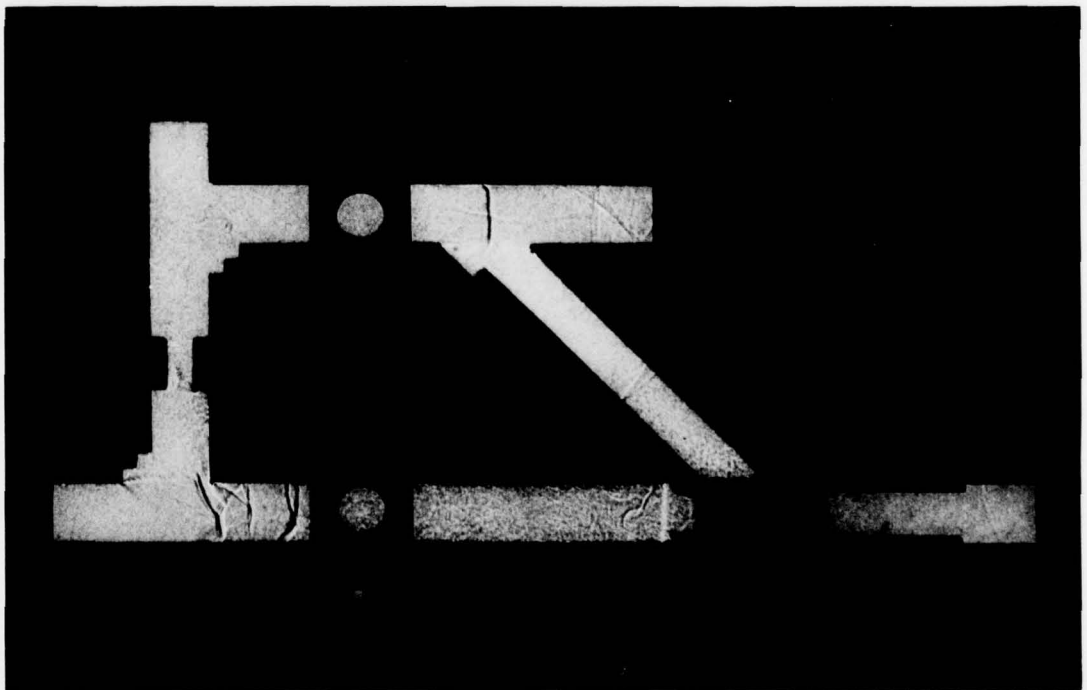


Figure 9

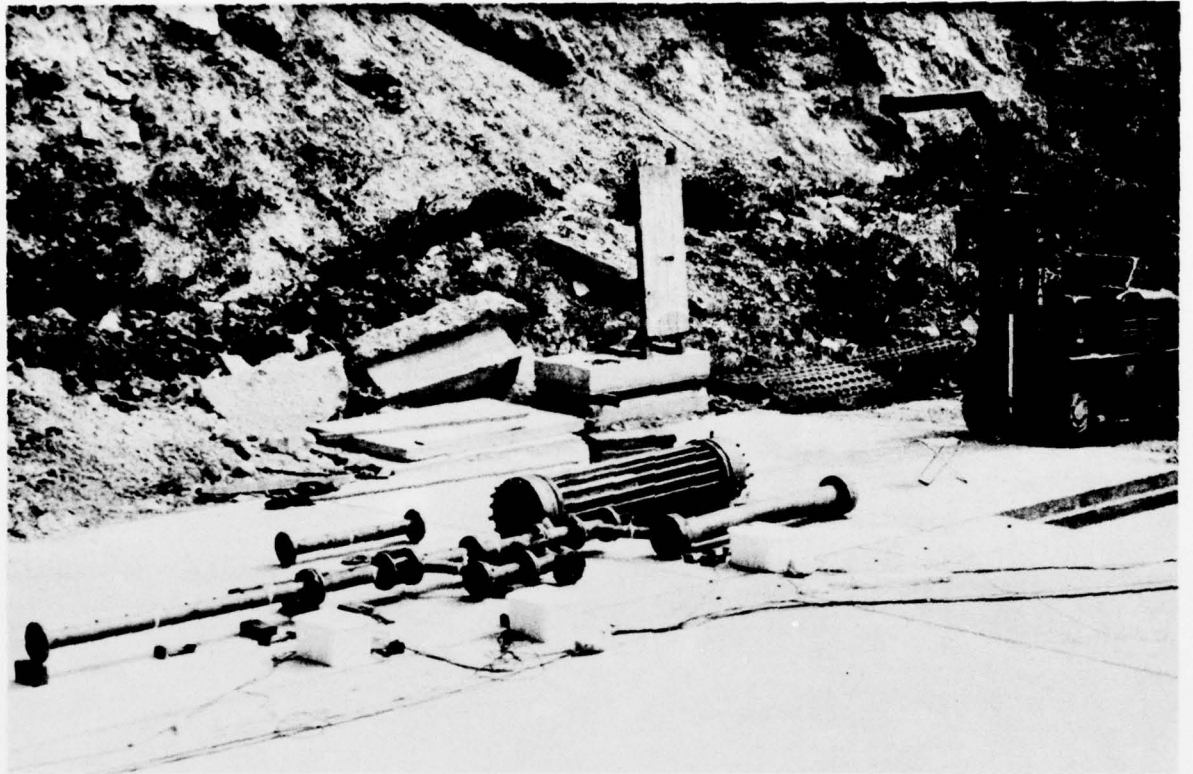


Figure 10

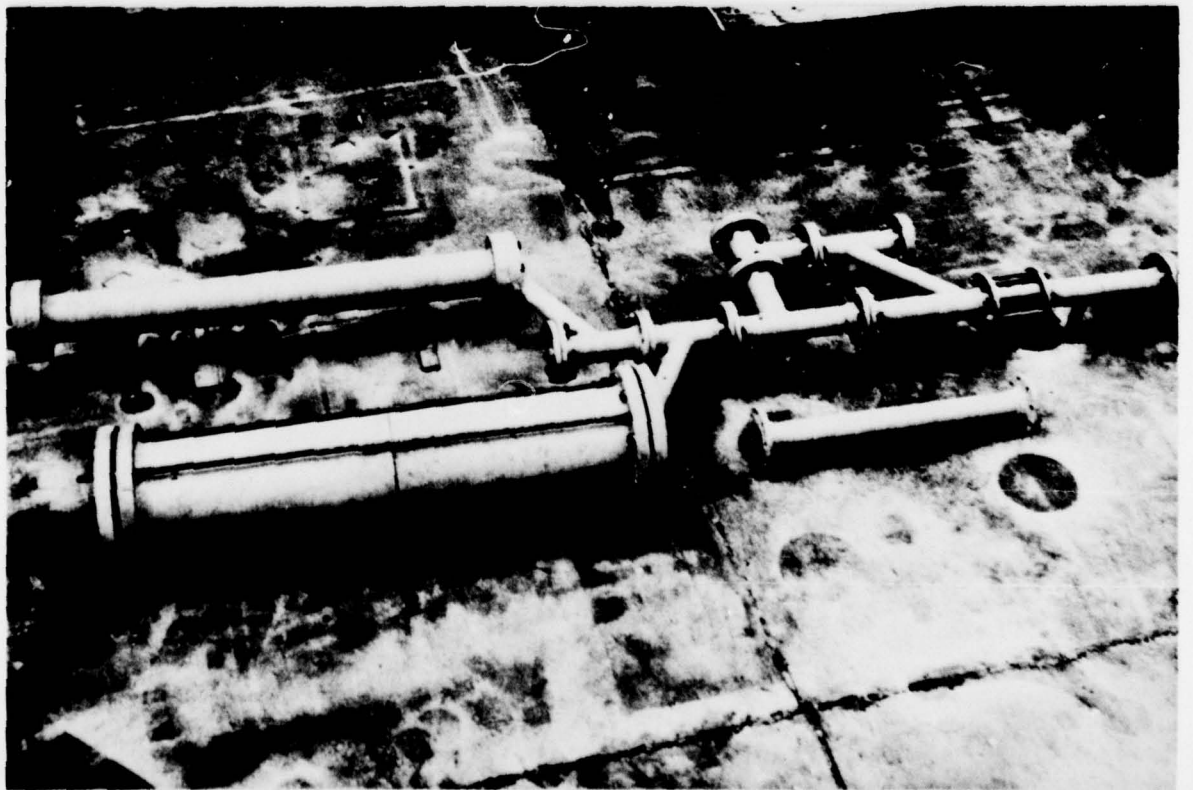


Figure 11