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ABSTRACT

This document records the results of a company funded research ~~study~~ to develop preliminary designs of superhard launch facility closures near the limit of survivability and to develop closure operating mechanisms and methods of handling debris.

Part I of the document presents a review of known closure and debris handling methods and several concepts for further development.

Part II of the document presents a further definition of weapons effects applicable in the range of interest and presents preliminary designs of closure systems which will survive the postulated environment.

KEY WORDS

Closures	Dynamic Pressure
Debris Impact	Overpressure
33-1/3X psi Nuclear Environment	Superhard Structures
X-Hardness of Minuteman B System	Weapons Effects
Orthogonal Grid (Egg-crate)	

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CLOSURES AND DEBRIS HANDLING CONCEPTS

FOR SUPERHARD MISSILE LAUNCH FACILITIES

PART I (1967 STUDY)

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LIST OF ILLUSTRATIONS (PART II)

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1.0 INTRODUCTION

1.1 Purpose

The purpose of this document is to record the results of a Company-funded Technical Competency Research Study on survivable, superhard launch facilities. It is intended that the document serve as an aid in simplifying the future design of critical launch facility elements for superhard environments. The document was prepared under 1967 TRP 363 (Technical Research Program) "Superhard (Cold Launch) Missile Launch Facilities".

1.2 Objectives and Scope of Study

The primary objective of the research study was to develop preliminary designs of silo closures, operating mechanisms, and methods of penetrating or removing debris. These designs were to be applicable to a 33 1/3X psi overpressure nuclear environment. As a secondary measure it was intended to develop in-house design capability to meet future weapon system demands, improve capability to respond to customer requests for superhard weapon systems in a competent and timely manner, and to increase our knowledge in the use of materials, equipment, and technology beyond the present state-of-the-art.

In pursuit of these objectives, state-of-the-art closures and debris-handling mechanisms previously proposed for lower overpressure environments were evaluated for extension to the 33 1/3X psi region. In addition, concepts were developed specifically for this superhard environment. Conventional design methods and principles were reviewed for applicability to the superhard design problem and in many instances these methods do not provide the degree of confidence necessary to insure the integrity of the completed design. New and alternative methods of design which can overcome these major design problems are being explored and will be developed for future use.

1.3 Document Organization

The document is organized to permit chronological reporting of research results. The study plan which was followed is shown. The early literature search effort is covered under "Review of Weapons Effects", and "Design Considerations".

The "Evaluation of Known Closure and Debris-Handling Concepts" Section of this document summarizes a review of concepts proposed for hardness ranging from that of Minuteman B to a hardness 10 times that of Minuteman. The actual preliminary desi : effort is covered in Section 7.0, "Development of Superhard Concepts". This latter section covers design requirements, the selection of preliminary concepts, and layouts and functional descriptions of selected concepts. The results of 1967 research are covered in "Conclusions". A bibliography of the most useful literature found during the study is also included.

NOTE: This document shall maintain the current state-of-the-art for silo closures.

2.0 Summary: (1967)

The study conducted included a literature search of weapon effects and a critical review of existing and proposed silo closure and debris handling methods. From this baseline criteria was set up for the development of silo closure conceptual configurations. These concepts are shown in section 7.0.

The closure and debris handling methods are independent of the launcher structure and exposed to extreme overpressure levels (33 1/3X). It is unfortunate that at this point in time (December, 1967) the technical community is still undecided as to survivability limits for cavity type structures constructed in rock. There is promise such a decision is forthcoming within a few months because of the urgency of implementing a new hardened national weapon system. Survivability of such structures apparently depends mostly on the anticipated rock stress at a given air overpressure level, and various authorities are in disagreement to such an extent that this rock stress could be predicted anywhere from levels equal to the air overpressure, up to four times that amount. This being the case, the region investigated in this study could well be outside the realm of practicability because the launcher structures under the closures might not be survivable.

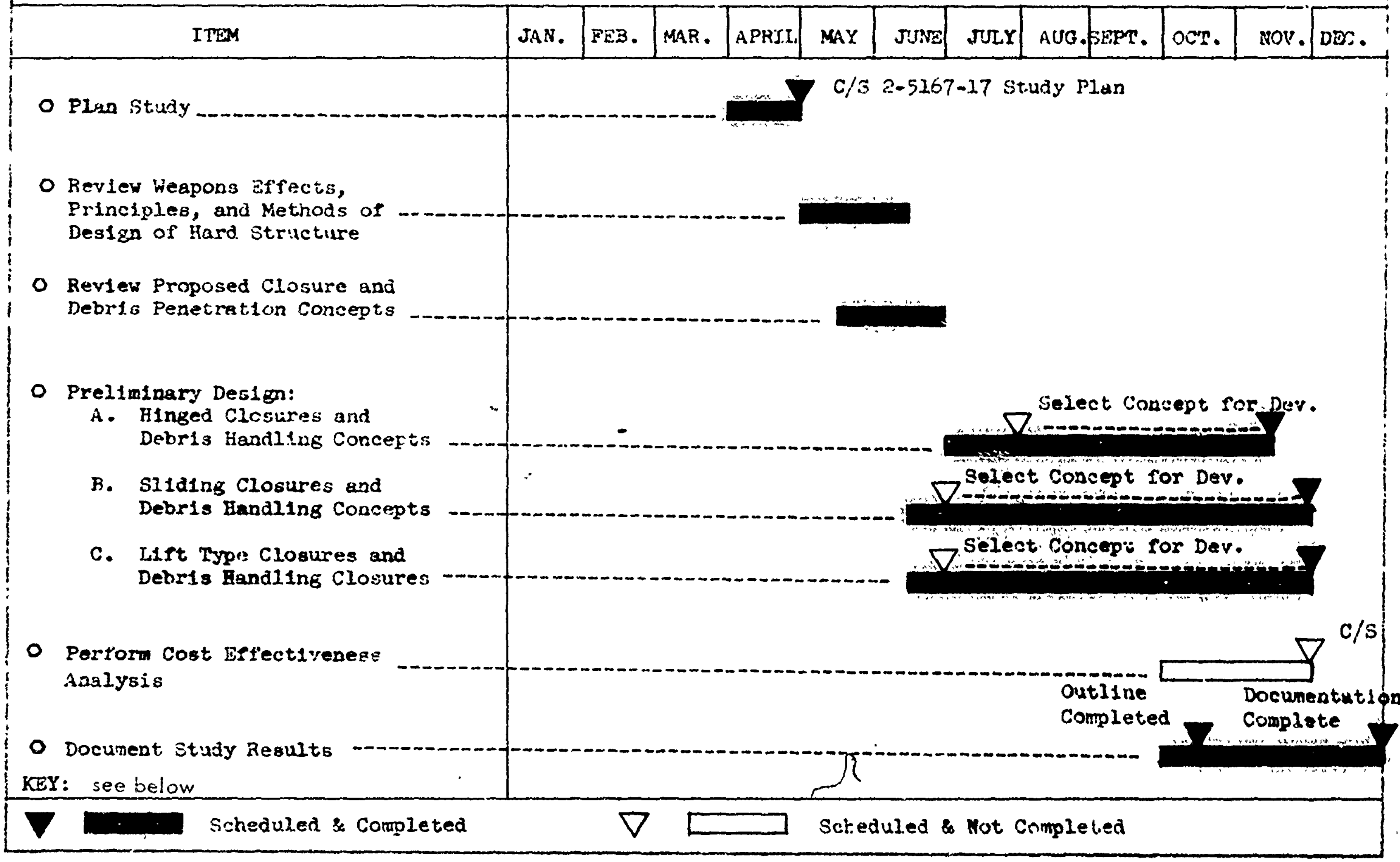
3.0 STUDY PLAN

An over-all picture of the study plan developed early in the study is shown on page 5. Research started with an orientation period, allowing each assigned engineer to investigate nuclear weapon effects on hardened underground equipment, and to research design principles and practices which could be extended or adapted to apply to superhard structures. Known closure and debris handling concepts were to be reviewed, the limitations of each defined, and the most promising concepts considered for futher design development. The actual design development work was divided arbitrarily into three separate categories, each of which were to be assigned to an individual. Layouts, substantiating calculations, and functional descriptions of each feasible concept were to be produced. Cost comparisons were to be performed for the most promising concepts. The entire study was then to be summarized, documented and circulated for critical review.

The plan was generally followed up to the point of selecting the promising concepts. None of the concepts proposed at the schedule point were considered truly outstanding and all required additional study and definition. The remainder of the 1967 study effort was devoted to additional conceptual design work, the identification of problems associated with these concepts, and the selection of three basic concepts for further development. It is not considered worthwhile to attempt a detailed evaluation and cost analysis until such time as the free-field phenomena and its interaction with integrated structures can be more accurately predicted.

STUDY PLAN 1967

CLOSURES AND DEBRIS HANDLING CONCEPTS FOR SUPERHARD MISSILE LAUNCH FACILITIES



4.0 REVIEW OF WEAPONS EFFECTS

Weapons effects criteria considered in this study were derived from References 1 through 7. Consideration was limited to a 20 megaton weapon employed against a facility deployed in competent rock. The facility was assumed to be the proper distance from ground zero to be subjected to a 33 1/3X psi peak overpressure shock wave and the attendant thermal and nuclear radiation and seismic activity.

The extent to which weapons effects parameters were considered varied from a cursory, qualitative look to a quantitative analysis depending on the concept under study and the level of confidence in the available weapons effects data. Generally, since the emphasis was on "conceptual" rather than detailed design, the qualitative approach was taken.

4.1 Weapons Effects Parameters

The following discussion of weapons effects parameters is not intended to provide detailed data on weapons effects. Rather, it is intended to provide the designer with a broad overview of the weapons effects problem so that he will be better equipped to perform the detailed research that is applicable to his particular problem.

4.1.1 Peak Overpressure

This was considered to be the primary peak overpressure wave generated by a surface contact burst of a 20 megaton yield weapon. For purposes of this study, distance from ground zero was such that the overpressure wave had attenuated to 33 1/3X psi as the shock front passed over the center of the facility. In all concepts where the facility closure is flush with the ground level, dynamic effects were ignored and 33 1/3X psi served as a basis for structural design (configuration and mass) of the closure.

4.1.2 Reflected Pressure

Reflected pressures result from impingement of the primary peak overpressure shock front against any protrusion above the surrounding ground level whether it be a protruding structure or changes in the terrain. The reflected pressures thus generated are a function of the primary peak overpressure and the angle of incidence with which it impinges on the protruding medium. Depending on the angle of incidence, pressures far in excess of the primary overpressure wave can be developed. Reflected pressures many times the primary overpressure wave can result from impingement of a 33 1/3X psi primary shock front against a flat plate surface at a face-on (zero degree) incidence angle. The pressure-time impulse from such a collision results in an almost incomprehensible destructive force which can be shown capable of accelerating tremendous masses (millions of pounds) to high velocities (100 - 150 feet per second). It becomes obvious that any structure which is to survive in the 33 1/3X psi region must be designed to minimize or entirely avoid these dynamic effects. Accordingly, the closure concepts in this study, with the exception of the hard mountain concept, are for use in essentailly flat terrain and are eigher flush with the ground level or are submerged below it.

4.1.3 Effects in Tunnels

Tunnel effects refer to the dynamic pressure phenomena occurring when an overpressure shock wave intercepts an opening in the ground surface. These effects are pertinent to this study because of the submerged closure and debris handling concepts included in Sections 6.0 and 7.0 of this document.

A detailed quantitative analysis of these effects was not accomplished. Sufficient contact was maintained with the Technical Staff however, to permit

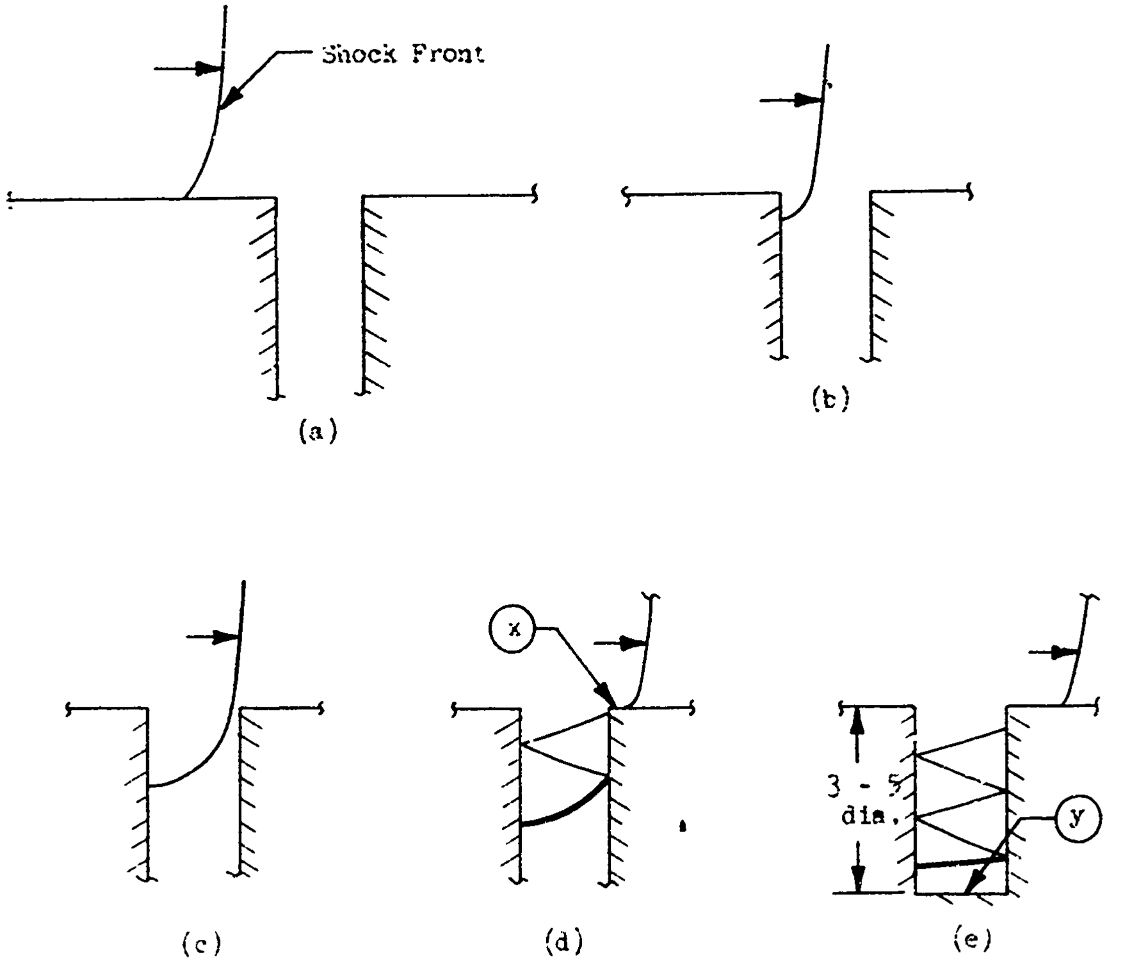


Figure 4-1

qualitative application of gas dynamics principles to some of the conceptual designs presented in Section 7.0.

Generally, an overpressure shock front traversing a flat ground surface and intercepting a cylindrical hole in the ground, takes the form shown in the sequence depicted in Figure 4-1. The shock front approaches the opening as in (a) and starts to intercept the opening in (b). In (c) the shock front is traveling across the opening and a portion of it has turned down in an effort to expand into the hole. It slams into the opposite side of the hole at point (x) in (d) and a new shock wave, or rather a segment of the primary wave, has been formed within the hole and propogates downward within it. Excluding dynamic effects and considering the hole to have infinite depth, the new shock wave is of considerably less intensity than the primary shock front (approximately 20 - 30% of initial overpressure). Under these conditions the new shock wave will attenuate as it travels down the hole.

Dynamic effects cannot be ignored however. Reflections from the primary shock wave at point (x) in Figure 4-1 (d) will create overpressure on the lip of the opening which is far in excess of the primary shock wave overpressure. This phenomenon necessitates super-hardening of the lip of any uncovered access to submerged closure structures. With a bottom in the hole as in 4-1 (e), reflections from the reduced intensity shock wave can create overpressures at point (y) which may be more or less than the overpressure of the primary shock front depending on the depth and geometry of the hole. Generally, it can be said that for a smooth cylindrical hole with a depth 3 - 5 hole diameters, the reflected pressure at point (y) will approximate or exceed that of the primary shock. At greater depths the dynamic effects will tend to diminish.

There are several possibilities for attenuating the shock effects associated with openings to submerged structures. This fact tends to make submerged closures attractive. Shock diffusion, baffles, increased hole diameter below ground level, and multiple, expendable closures with or without gas medium changes are all possibilities for reducing effective overpressures to below the primary shock wave values. Diffusion reduces shock effects in selected areas by turning or directing the shock front away from the area of interest such as a primary closure. Increasing hole diameter below grade level effectively increases the area over which the shock front is dissipated. Baffles along the sides of the opening or any other method of increasing surface roughness of the walls of the opening will tend to reduce the shock overpressure. Multiple, expendable, secondary closures tend to dissipate the shock front in successive steps and changes in gas medium result in attenuation through changes in shock front propagation characteristics. Utilizing one or a combination of these techniques may permit design of effective 33 1/3X psi closures of significantly less structural mass. Some of these techniques are embodied in the concepts shown in Section 7.0.

4.1.4 . Cratering

Crater scaling is not a significant factor in this study. At the time this program was initiated the 33 1/3X psi environment under study was defined as occuring outside the crater radius and the fracture zone surrounding it. This was true for most earth soil mediums and particularly true for the rock medium under consideration. Aside from this it has been assumed that currently projected technology will not permit design for structural survival within the crater environment or fracture zones. Accordingly, for purposes of this study, the facility is assumed to be located in the so-called "elastic" region sufficiently far from ground zero that fracturing does not occur. As crater and fracture zone evaluation changes, the actual value ascribed to the 33 1/3X psi baseline may have to change accordingly.

4.1.5 . Ground Shock

Seismic activity arises from two sources, i.e., directly coupled ground shock resulting from contact detonation of the weapon, and air induced ground shock resulting from the overpressure shock wave generated by the blast. There is currently some uncertainty as to the relative contribution of these two sources to the seismic environment. Depending on the coupling factors assumed, the direct-coupled ground shock may contribute more or less than the air induced ground shock. Currently, the consensus appears to be that in the 33 1/3X psi range of a surface contact burst, stresses induced by the direct-coupled shock source will exceed those of the air induced source, perhaps by as much as two to five times.

Seismic velocities of the rock mediums under consideration are in the range of 15,000 - 22,000 feet per second. The air shock front velocity exceeds these values in the 33 1/3X psi region and "outrunning", i.e., having the ground shock precede the air shock is not likely to occur. The resulting free field shock spectrum incident on the facility is the time and location dependent combination of these shock effects and the air overpressure impulse.

Displacement in the rock medium consideration is somewhat arbitrary depending on the exact properties of the medium in question and its integrity. Generally, vertical displacements in the order of 2 to 4 feet could be expected with horizontal displacements somewhat less. Displacement occurs with very high acceleration.

Obviously any detailed seismic analysis that did not include the entire facility would be of little value. Accordingly this study has done little more than recognize the monumental interface problems that exist between the massive closure structure, the facility structure, and the rock medium. Basically it has looked only at the closure interface with the facility and assumed that interface structure could be designed to support the conceptual closure design in the seismic environment.

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4.1.6 Thermal Effects

At distance from ground zero at which 33 1/3X psi overpressure occurs the facility is well within the fireball and is subjected to extreme temperatures. The initial shock wave temperature approximates 12,000° C at the 33 1/3X psi level. Following the initial shock front the temperature increases rapidly (0.3 - 0.5 seconds) an order of magnitude or more then decays over the next several seconds.

While the mass of the closure structure will prevent significant temperature rises within the facility, the total thermal flux is sufficient to cause severe ablation of any exposed surfaces, structures or mechanisms. Accordingly, the facility closures must be designed to protect actuating devices and operating mechanisms and maintain structural integrity during and after the severe ablation that is certain to occur to all exposed surfaces.

At close in distances to a nuclear burst the heating of materials due to absorption of radiation, both gamma and neutron, has been identified as a major potential concern for hardened facilities. Data available suggest that exposed steel will suffer inches of complete melting, and annealing for more than a foot of additional depth due to only the nuclear radiation input. The further ablation due to the thermal radiant heating and the dynamic air phenomena will be in addition to this nuclear radiation although the presence of vaporized or molten metal will reduce the radiant heat transfer input.

4.1.7 Nuclear Radiation

In the 33 1/3X psi region under consideration, both gamma radiation and neutron bombardment occur with considerable intensity. Electronic equipment within the facility would be severely damaged by the prompt radiation dose delivered unless adequate shielding is incorporated in the facility closure concept.

While the gamma radiation is usually controlled by any closure meeting structural requirements, neutron flux is not. Conventional materials such as steel or lead, and in fact all of the heavier elements, are practically transparent to neutron bombardment. Monumental quantities of these materials would be required to reduce integrated neutron flux to an acceptable value.

Lighter elements are much more effective in slowing down and absorbing fast neutrons. Water is quite effective because of the hydrogen it contains and of course liquid hydrogen, helium, or in fact most of the lighter cryogenic fluids would make more efficient shields. Of the more conventional materials, concrete or sand is effective if used in sufficiently large quantities. For effective neutron attenuation, a combination of heavy and light elements for moderating the neutron flux along with hydrogen for capture of the particles is required. A combination concrete and steel structure provides a cost effective means to satisfy there requirements. Optimization requires a case analysis and structural/nuclear trade-off.

The concepts shown in Section 7.0 depend on concrete and/or sand for radiation shielding. While all of these designs are adequate from the standpoint of gamma radiation, some of them may be marginal in neutron flux attenuation. If so, these designs may be improved by an additional layer of sand or incorporation of additional steel or some type of exotic shielding material. It is believed that additional research might be productive in discovering materials or combinations whose properties would be better suited for combined structural/shielding applications.

For more detailed information on radiation effects, refer to Reference (3) and the sub-reference listed therein.

4.1.8 Ejecta Scaling

Crater ejecta and secondary debris from the shock front will result in a deposition of debris in the vicinity of the facility. Criteria for debris handling purposes is based on data from Reference (6). This reference indicates a 90% confidence factor that debris levels will not exceed ten feet at the 33 1/3 X psi distance for a single, large megaton surface contact burst. For our study three bursts were assumed and a thirty feet debris depth was used as a basis for all debris handling concepts.

Volume of debris to be handled was based on an inverted 90 degree conical frustum with a height of 30 feet and with radii varying with the concept under study. This results in a debris opening with debris walls sloping 45 degrees from the launch tube opening to the top of the debris layer.

Aside from the problem of penetrating or otherwise handling a static debris layer, the closure design must consider the dynamic factors related to crater ejects during the blast. The necessity to survive impacts with crater ejecta and/or secondary debris during the blast would place extreme design requirements on any above ground structures. This is a major reason why all of the concepts considered in Section 7.0 are either flush with the ground surface or submerged.

4.1.9 Time History of Weapons Effects

Any closure structure within the 33 1/3X psi range of the blast will be subjected to all of the weapons effects identified above. From the standpoint of potential failure modes a generalized discussion of the time history associated with these effects may be desirable. It is not intended to establish a detailed history for each paremeter, but rather to discuss those events whose timing may prove critical from the standpoint of maintaining the structural and operational integrity of the facility.

Actually, since by definition the facility must withstand all of the weapons effects for three successive bursts, a discussion of timing and failure modes for a single burst is almost academic. Regardless of the timing of weapons effects, the facility must be capable of sustaining whatever damage occurs with the first blast and survive to withstand the accumulative effects of the second and third bursts. Time relationships, however, are best described with reference to a single burst.

The first effects to which the facility is subjected is the intense, prompt, nuclear radiation dose and a relatively low level of radiant thermal energy generated by the initial blast. At this point in time the facility is intact and structurally undamaged and if designed with proper shielding should survive the radiant heat level present and the nuclear radiation effects. The peak overpressure shock front is the next thing that hits the facility. Since "outrunning" will not occur in the 33 1/3X psi region the air shock front will precede the direct ground shock wave by a small amount.

Coincident with arrival of the air shock front the temperature increases, almost as a step function, to the region of 12,000°C. and almost immediately further ablation of exposed surfaces will begin to occur. Also, coincident with the air induced shock front arrival the facility will be subjected to a severe seismic jolt from the air induced ground shock. During this time, temperature is increasing rapidly and nuclear radiation has decreased to a lower level following the prompt radiation dose.

As the air induced ground shock progresses downward the direct ground shock front arrives at the facility and the resulting shock spectra for the facility is a complex time and location dependent function. Following this, temperature and ablation rates increase to a peak, nuclear radiation continues at a relatively reduced level and debris activity becomes high. After reaching a peak, temperature and ablation rate decrease and become ineffective over the next few seconds. Debris will continue to arrive at the facility and nuclear radiation will continue at a reduced rate (compared to the prompt dose) after other effects have subsided. Due to fallout, nuclear radiation will continue long after debris activity has ceased.

While the above description of what occurs with a single surface burst is a very general approximation, certain conclusions can be drawn from it. Among these are:

a. The strongest radiation dose (the prompt dose) occurs before the facility has been subjected to overpressure, seismic disturbance or thermal ablation. The facility is structurally undamaged and radiation shielding should be intact at this time except for the severe heating effects at the surface.

b. The facility closure is subjected to the peak overpressure air shock wave and dynamic pressure phenomena before maximum thermal ablation has set in and slightly before seismic activity from the direct ground shock has started.

c. Although thermal ablation is occurring during seismic activity the major portion of ablation will occur after the seismic disturbance begins to subside.

d. The closure, operating mechanism, and any above ground superstructures must withstand horizontal debris impacts and the subsequent fallout of debris while being subjected to the other effects.

e. The closure and operating mechanisms must withstand the overpressure, radiation, debris, thermal and seismic environments and still be be capable of operating after all effects have subsided.

The above conclusions are based on a single burst and would require further consideration on the basis of the three successive cycles required by the study criteria. The environment could be altered considerably for the second and third bursts simply by the debris layer deposited by the first burst. This debris layer could offer increased radiation protection, reduce thermal effects and reduce debris impact problems. It would not, however, significantly affect air induced ground shock problems nor would it reduce the seismic activity associated with direct-coupled ground shock which is potentially the most severe stress that the interface between the closure and facility may be required to

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withstand. In any event the facility must handle the accumulative effects of the three bursts and remain operable.

Because of the lack of firm data on soil mechanics and dynamic coupling to facility structure, the assumption cannot be made that the closure and interface concepts shown in Section 7.0 will survive the environments just described. Neither the theoretical background nor available field test data is adequate to establish confidence that response predictions will approach the exactness obtained by standard engineering design practices for static loads. Work in progress by Boeing and other investigators will provide increased capability for analysis and will be used for future evaluation of concepts.

In addition to the severe effects above, the hardened site, with its external power and communication cables and the closure mechanism must be designed to survive EMP (Electromagnetic Pulse) effects, caused by intense electric and magnetic fields from nearby bursts. At the 33 1/3X level, the continuous steel envelope formed by the necessary structure provides the primary EMP shield inherently.

5.0 DESIGN CONSIDERATIONS

5.1 Scope

This section concerns itself with design considerations associated with Launch Facility Closures and operating mechanisms and their capability to survive and perform their intended functions in a nuclear attack environment. Although the main topic deals with launcher closures and the debris handling problem, the interfacing structure and equipment must be considered, at least on a secondary basis. In addition to the survival aspects of the problem, each closure must be capable of timely actuation for maintenance operations, using a minimum of equipment, special tools, skills and manpower.

5.2 Design Environment

Apart from the natural environment, the closure must withstand the nuclear weapons effects discussed in Section 4.0. Although the study is for a so-called 33 1/3X psi environment, the complete spectrum of attack environment must be considered in the analysis of any candidate design concept. This is especially true in view of the controversy and uncertainty reflected in current literature regarding energy coupling, mechanical loading and the free-field phenomena (velocity, acceleration and displacement) associated with the various weapon yields, burst elevations and the rock or soil media involved.

The consensus appears to be that maximum destruction is associated with a surface burst and such has been assumed for this study. While higher overpressures may possibly result from an air burst which would produce a mach stem, the resulting decrease in direct coupled ground shock probably tends to reduce the combined effects to below surface burst destruction levels. Similarly while a penetration burst would result in increased direct coupled ground shock the

5.2 Design Environment (Continued)

decrease in air blast overpressure and the dynamic effects associated with it may tend to equalize the combined destructive effects to a level below that of a surface burst. This view may change as additional data becomes available. Recent data derived from the "Piledriver" experiments indicates that direct coupled ground shock is considerably more severe than previously anticipated and this aspect will be carefully watched in future studies.

Existing data shows general agreement regarding overpressure effects from either an air or surface burst and these effects are well documented. Air induced ground effects for a particular medium are also adequately described for preliminary design estimates and direct coupled effects are available from both analytical studies and test data from underground shots. The data applicable to at-surface free-field phenomena however, is difficult to assess. Velocity, displacement and acceleration relative to time, and permanent displacement produced by the combined effects assume rather nebulous quantitative values when the possible variations in integrity, stratification and seismic characteristics of the media involved and the phasing (time history) of combined effects are applied. Existing literature does not describe such effects in the detail necessary to permit accurate assessment of mechanical coupling to integrated structures.

Perhaps a sophisticated description of the total phenomena for all cases is not practical for use because of the complexity and cost. When the designer introduces structure(s) in a free-field media of varying density, physical properties and quantity, such a sophisticated analysis must be repeated for each case with the structure(s) included and the problem is compounded further. The total mechanical loading on the closure, depending on the design configuration, must be derived from some, and in many cases all, of the following factors:

5.2 Design Environment (Continued)

Direct overpressure versus time,

Reflection and refraction effects,

Dynamic (wind) loading,

Flying debris loading,

Loads introduced through proximity and adjacent or interfacing structure,

Interaction between structures, and

Interaction between the closure and surrounding media.

Additional requirements for emergency power air breathing pop-ups, vents, sump discharges, antennas, maintenance access shafts and closure, and debris pits may be imposed on the closure or adjacent structure to add to the complexity of the problem. In the end the analysis may be so complicated that the confidence level of the analytical results is seriously degraded. The skeptical designer would then tend to overdesign and subsequently impose almost intolerable requirements on the over-all structure.

The foregoing merely emphasizes that the design environment is not adequately described by overpressure alone. The requirement to design for a specific hardness, i.e., 33 1/3X psi, is at best a hazy description of the environment for design purposes. The location, depth and complexity of the facility structure, together with the aforementioned variations in environmental parameters all have a direct bearing on the complexity of analysis and the resulting confidence in analytical results.

Fortunately, many requirements may be ignored in the initial pure trade studies of various closure configurations. As shown in Section 6.0, various concepts can be qualitatively compared on the basis of their ability to satisfy the primary functional and survivability requirements. The most promising

5.2 Design Environment (Continued)

concepts can be selected for further development and preliminary designs can be evolved based on the dominant environment factors. These candidate closure designs can then be evaluated, on a case by case basis, for their capability to meet all other requirements individually and finally to withstand the combined accumulative effects of the nuclear attack environment. Basically this is the design approach taken for this study. This appears to be the most logical course to pursue until such time as free-field phenomena and its interaction with integrated structures can be more accurately predicted.

5.3 Materials and Structure Composition

With strength and cost as a main consideration, the prime material and composition candidates selected to date have been: All steel (shaped), re-inforced concrete with steel outer skin (flat slab, arches and domes) and the all steel egg-crate structure with or without concrete (or other material) filler. Other materials such as high strenth aluminum and fiberglass have been considered on a limited basis for high strength to weight ratio. High strength ablative materials have been considered for the closure top surface. Designs utilizing yielding or crushable elements have not proven successful because the period of positive phase pressure is generally longer than the structure response. For a yielding design to be successful, sufficient mass must be added to the lid structure to slow the reaction time relative to the positive phase pulse.

Concrete

The silo structure will require judicious use of bulktype materials such as concrete to minimize cost. However, that material may not be capable of resisting the loads even with large quantities of reinforcing steel and with large thicknesses. This may be overcome by special design wherein the increase in strength of confined concrete can be utilized. For example, the use of composite steel concrete construction design, (e.g., orthogonal grid and egg-crate construction, Ref. 2), using a selective aggregate strength and high strength steel to attain strengths greater than 5,000 to 7,000 psi. Little actual data on material response under field dynamic loading of the designated magnitude is available.

Prestress

Techniques of prestressing in tension or in compression, depending on the dynamic stressing pattern the material will exhibit, may be worthy of consideration for composite structures. However, such initial stressing will likely be capable of negating only a portion of the potential dynamic load due to the need to prestress the material under static loads which is a lesser condition.

Steel

High strength structural steel and the new maraging steels will allow more flexibility in design; however, their use must be balanced with the radiation shielding requirements where the additional mass of lower strength steel may be beneficial.

Plastics

The use of other lightweight high strength materials such as fiberglass and filament structures can offer some advantages from a strength and actuation power standpoint. The compatibility with radiation shielding requirements will limit their usefulness, and the cost and availability are serious disadvantages.

A high degree of success has been attained by the use of boron filaments in metals and plastics to increase their strengths. These have been developed primarily for missile nose cones, and for hypersonic aircraft skins to increase strength to weight ratio. Their use merits consideration for hardened structure

Plastics (Continued)

skin and/or components; however, their cost and availability will be serious drawbacks for the forseeable future.

5.4 Design Approach

It is very difficult, within the present state-of-the-art, to propose a "best" approach to debris handling and closure design. In the absence of an adequate description of the total free-shield phenomena associated with the 33 1/3 X psi regin, quantitative data on which to base a structural design is at best a somewhat arbitrary estimate.

In addition, the structural response of the silo and closure due to the combined effects of the direct ground shock, the air induced ground shock, the air overpressure can result in component loadings in excess of the maximum nominal loading. The phasing and structure response timing can amplify the downward loading far in excess of the 33 1/3 X psi times the closure-cap area and could impose magnified upward and sideways loadings on locks, tie-downs or other components. The necessity for handling debris may impose additional loads by exposure of the closure to reflected, refracted and dynamic loading in addition to overpressure and ground effects. The over-all complexity of the dynamic overpressure and seismic forces involved make it extremely difficult to analyze each design other than on a qualitative basis. Quantitative data however, is essential to the implementation of any design and in those cases where it is not available it must be hypothesized.

Many past designs are based on a 33 1/3 X psi static pressure load and yield strength of the structural material(s). This supposedly results in a conservative design with an automatic safety factor, expecially if the material possesses sufficient ductility to absorb some of the peak impulse energy in the overpressure shock front.

For the present exercise the designs shown in Section 7.0 were evolved using essentially standard design practices for static loeds. The formulas and techniques for sizing the closures are shown in the appendix. In most cases the designs are based on the following design philosophy which is believed to be consistent with the requirement for survival in the nuclear environment as it is interpreted for this study.

The closure and/or cap structure should be at least flush with the grade if not semi-buried or submerged in some manner. Since most of the launch facility is likely to be buried, the cap and closure should not be subjected to a set of forces which could be entirely different from the basic facility structure. The silo cap and closure should be as integral with the silo structure as possible, consistent with the requirement for launching a missile from the facility. A simple symmetrical shape is desirable to avoid uneven loading and minimize surface exposure to shock waves from any direction. The closure span should be a minimum consistent with projected missile size and launch technique and the closure/cap configuration should possess the best possible strength/weight ratio consistent with structural requirements and the thermal and nuclear radiation environment. Separate hardened access shafts should be avoided where possible.

Each exposed closure design usually includes sufficient surface steel or other material to provide for thermal ablation from multiple bursts. Generally, there is ample high density material to attenuate gamma radiation to acceptable levels. High densith materials alone, however, are relatively ineffeictive against the high neutron flux expected at the 33 1/3 X level and each design must be adjusted to incorporate the necessary additional shielding for neutron flux reduction. Sufficient steel is normally included in the structure to reduce Electromaghitic Pulse (EMP) effects to acceptable levels. Silo penetrations such as power lines vent openings, etc., must be examined individually for each detailed design.

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The design practices associated with past study programs have not been significantly altered to date. Although information is becoming increasingly available through computer analysis and sub scale and laboratory test programs, this information has as yet provided only a scant increase in the confidence level of predicted results. With the increased effort being applied in this area however it is expected that newer techniques will soon be evolved, yielding increasingly accurate predictions of design performance. Work is also underway to further define the ablative and thermal effects including annealing of the surface steel, and to define the magnitude of the bulk heating effects due to radiation attenuation. These techniques will be included in the document as they are developed.

5.5 DEBRIS HANDLING

It is assumed that after three nuclear bursts the debris level will be approximately 30 to 35 feet. This assumed level is taken from a currently accepted debris model which is acknowledged as basically unsubstantiated but which represents the order of magnitude of the expected level of debris and serves to illustrate the problems encountered. The debris levels anticipated using this debris model are illustrated in Figure 5.5-1.

To combat the debris problem for missile launch, many proposals have been suggested. Two fundamental methods evolved for handling high debris levels where the Minuteman method of scraping the debris aside becomes impractical. These are first, to penetrate the debris with a vertical rising member and second, to let the debris fall into a pit or other space provided for the purpose.

Each method has particular problems that present difficulties in application along with common problems of defining the composition, spatial distribution, and size distribution of the debris for a particular location.

The penetration concepts are the most predictable once the quantity and nature of the debris is defined. The most apparent problems are the large forces required and the complication of freezing where conditions are right. Preliminary estimates indicate a breakout force of about 12×10^6 pounds for 30 feet of debris with a 30% increase likely for a long term freezing assumption. These forces, when taken with a rapid response time, result in extremely high though not impossible power requirements.

The debris pit concepts have numerous problems and are much more sensitive to the debris model definition. For the assumed debris level and a typical advanced silo, the minimum debris pit volume required is approximately the same as the silo volume, (30,000 - 50,[illegible] [illegible] feet). The pit must survive the blast effects the same as the silo and has similar material requirements and structural problems as the silo. In addition, the interaction of two cavities in a highly stressed medium will decrease the confidence in survival.

These concepts are dependent on the debris deposition mechanism in addition to the depth of debris because of the tendency of an open pit to receive more than the nominal debris defined by a conical depression at the natural angle of repose of the bulk material.

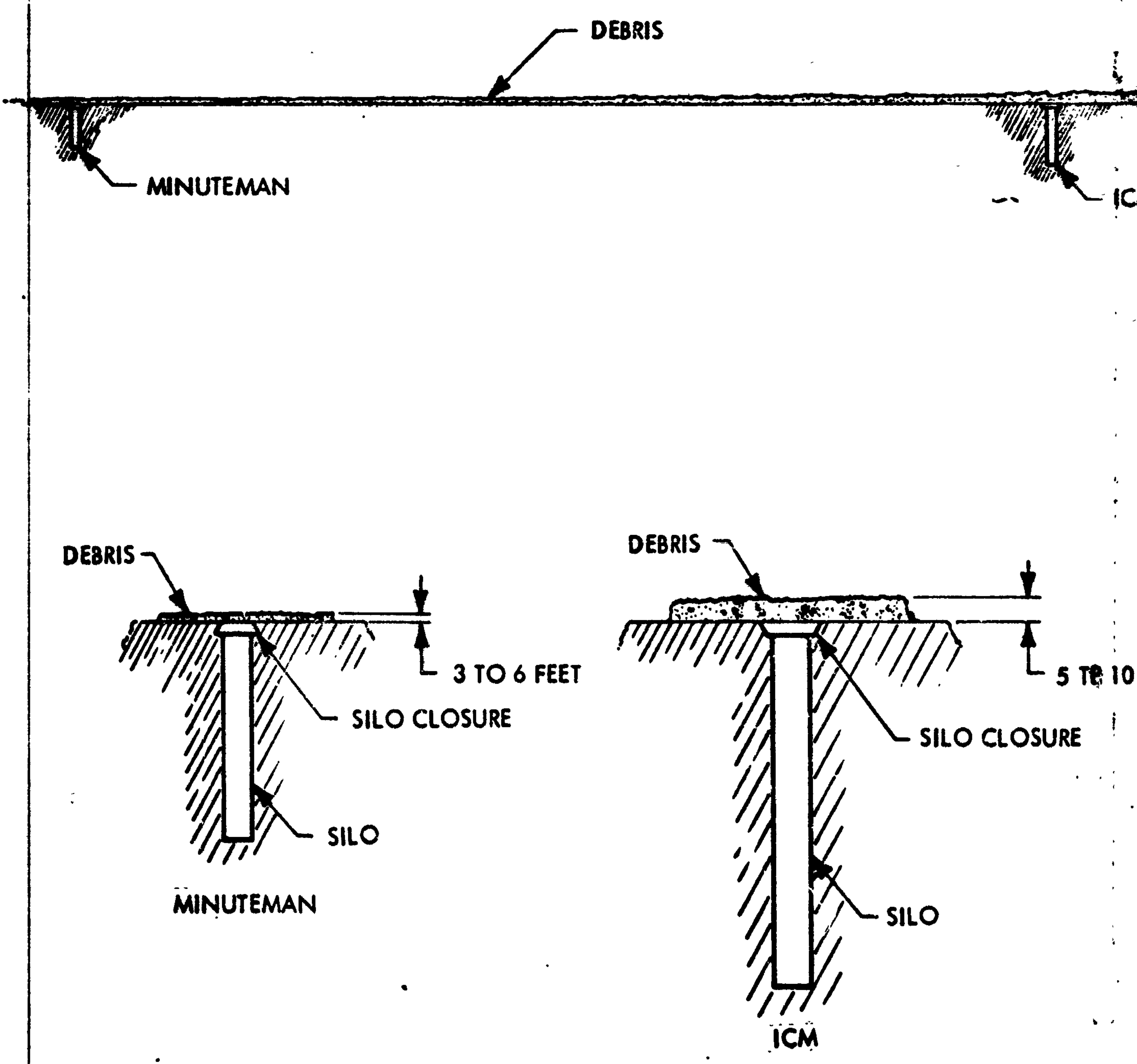
The additional debris can arise from two sources. The first is the result of the horizontally moving debris being intercepted by the opening as it passes by, and the second is the "snowfence" effect or turbulence in the air flow which gives the smaller debris particles a downward velocity component at the edge of the opening. These effects can only be postulated but the tendency for depressions to fill level with debris has been observed in tests.

The overfilling tendency cannot be estimated with any confidence but will result in considerably increased volume requirements at best.

A possible solution to the overfilling problem is to provide a covered debris pit, either with separate closure or by utilizing the silo closure and providing a secondary closure which diverts the debris to the debris pit.

This system is complicated by the possibility of debris freezing and arching across the opening if an inward opening closure is used.

A preferred method cannot be identified without tracing the structural and cost parameters as well as the integration with the silo and closure; however, the penetration method has the big advantage of simplicity (relative) of analysis and a higher confidence level.



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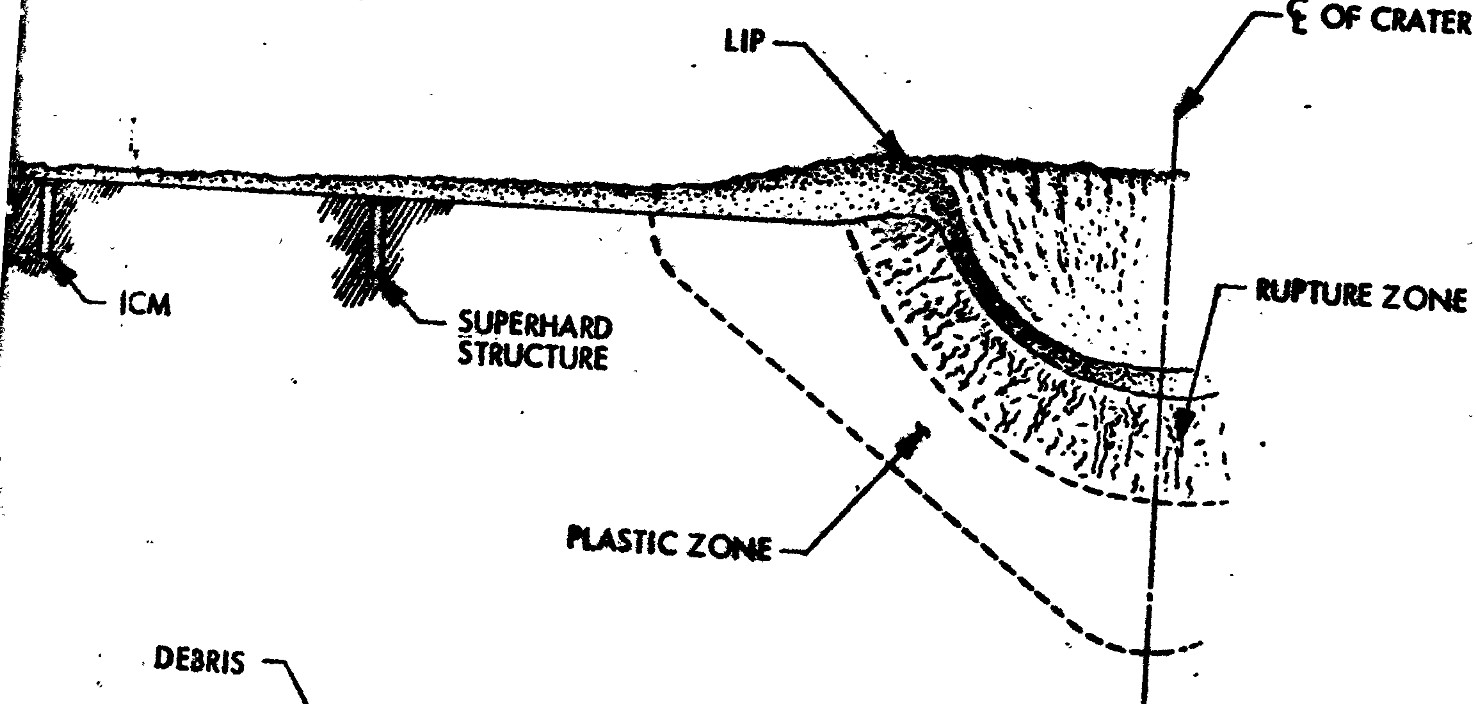

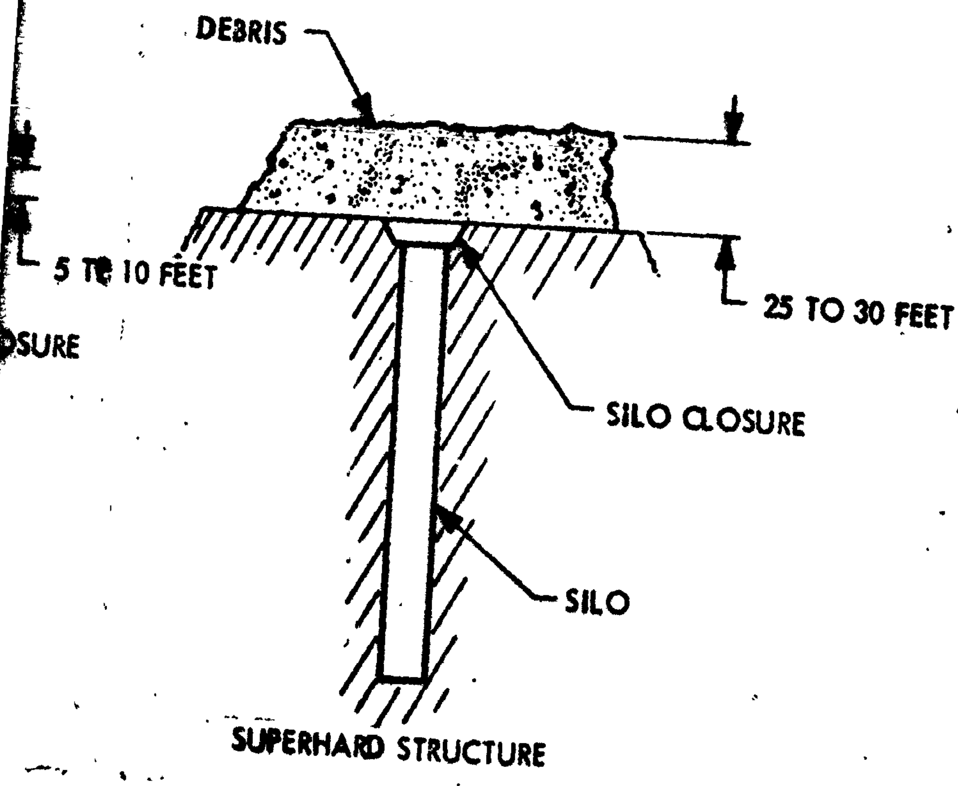

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6.0 EVALUATION OF KNOWN CLOSURE AND DEBRIS-HANDLING CONCEPTS

The following configurations, (from a literature search), were selected from previously proposed closure and debris handling concepts. Although, they were originally proposed for lower overpressure and debris levels, the conceptual ideas of each are worthy of analysis and evaluation for superhard application.

Thus, two basic evaluation considerations are: (1) The projected economics of each concept in relation to its adaptability to superhard environments, function and advantages and disadvantages. (2) The debris handling methods of each.

Through the review process, it is possible to eliminate unaccepted concepts and refine aspects of candidate configurations. Finally, the relative merits, advantages, and disadvantages of each concept can be combined to produce a composite design that would satisfy the needs of the superhard requirements.

6.1 The many closure and debris handling concepts shown on the following pages are presented with comments on the face of the drawings. Most of these show a closure structure independent of the silo structure with various types of closure actuators.

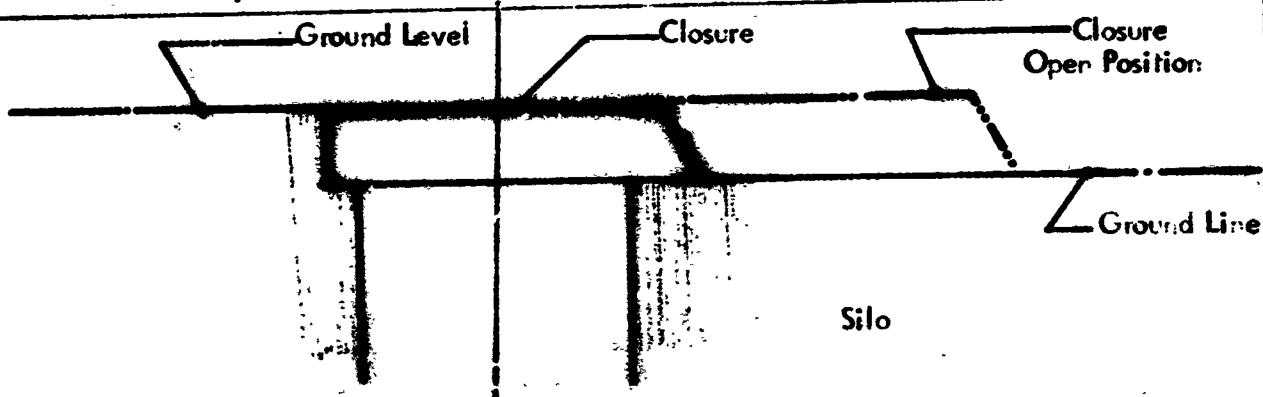

Figure 6.1-1

6.1.1 EXPOSED, SEMI-FLUSH, HORIZONTAL SLIDING CLOSURE

FUNCTIONAL DESCRIPTION: This closure lies flat and flush with the surface except for the depression on one side where it must slide when opened. It effectively seals the launch tube against the nuclear environment and debris impacts during an attack. After an attack the closure can be unlocked and moved to one side, slicing its way into the debris along the side and carrying whatever debris is on top with it.

ADVANTAGES: The concept and mechanism is simple. Dynamic overpressure buildup is minimized by the flush concept. Maintenance access is simple. Power requirements for opening are moderate.

DISADVANTAGES: Debris handling capability very limited. Excess debris would fall in launch tube.

SUMMARY: Limited debris handling capability makes this concept unsuitable for extension to superhard applications.

DEBRIS HANDLING REQUIREMENTS REQUIRE ADDITIONAL AND SEPARATE MECHANISM OR PIT

LOCK/TIE-DOWN REQUIREMENTS ARE EXTENSIVE

NOTE: Concept is similar to existing Minuteman closure with corresponding greatest experience.

Reference source:

Minuteman System

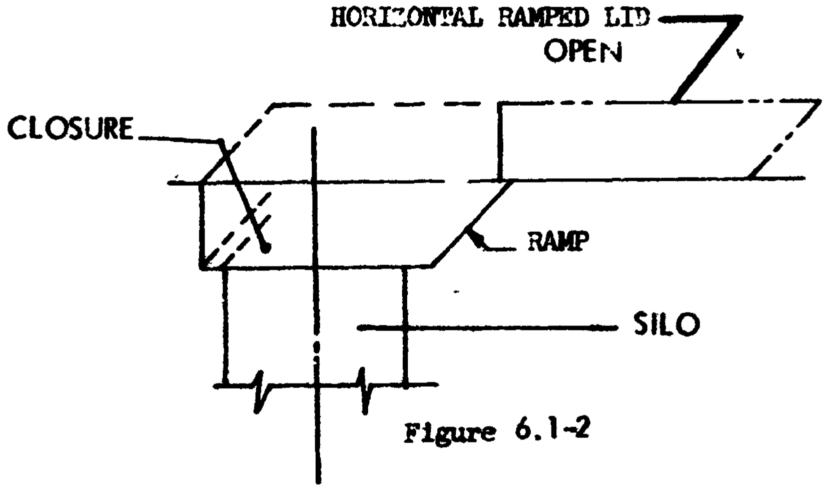

Figure 6.1-2

6.1.2 FLUSH, HORIZONTAL, SINGLE RAMPED CLOSURE

FUNCTIONAL DESCRIPTION: The lid is completely flush with the ground surface, having only the top exposed. On command the lid lifts the accumulated debris up the ramp and translates to clear the launcher opening, carrying some of the debris with it. It is an extension of the sliding lid of Figure 6-1.

ADVANTAGES: Lid is completely flush, having no exposed edges that can be loaded by dynamic or reflected pressures. Will handle somewhat more debris than scheme shown in Figure 6-1, which tends to plow under.

DISADVANTAGES: Actuating mechanism becomes complex and requires a large controlled power supply. Large amounts of debris will spill into opening.

SUMMARY: Because of the mass required and the large amount of debris at very high overpressure levels, this type of lid and actuation system appear unattractive.

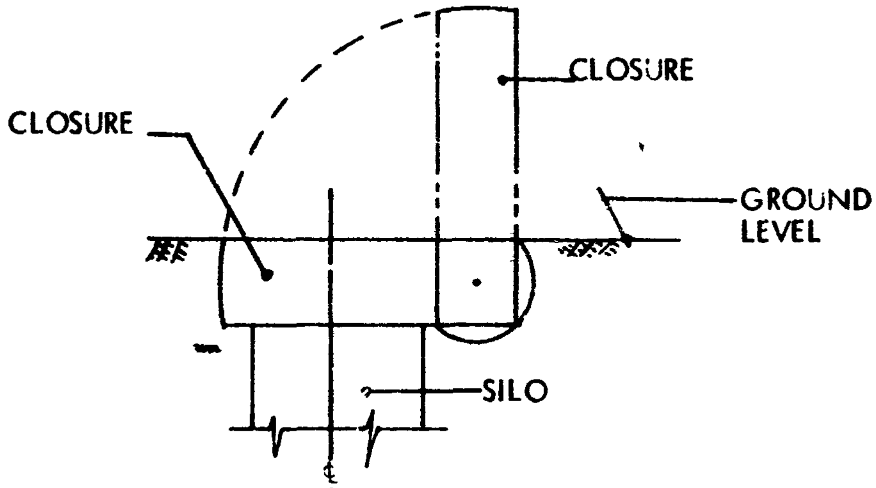

Figure 6.1-3

6.1.3 FLAT, SINGLE, HINGED CLOSURE

FUNCTIONAL DESCRIPTION: The lid is a simple hinged cover which rotates about one end, lifting and crowding accumulated debris to one side.

ADVANTAGES: It is simple, there are no exposed edges that can be loaded by dynamic or reflected pressure, and is adaptable to modifications such as adding a following debris shield.

DISADVANTAGES: The main disadvantage is the "crowding" action which tends to jam the hinge on rotation. If circular, debris spillage is severe, and the hinge mechanism complicated. Also, it requires a large power supply.

SUMMARY: Limited to fairly low debris levels, and necessarily a function of the lid length.

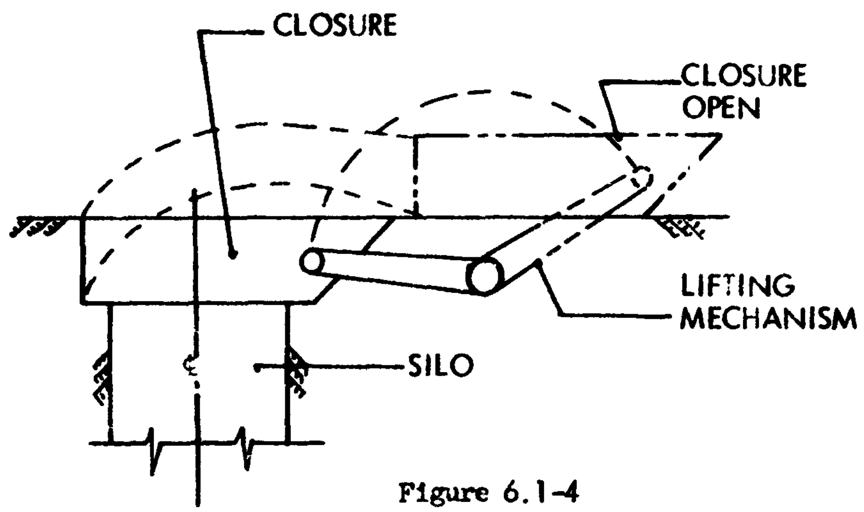

Figure 6.1-4

6.1.4 FLUSH, HORIZONTAL CRANK CLOSURE

FUNCTIONAL DESCRIPTION: The lid is completely flush and similar to that described in Figure 6-2, except that the actuator lifts and translates rather than slides the lid.

ADVANTAGES: It has somewhat better debris control in the lift and translate sequence than Figure 6-2. It is completely flush, only exposed at the top.

DISADVANTAGES: The actuation mechanism is very complex and requires slots at the surface which are quite vulnerable. Also requires large power source.

SUMMARY: This system is too complicated with its attendant mechanical reliability problems at high overpressures.

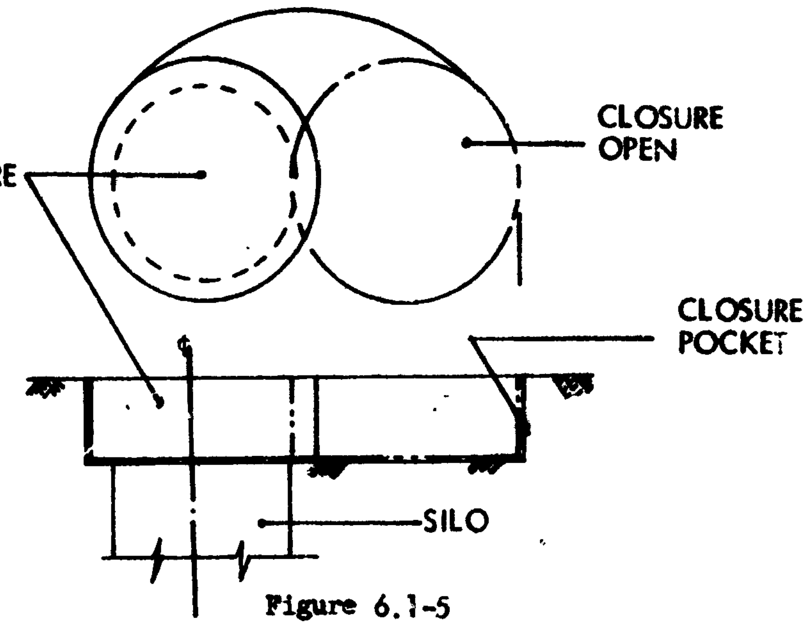

Figure 6.1-5

6.1.5 FLAT, HORIZONTAL ROTATING CLOSURE

FUNCTIONAL DESCRIPTION: This circular lid rotates and translates in an enlarged depression.

ADVANTAGES: It provides some protection against dynamic and reflected pressures.

DISADVANTAGES: It is vulnerable to debris preventing lid actuation, unless the depression is covered, in which case it must be hardened.

SUMMARY: This concept feasible only at very low levels.

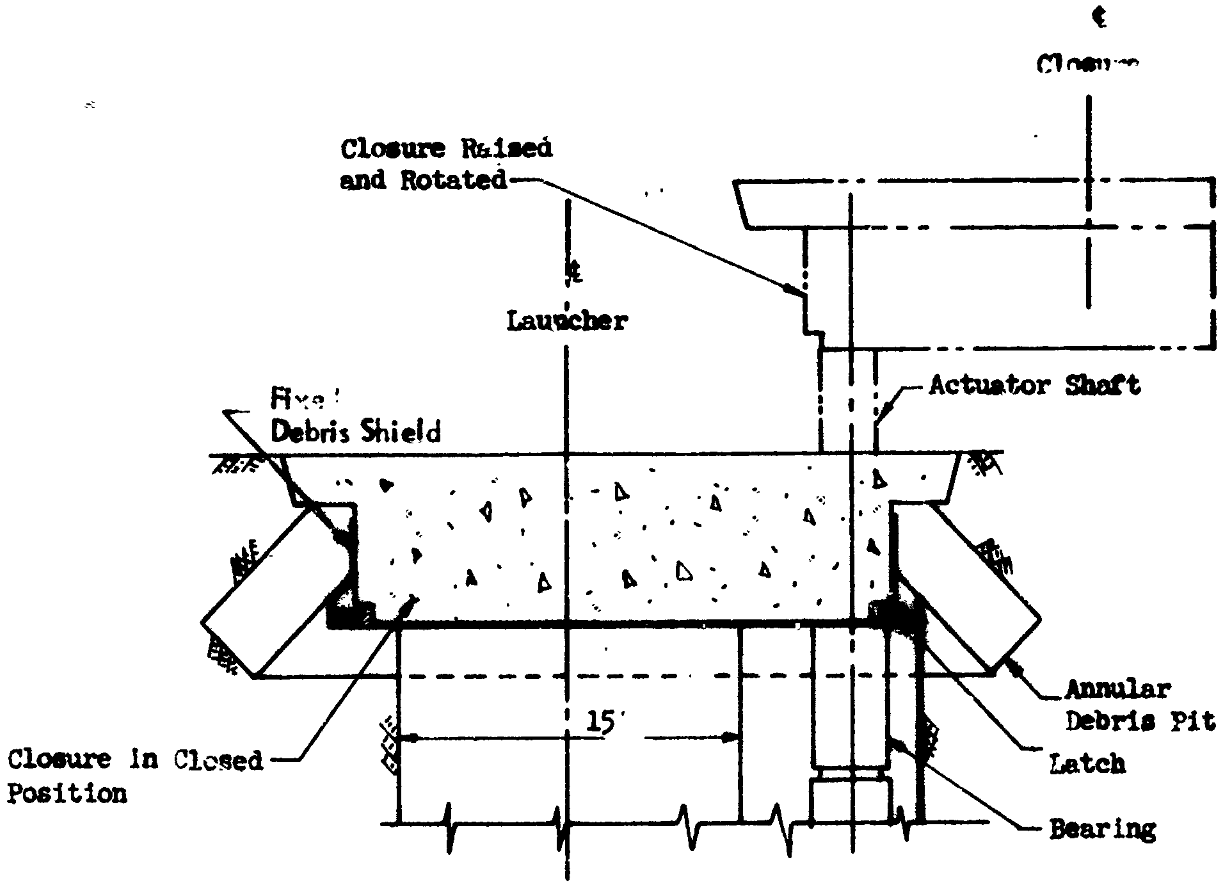

Figure 6.1-6

6.1.6 FLUSH, LIFT AND SWING CLOSURE WITH ANNULAR DEBRIS PIT- FIXED DEBRIS SHIELD

FUNTIONAL DESCRIPTION: This lid is completely flush with the ground surface, and fully contained. On command a large cylinder pushes the lid up through the debris, and then rotates the lid and debris to clear the opening.

ADVANTAGES: It has good debris control, and can pull a debris shield up with it to prevent spillage from dropping into opening.

DISADVANTAGES: The actuator must be designed to take large bending loads as a cantilever, as well as providing the thrust. A second mechanism must be sequenced to start and stop the rotation. Requires a large power source.

SUMMARY: This system or a modification, appears feasible to fairly high over-pressure levels.

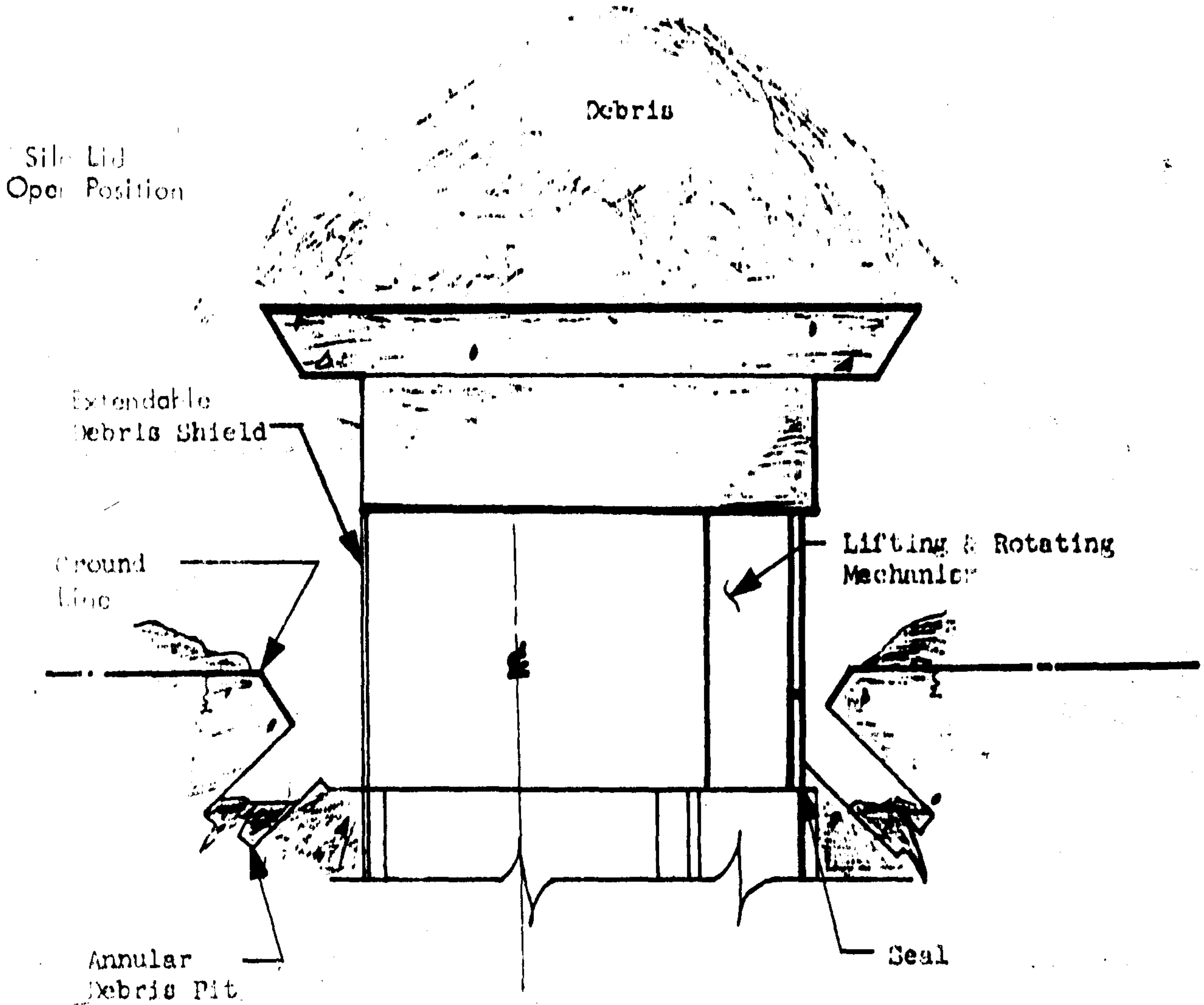

Figure 6.1-7

6.1.7 FLUSH LIFT AND SWING CLOSURE WITH ANNULAR DEBRIS PIT AND DEBRIS SHIELD EXTENDABLE DEBRIS SHIELD

FUNCTIONAL DESCRIPTION: The closure is pushed up through the debris by a large cylinder, which also rotates to clear the hole. The debris shield follows the lid up.

ADVANTAGES: Addition of a recessed debris pit to Figure 6.1-6, improves the debris handling capability by ingesting some of the debris.

DISADVANTAGES: The actuator must be designed to take large bending loads as a cantilever, as well as providing the thrust. A second mechanism must be sequenced to start and stop the rotation. Requires a large power source.

SUMMARY: This system or a modification, appears feasible to fairly high over-pressure levels.

Reference source:
C/S 2-5167-24

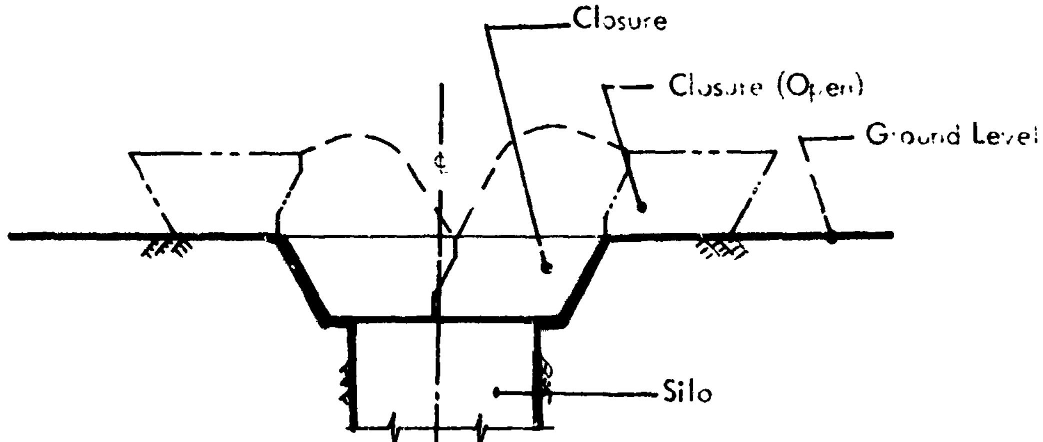

Figure 6.1-8

6.1.8 FLUSH, HORIZONTAL DOUBLE RAMPED CLOSURE

FUNCTIONAL DESCRIPTION: This closure is a two piece lid, flush with the ground surface. The two halves actuate sequentially to travel up the edge ramp and then horizontally out away from the opening.

ADVANTAGES: The weight of closure is reduced by making two sections.

DISADVANTAGES: This concept has poor debris control, and would require an inner or secondary protection for the missile since debris would drop as the two halves separate. The separation joint is also difficult to seal against all weapon effects.

SUMMARY: Not a good concept.

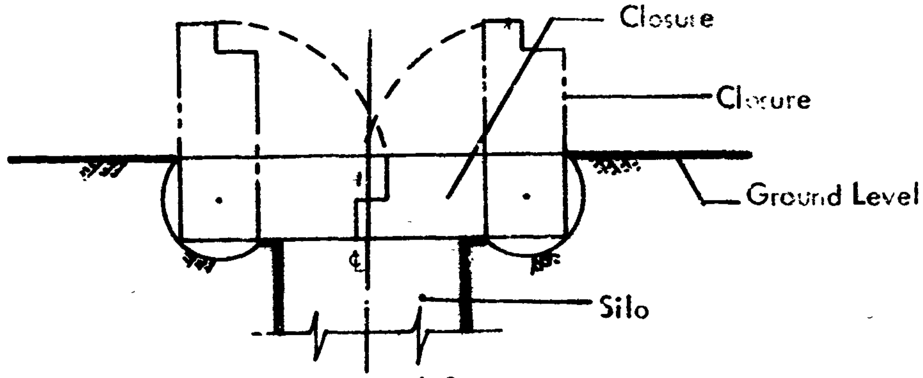

Figure 6.1-9

6.1.9 FLUSH, HORIZONTAL, DOUBLE HINGED CLOSURE

FUNCTIONAL DESCRIPTION: The closure shown is a double leaf hinged lid. One half actuates slightly in advance of the other. Debris is "crowded" aside.

ADVANTAGES: Power requirements can be met by two smaller sources as opposed to one for the single lid.

DISADVANTAGES: It has poor debris control, is weaker structurally than the single lid, and is difficult to seal.

SUMMARY: Not a good concept.

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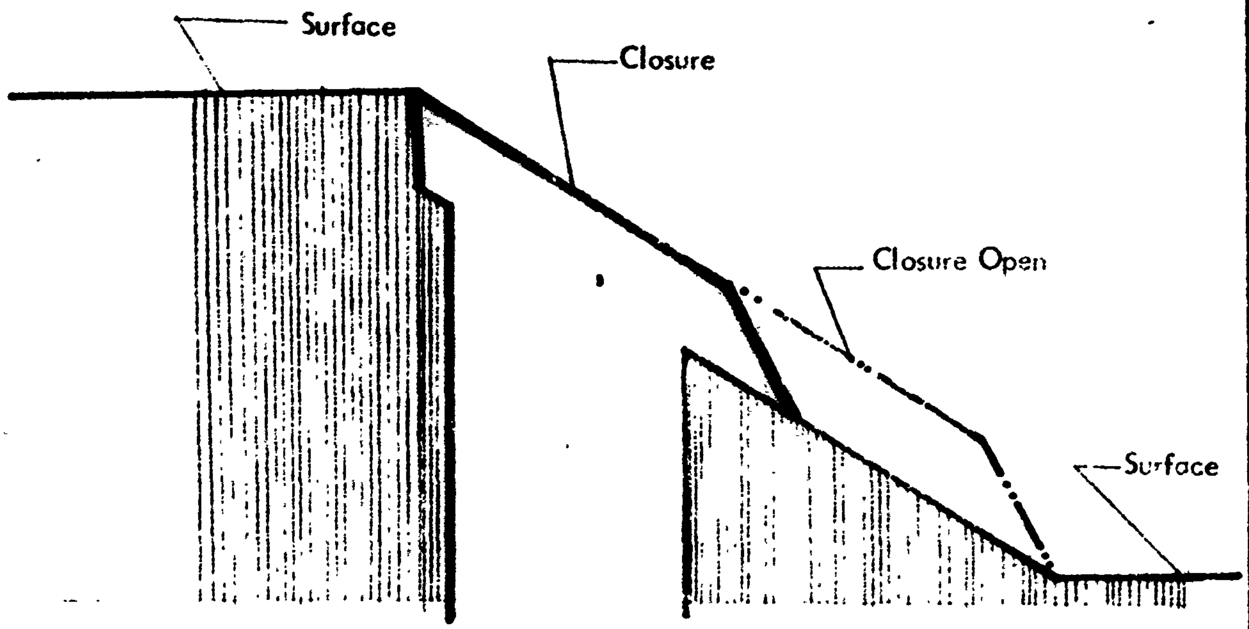

Figure 6.1-10

6.1.10 EXPOSED, INCLINED SLIDING CLOSURE

FUNCTIONAL DESCRIPTION: During a nuclear attack, debris falling on the closure is shed down the slope, toward the lower surface level. After the attack, the closure is unlocked and forced to knife through the debris to the fully open position.

ADVANTAGES: Moderately fair debris control depending on level of lower ground surface. Good maintenance access. Simple reliable action with relatively low power requirements.

DISADVANTAGES: Closure exposed to dynamic pressure buildup. Large closure span because of the incline. Closure track would require protection from nuclear environment. Increase of exposure to debris impacts. Missile emplacement may be difficult. Requires separate mechanism for closing closure after maintenance. Lock/Tie-down requirement accentuated.

SUMMARY: This concept should be considered for extension to superhard environment, particularly for hard mountain sites where natural slopes and lower surface level is sufficient to handle anticipated debris levels.

Reference source:
D2-125426-1 (SRD)

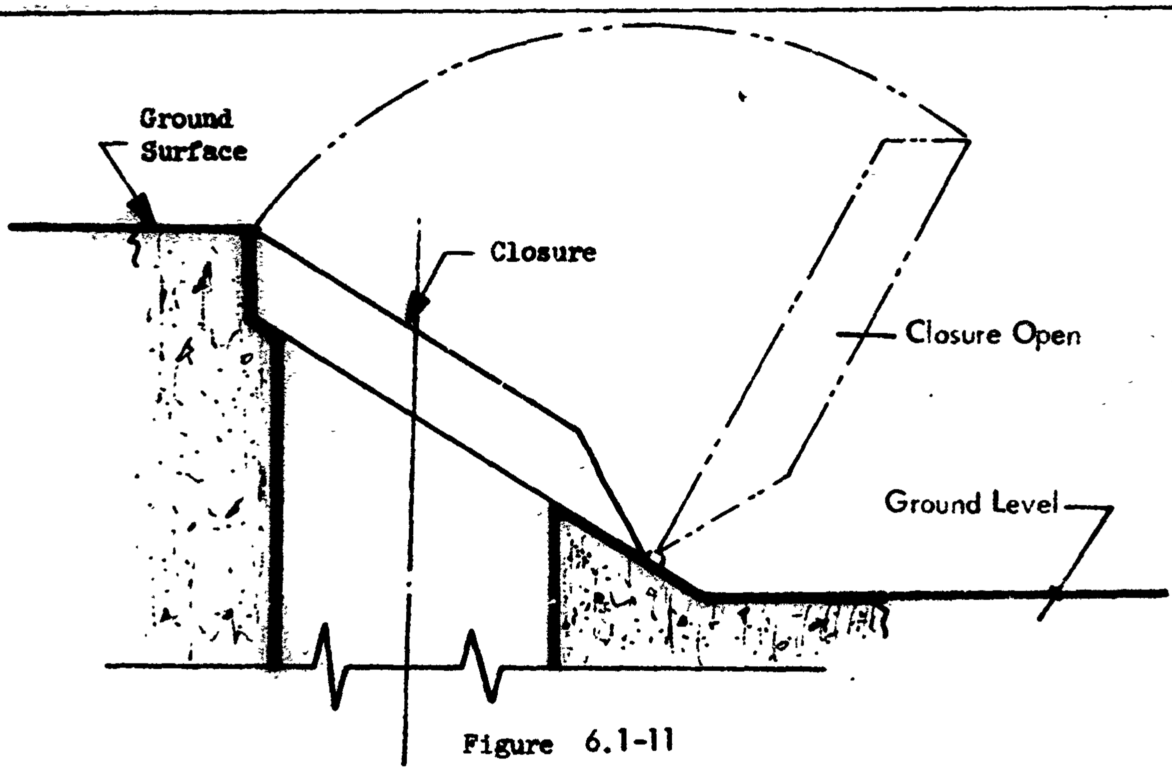

Figure 6.1-11

6.1.11 INCLINED, SINGLE HINGED CLOSURE

FUNCTIONAL DESCRIPTION: During a nuclear attack, debris falling on the closure is at least partially shed down the slope to the lower surface level. After the attack, the closure is unlocked and forced to open up through the remaining debris, shoving it aside.

ADVANTAGES: Fair debris control depending on level of lower ground surface. Simple single hinged action should exhibit good reliability. Easy maintenance access except for missile emplacement.

DISADVANTAGES: Exposed to dynamic pressure buildup. Closure span increased because of incline. Increased exposure to debris impacts. Requires more power than Fig. 6-10 for opening. Missile emplacement may be difficult.

SUMMARY: Could be extended to superhard environment, although it exhibits no advantage over the concept of Fig. 6-10.

Reference source:
D2-125426-1 (SRD)

USE FOR DRAWING AND HANDPRINTING — NO TYPEWRITTEN MATERIAL

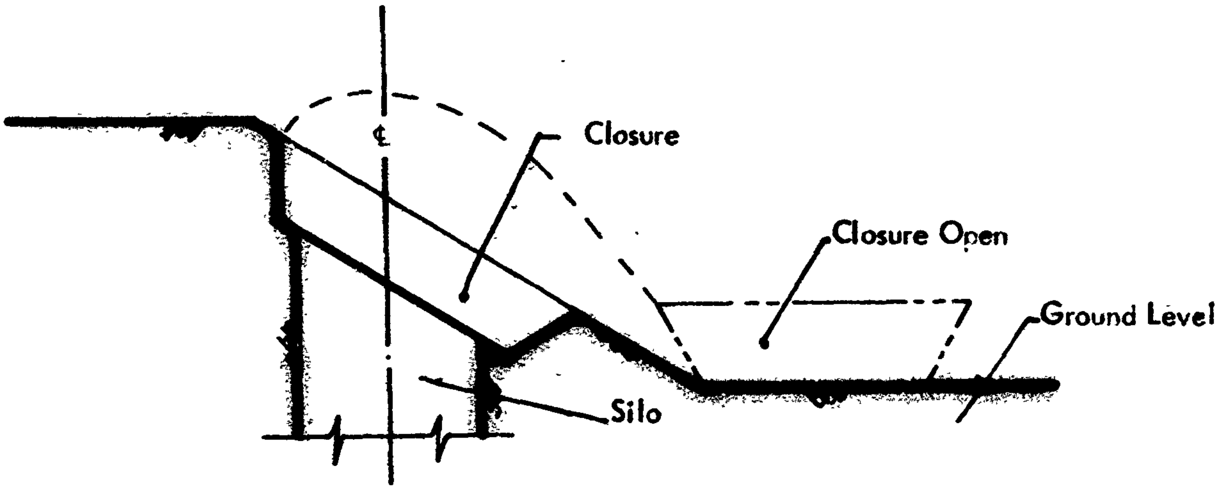

Figure 6.1-12

6.1.12 INCLINED, SINGLE RAMPED CLOSURE

FUNCTIONAL DESCRIPTION: This concept shows an inclined closure which is flush mounted having no exposed edges. The lid is pushed laterally and translates clear of the opening.

ADVANTAGES: It is flush with the surface, having no edges exposed. The inclined top surface will tend to shed debris. Debris control is fairly good.

DISADVANTAGES: The inclined top surface will be subjected to dynamic and reflected pressures. Missile emplacement and maintenance will be difficult because of the slope.

SUMMARY: This has some potential for specific application in the medium and low ranges.

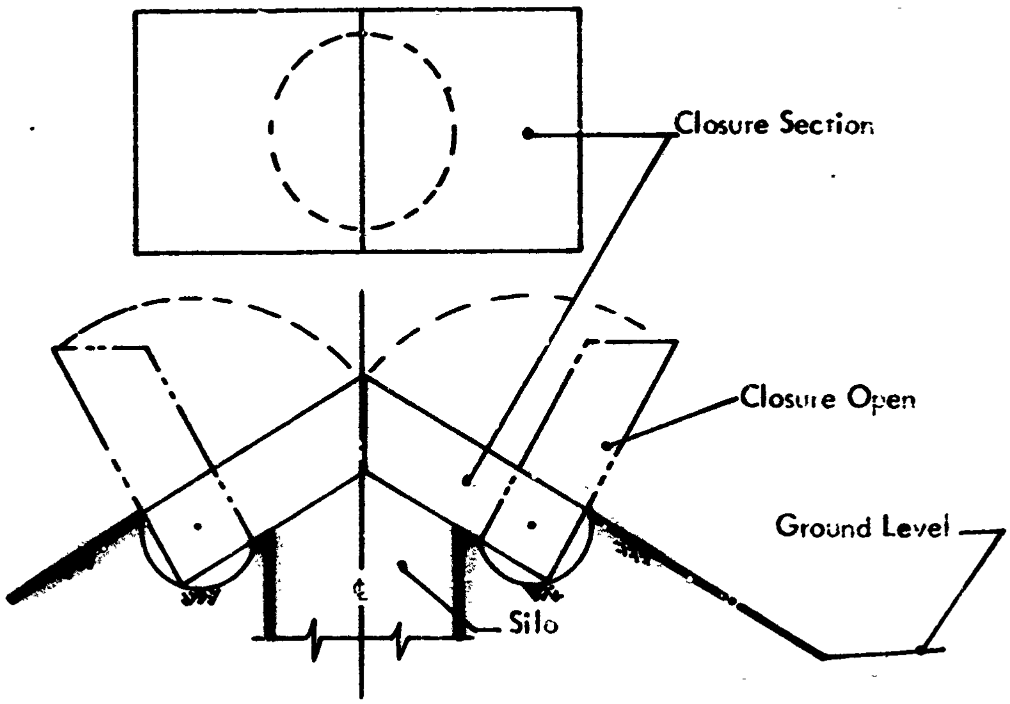

Figure 6.1-13

6.1.13 INCLINED, DOUBLE HINGED CLOSURE

FUNCTIONAL DESCRIPTION: The closure consists of two inclined hinged parts. Both leaves actuate simultaneously, hinging outward to clear the opening.

ADVANTAGES: Has good debris control up to the amount of rise of the lids. The "crowding" on opening is less severe than with the flat concept as debris is pushed downhill.

DISADVANTAGES: The rise must be minimal to keep excessive dynamic and reflection pressures to a minimum. Sealing will be difficult at the peak.

SUMMARY: This concept limited to low ranges.

USE FOR DRAWING AND HANDPRINTING -- NO TYPEWRITTEN MATERIAL

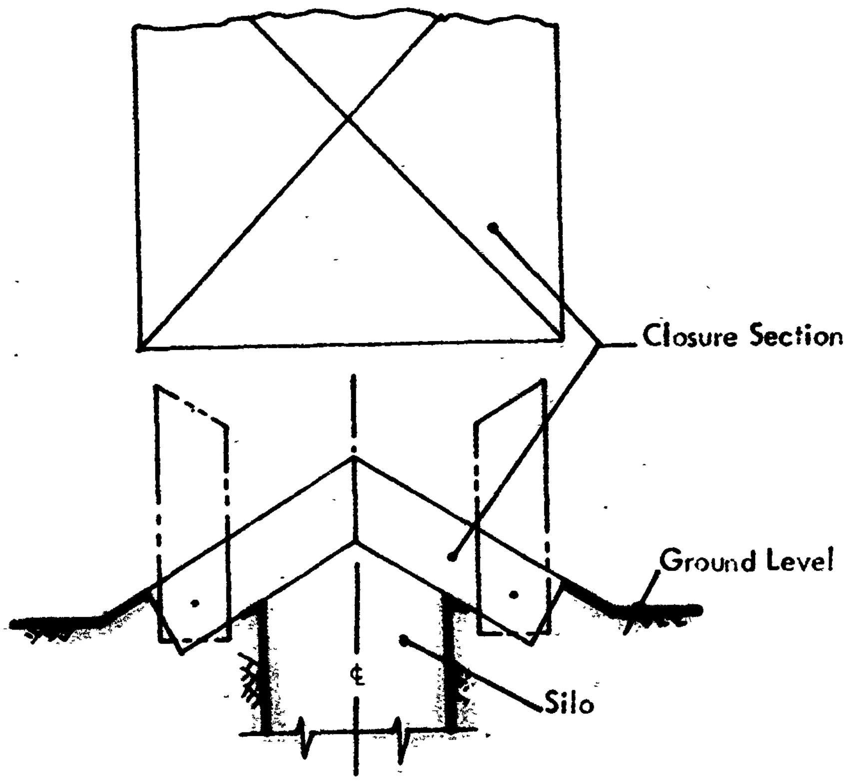

Figure 6.1-14

6.1.14 INCLINED, QUAD HINGED, ORANGE PEEL CLOSURE

FUNCTIONAL DESCRIPTION: The closure consists of four triangular shaped leaves which hinge about their base.

ADVANTAGES: The shape minimizes the dynamic and reflected pressures, and debris is pushed away from center.

DISADVANTAGES: Complex mechanism compromise reliability. Exposed to dynamic pressure. Missile emplacement difficult. Power requirements for opening fairly high. Difficult to seal.

SUMMARY: Could be extended to superhard applications but its complexity, limited debris handling capability and exposure to dynamic pressure make it less desirable than some other concepts.

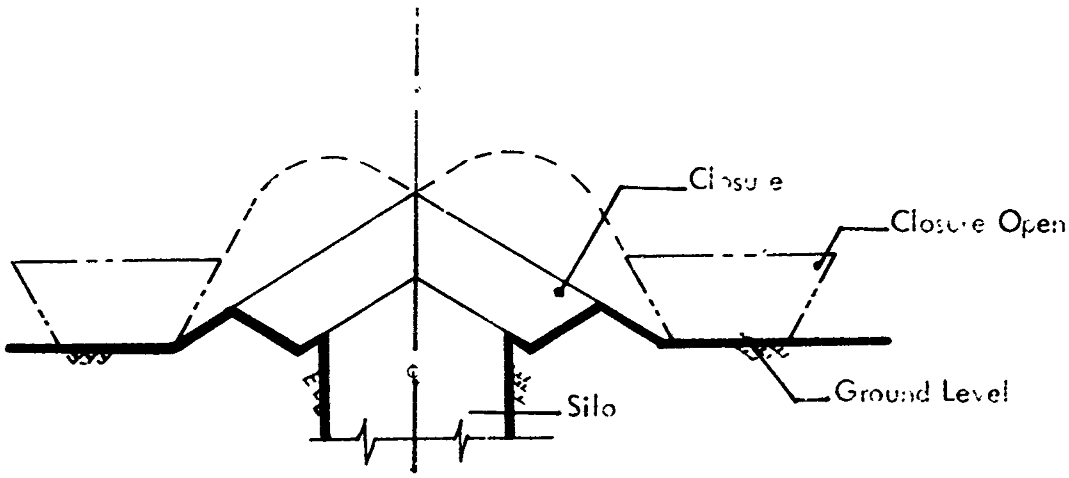

Figure 6.1-15

6.1.15 INCLINED, DOUBLE RAMPED CLOSURE

FUNCTIONAL DESCRIPTION: The closure is composed of two leaves flush mounted at the bottom and meeting at a peak in the center. Both leaves are actuated outward, sliding away from the opening.

ADVANTAGES: The two leaves would reduce the mass to be actuated.

DISADVANTAGES: The actuation becomes extremely complicated with these two inclined lids reacting against each other. The reliability of such a closure would be low. Also the inclined surfaces would be exposed to dynamic and reflected pressure. Would be difficult to service the launcher.

SUMMARY: This is not a good concept.

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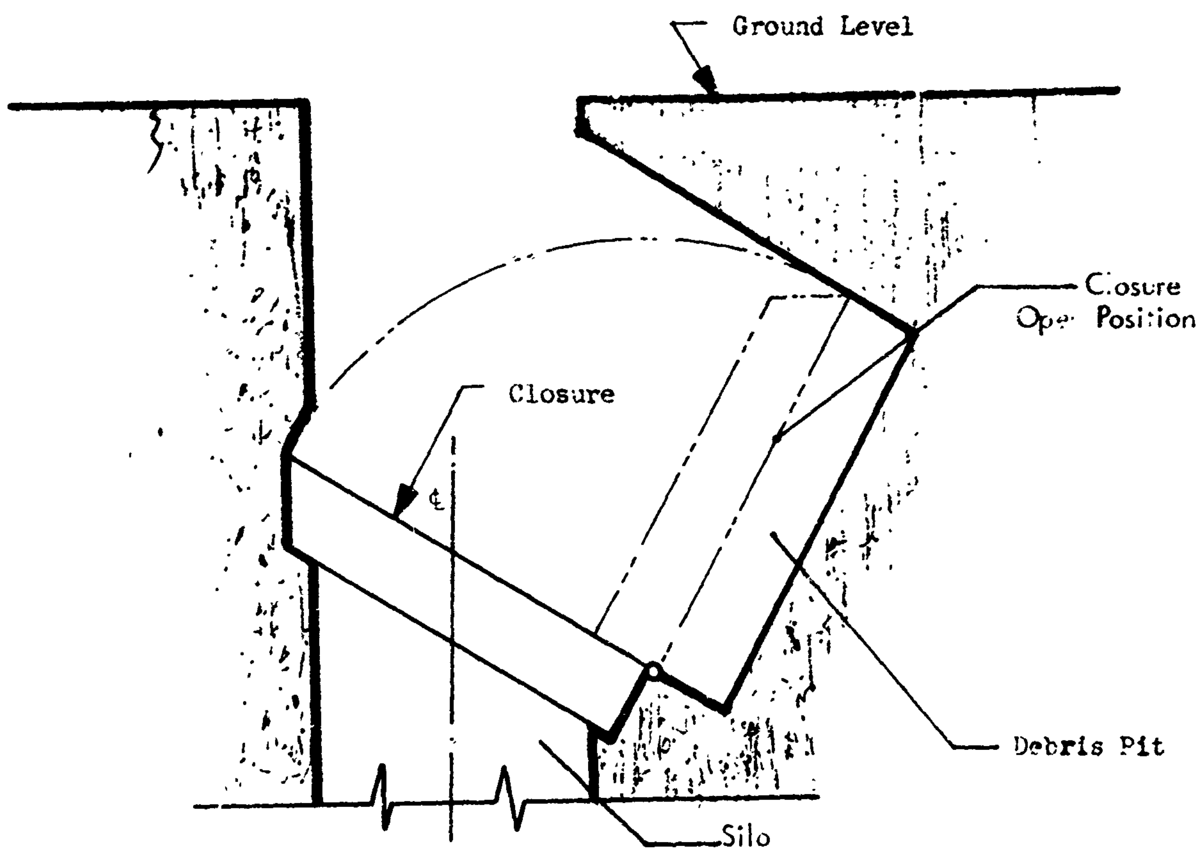


Figure 6.1-16

6.1.16 SUBMERGED, INCLINED SINGLE HINGED CLOSURE

FUNCTIONAL DESCRIPTION: A hardened debris pit provides a space for the lid to push the debris into as the lid swings open about a hinge at the lower end.

ADVANTAGES: It is a simple concept, avoiding dynamic pressure effects, and providing for moving any debris remaining on the lid to a cavity.

DISADVANTAGES: The debris pit must be large and the lid must be down fairly deep to accomodate the lid swing. Some crowding at the hinge will occur.

SUMMARY: This concept requires more space and power than that shown on Fig. 6-17, but may be possible to extend to superhard concepts.

Reference source:
D2-125426-1 (SRD)

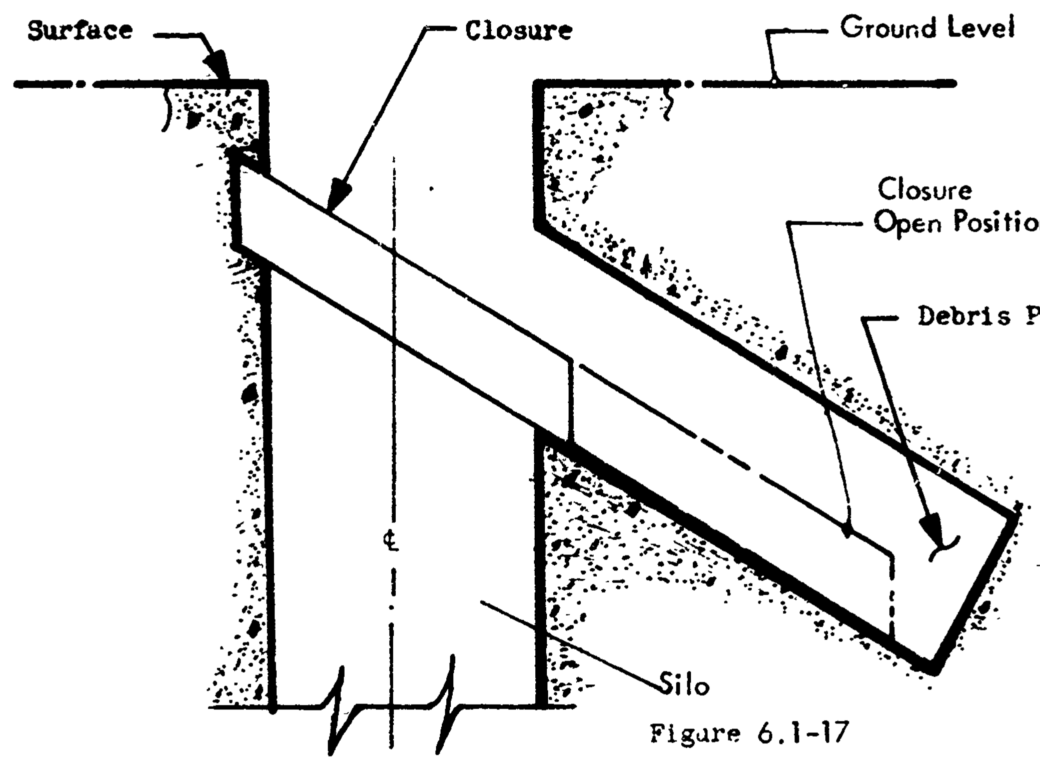


Figure 6.1-17

6.1.17 SUBMERGED, INCLINED SLIDING CLOSURE WITH DEBRIS PIT

FUNCTIONAL DESCRIPTION: During a nuclear attack, debris falling on the closure slides into the debris pit. After the attack, the closure can be unlocked and opened by either an actuator or gravity.

ADVANTAGES: Power requirements for opening are low. Maintenance access is relatively simple. Reliable single action. No lifting or rotating. Improved radiation protection. Good debris control.

DISADVANTAGES: The debris pit must be hardened to prevent collapse during several nuclear bursts. Closure span is larger because of the slope. Closure rails must be protected against nuclear environment. The debris pit and the closure may be exposed to higher pressures due to dynamic effects from over-pressure shock wave.

SUMMARY: Possible to extend this concept for superhard applications.

Reference source:
C/S 2-5167-24

USE FOR DRAWING AND HANDPRINTING — NO TYPEWRITTEN MATERIAL

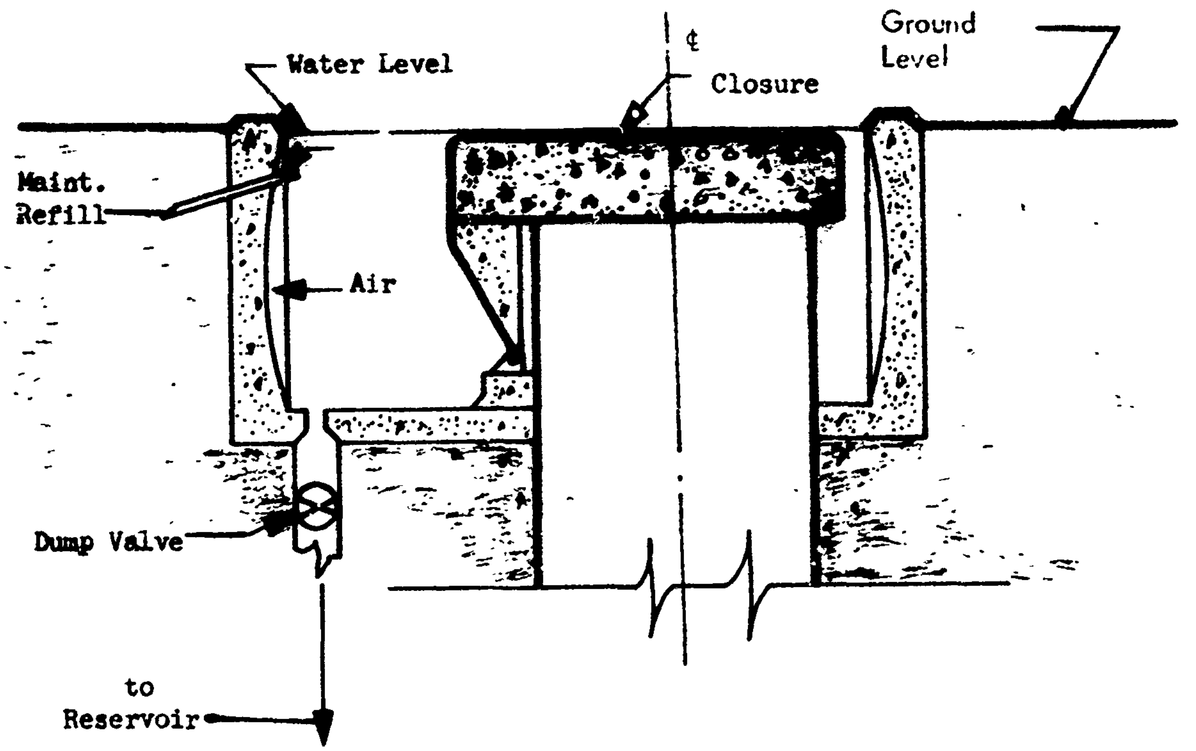


Figure 6.1-18

6.1.18 FLIP LID CLOSURE WITH WATER RADIATION SHIELD AND VOLUME EXPANSION

FUNCTIONAL DESCRIPTION: The entire closure and the neck of the launcher are immersed in a pool of liquid. The liquid volume provides space for the debris to fall and provides radiation attenuation as well as a level top surface. The lid hinges and dumps any remaining debris, after the liquid is dumped to a reservoir underground.

ADVANTAGES: Provides flush surface, space for debris, and radiation protection.

DISADVANTAGES: Requires deep liquid pool for multiple blasts, requires large underground reservoir and valve. Pool must be survivable for multiple blasts.

SUMMARY: This is a fairly credible concept for one blast.

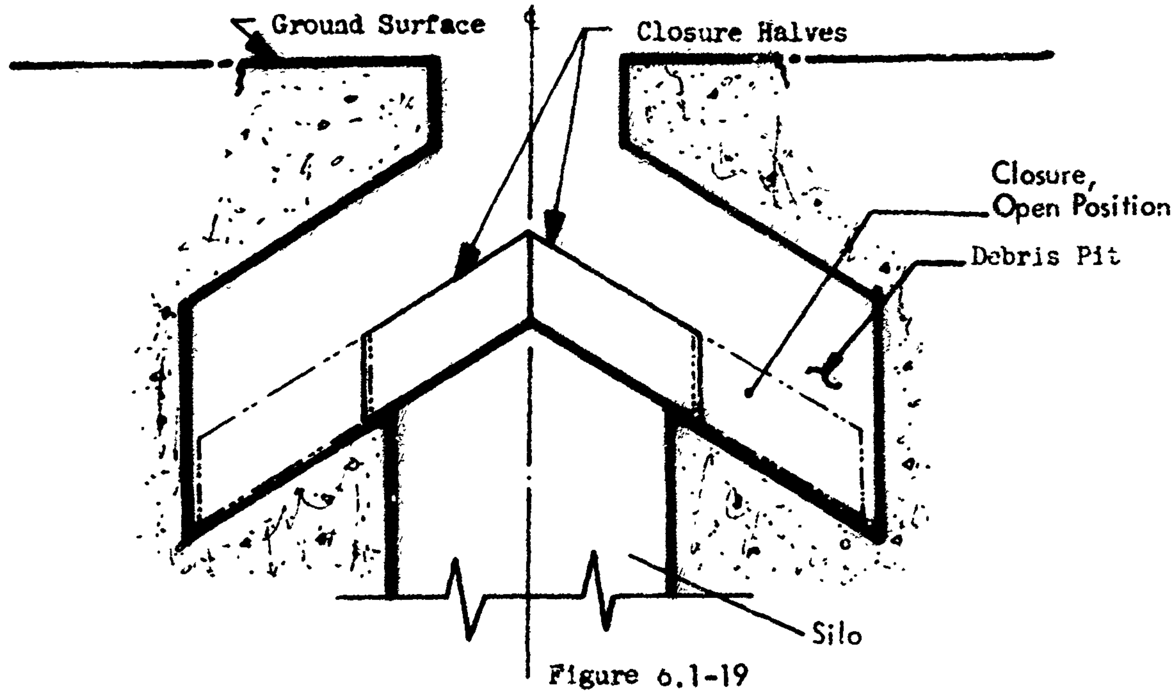


Figure 6.1-19

6.1.19 SUBMERGED, INCLINED, DUAL-SLIDING CLOSURE WITH DEBRIS PIT

FUNCTIONAL DESCRIPTION: During a nuclear attack, debris falling through the ground opening into the closure halves is shed into the debris pits. After the attack, the closure halves are unlocked and allowed to slide (with power or by gravity) into the debris pits thereby opening the launch tubes.

ADVANTAGES: Closures are protected from dynamic effects, debris is funneled away from the lid, and power to open can be quite small.

DISADVANTAGES: Split lids are difficult to seal, and the peak is more vulnerable than a flat full section. The debris pits must be survivable. Reliability is not as good for two parts as for one.

SUMMARY: Not as credible as the single lid with a pit, but a possibility.

Reference source:

D2-125426-1 (SRD)

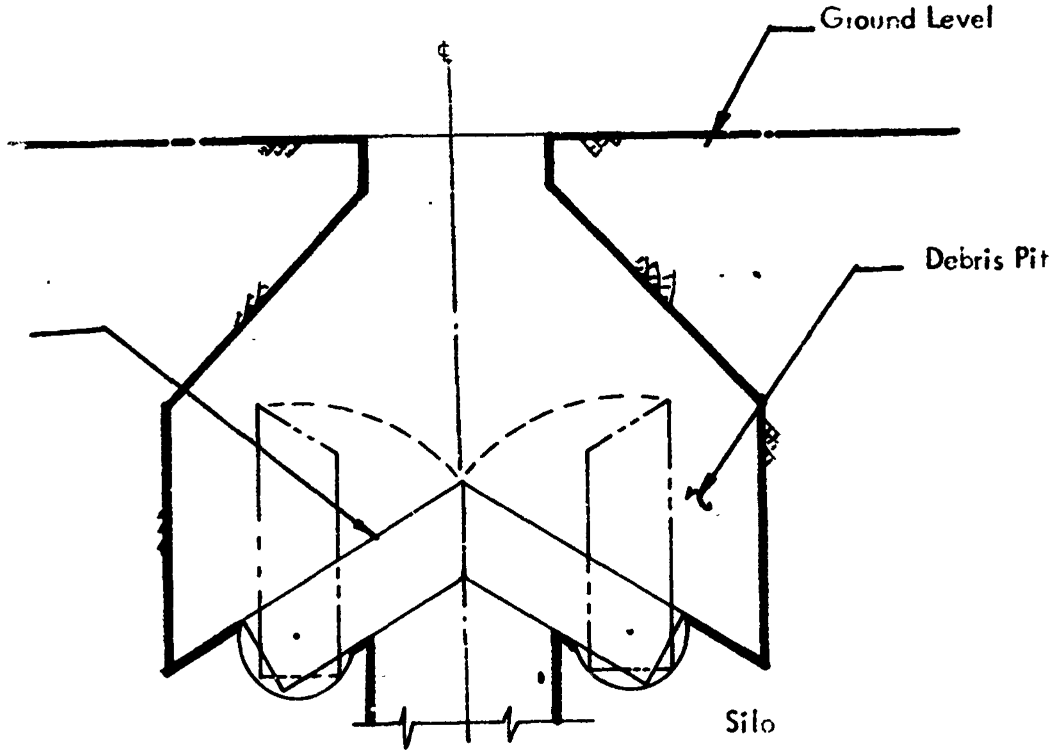


Figure 6.1-20

6.1.20 SUBMERGED, INCLINED, DOUBLE HINGED CLOSURE WITH DEBRIS PIT

FUNCTIONAL DESCRIPTION: The closure consists of a double hinged lid, with the center meeting at a peak, and the lid submerged below the surface in a double debris pit. The two leaves hinge away from the opening.

ADVANTAGES: Debris will shed off the inclined lid halves and be diverted into two debris pits. The lid is protected from dynamic pressures and shielded somewhat from radiation and thermal effects. Power requirements should be moderate.

DISADVANTAGES: It is difficult to seal the center joint, especially when peaked. Reliability is somewhat degraded by two actuators, and two debris pits must survive.

SUMMARY: This concept or modifications may have some possibility of application in the superhard range.

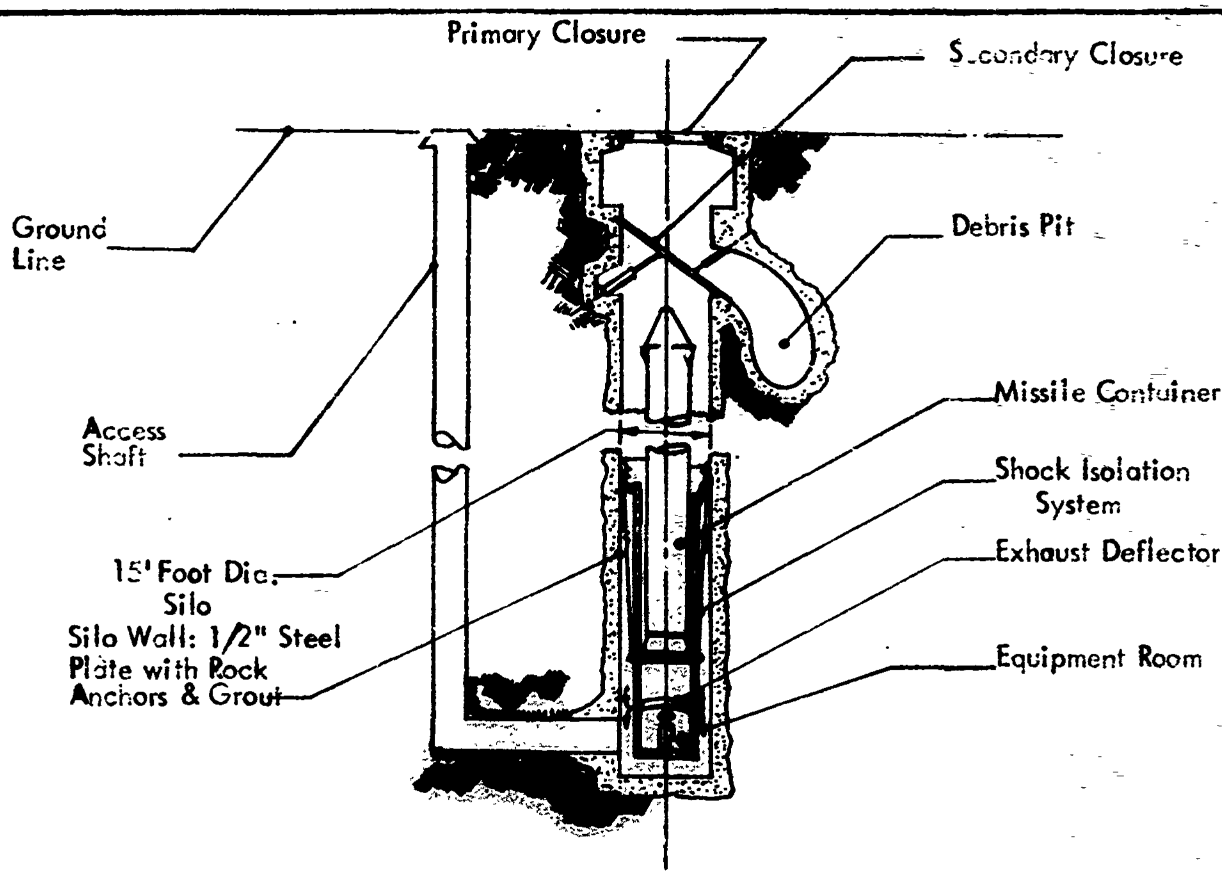


FIGURE 6.1-21

6.1.21 MULTIPLE CLOSURE CONCEPT/INCLINED SECONDARY CLOSURE

FUNCTIONAL DESCRIPTION: After the nuclear attack the closure is covered with debris. Upon command the primary closure is opened and the debris falls into the silo. The secondary closure deflects the large debris particles to the debris pit and the small debris particles to the silo shaft deflected by the missile container.

ADVANTAGES: Primary lid is flush with ground surface. No exposed edges to dynamic or reflected pressure. Excellent debris control.

DISADVANTAGES: The sequential operation of three (3) closures. Missile must be stored in a container.

SUMMARY: Could be developed for superhard applications.

Reference source: Memo: G. M. Gardner to R. S. Yoseph, March 23, 1967

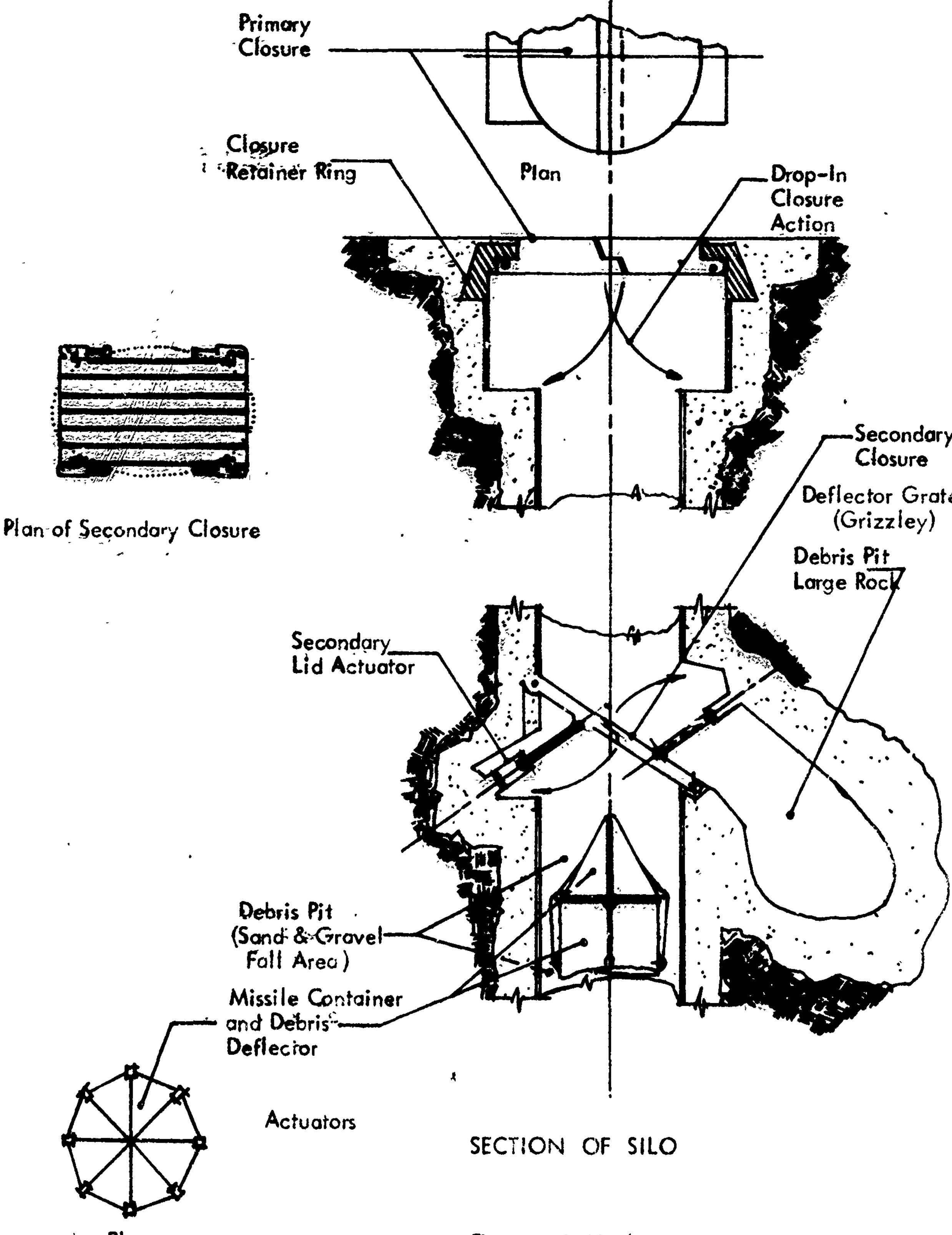


Figure 6.1-21 (continued)

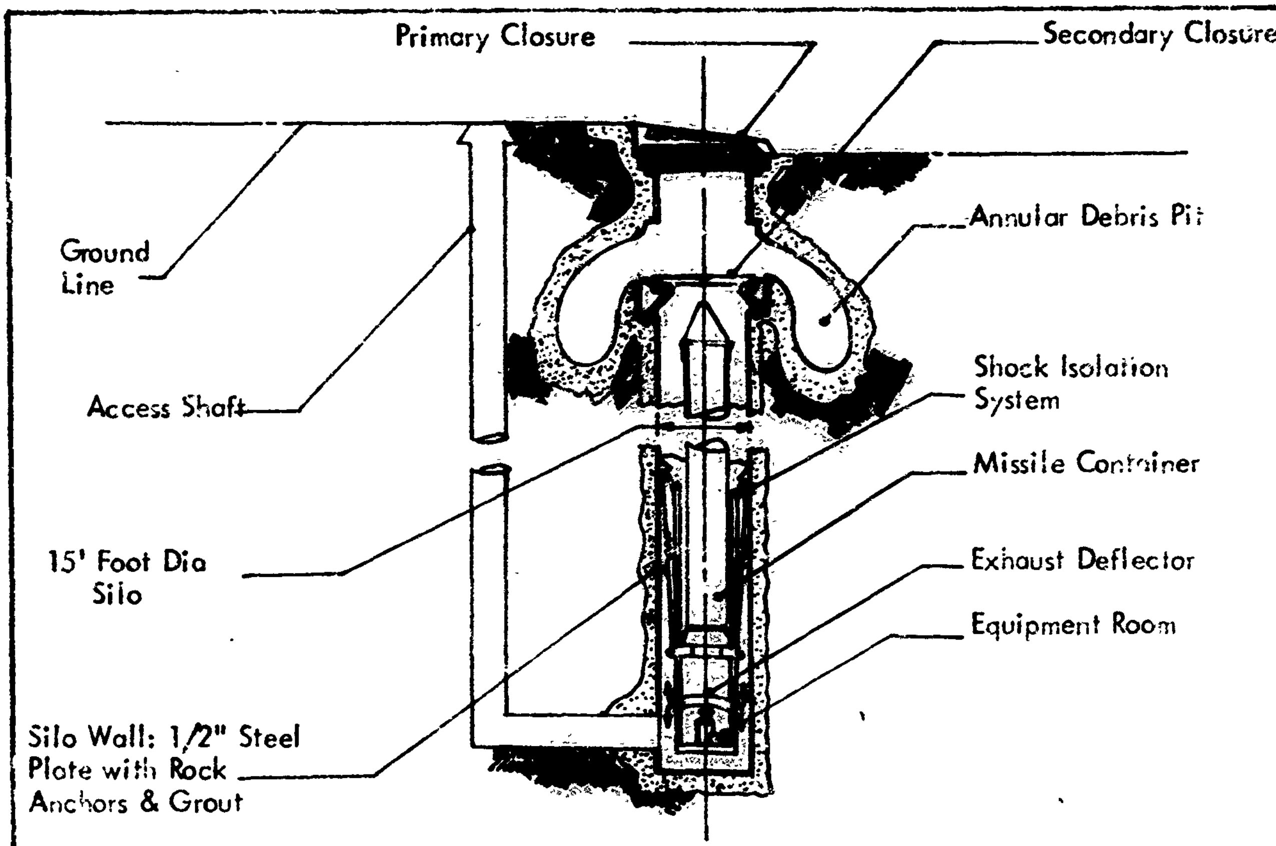


FIGURE 6.1-22

6.1.22 MULTIPLE CLOSURE CONCEPT/HORIZONTAL SECONDARY CLOSURE

FUNCTIONAL DESCRIPTION: Same as 6.1.21 - except primary closure slides on tracks horizontally to open and a larger debris pit is provided.

ADVANTAGES: Same as 6.1.21.

DISADVANTAGES: Same as 6.1.21.

SUMMARY: A modification of this system appears feasible for superhard environment.

Reference source: Memo: G.M. Gardner to R.S. Yoseph, March 23, 1967

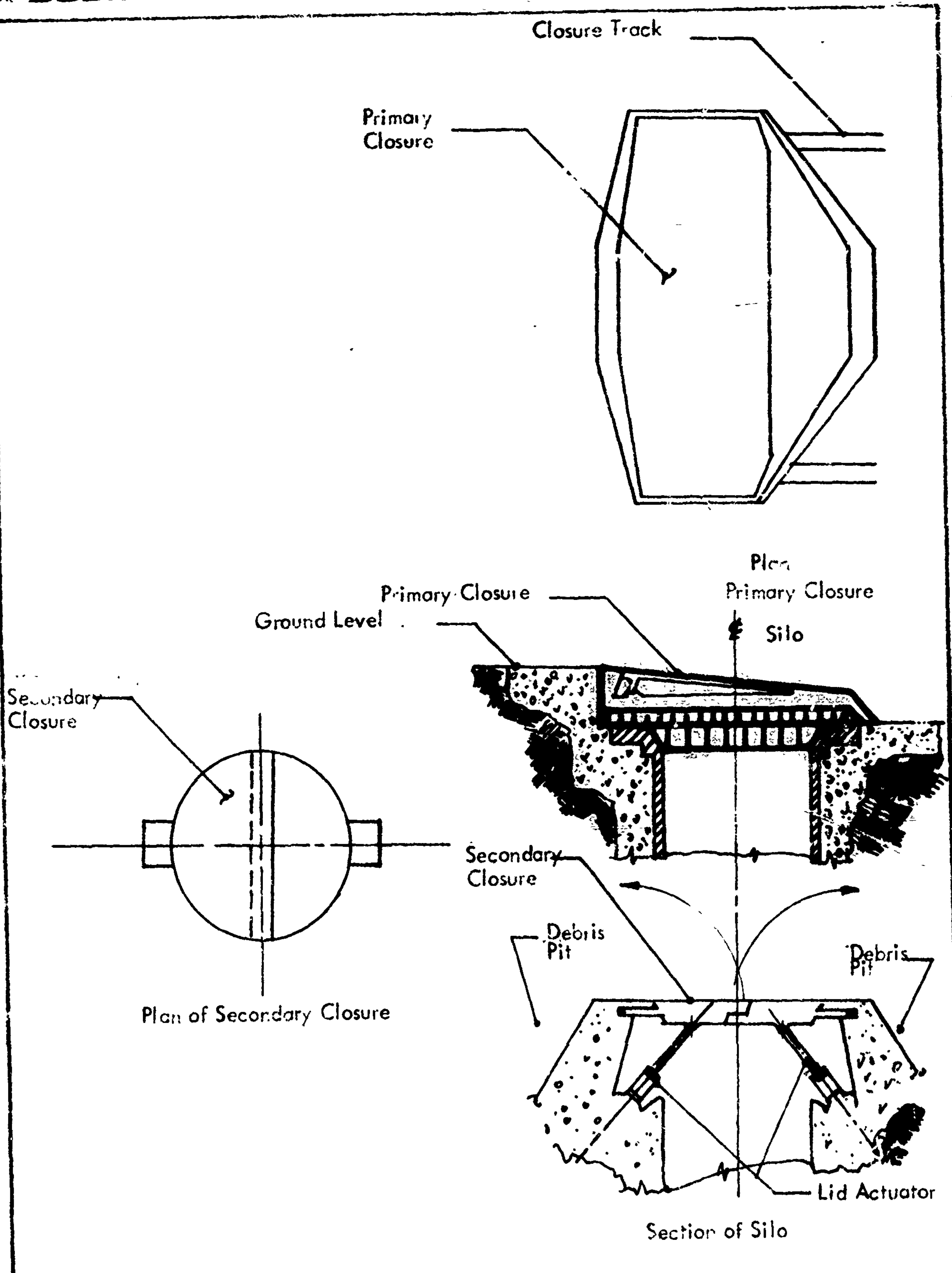


Figure 6.1-22 (continued)

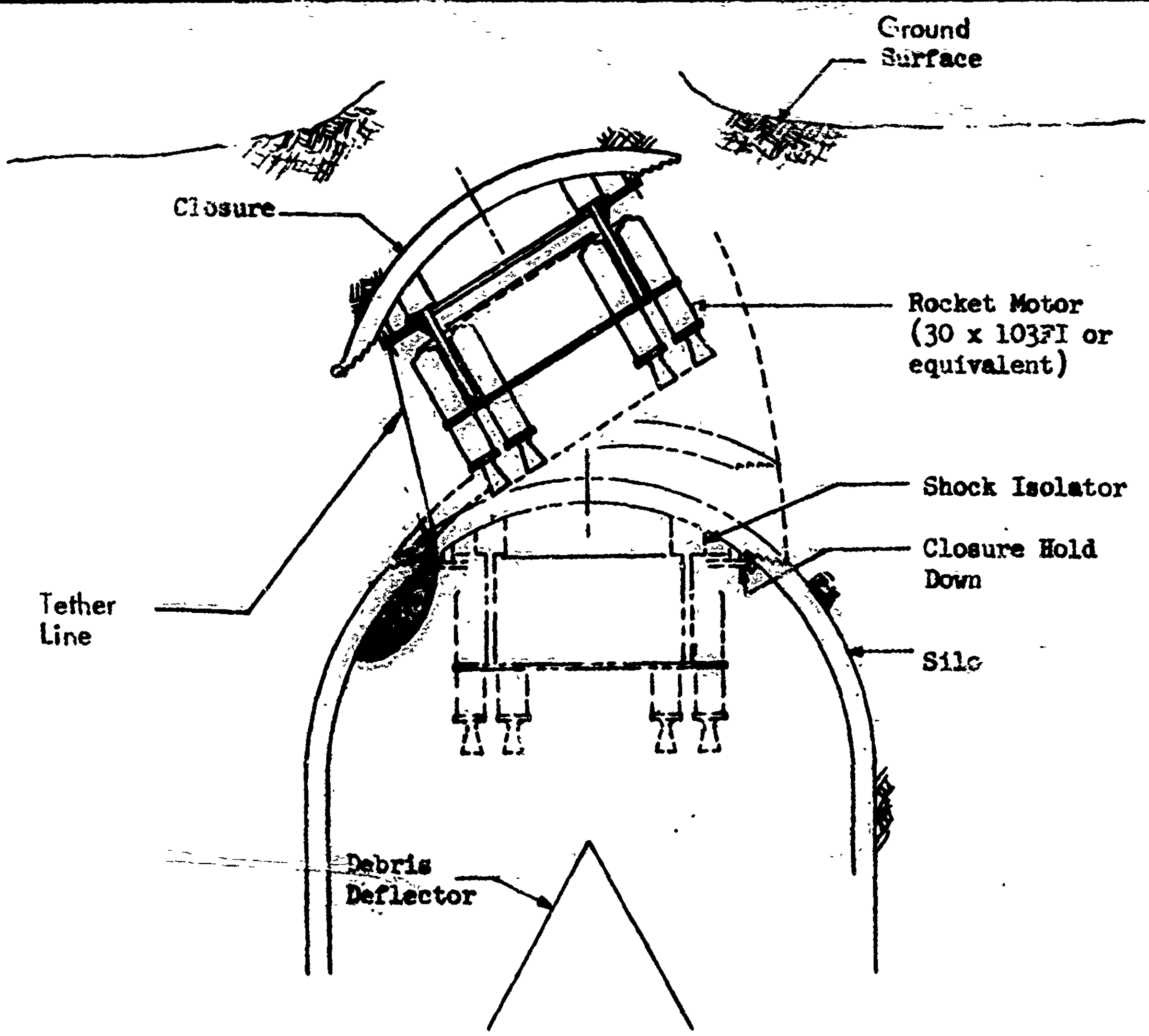


Figure 6.1-23

6.1.23 BURIED FLYOUT CLOSURE

FUNCTIONAL DESCRIPTION: After the nuclear attack, the rocket motors are ignited, the closure hold down is released and motor thrust shears the retaining pins forcing the closure upward through the debris. Both motor exhaust and remaining debris are deflected around the launch tube by the debris deflector which later opens for launch.

ADVANTAGES: Low electrical power requirements. Reliable positive action. Simple sealing. Good radiation and thermal protection. Freedom from dynamic pressure and debris impacts.

DISADVANTAGES: Poor maintenance access. Complex and costly rocket motor arrangement. Missile emplacement difficult.

SUMMARY: Could be developed for superhard applications.

Reference source:
Coordination Sheet No. 2-5167-19
May 8, 1967

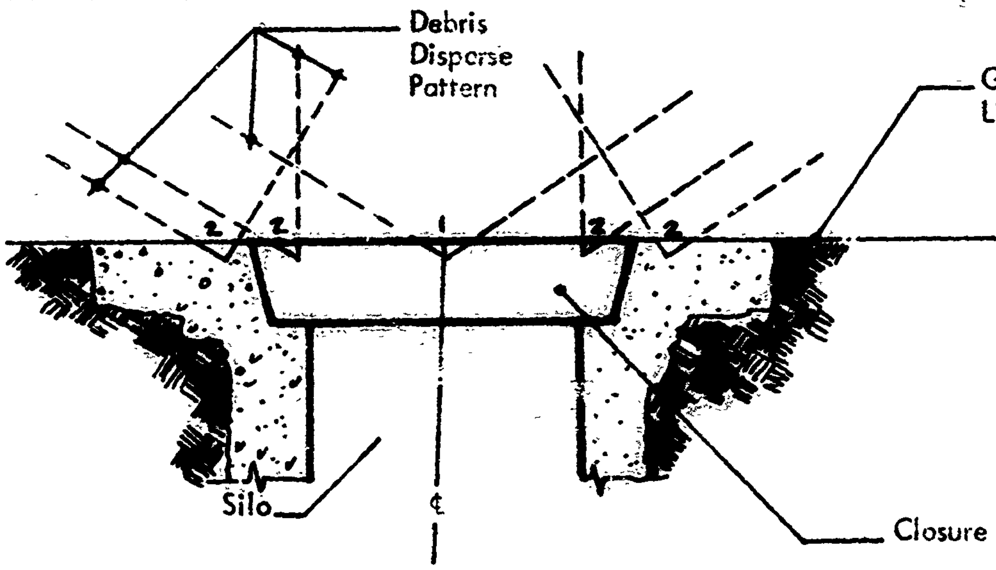


Figure 6.1-24

6.1.24 EXPLOSIVE DEBRIS REMOVAL CONCEPT WITH 1, 2, 3 FIRING SEQUENCE

FUNCTIONAL DESCRIPTION: This concept shows a debris removal system which can be applied to any method of actuating the lid. Shaped charges, protected in the lid during the attack, are fired sequentially to break up and disperse the debris on and around the closure

ADVANTAGES: Actuation of the lid can take place in a debris free environment

DISADVANTAGES: It is improbable that the charges can be protected sufficiently during a nuclear blast, and then be exposed and actuated when desired with good reliability.

SUMMARY: Not a practical application at the high range.

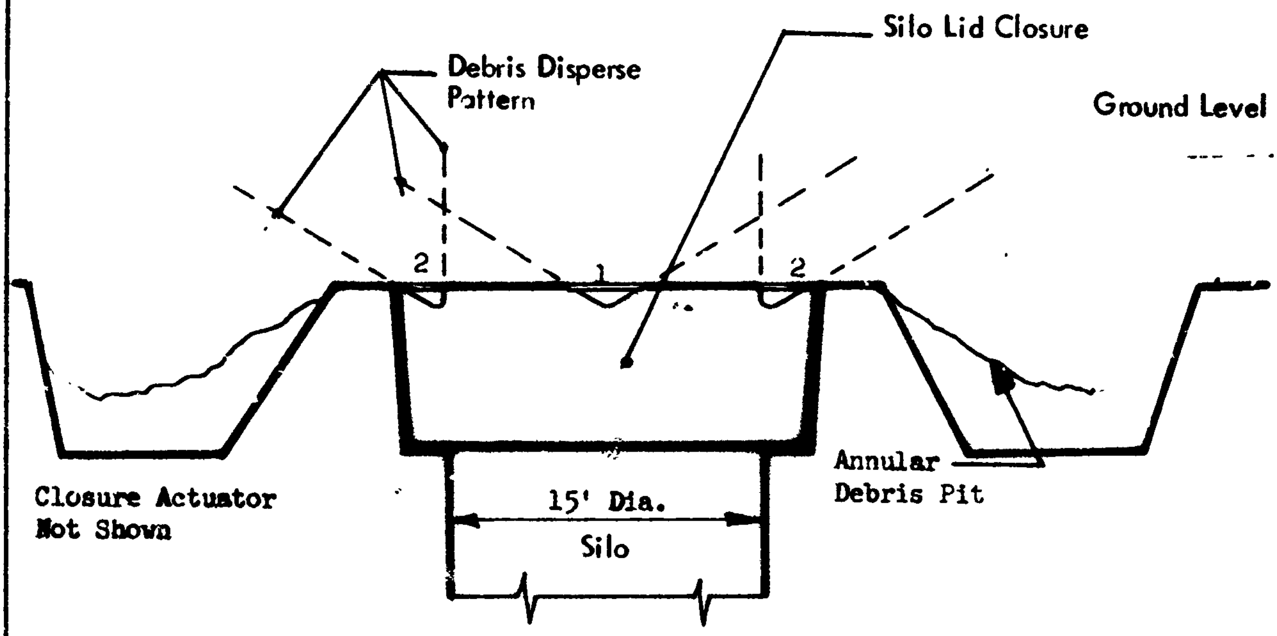


Figure 6.1-25

6.1.25 EXPLOSIVE DEBRIS REMOVAL CONCEPT WITH 1, 2 FIRING SEQUENCE AND DEBRIS PIT

FUNCTIONAL DESCRIPTION: Same as shown on Fig. 6.1-24, except space for the debris is provided.

ADVANTAGES: Same as Fig. 6.1-24.

DISADVANTAGES: Same as Fig. 6.1-24, with the additional problems because it is not flush.

SUMMARY: Same as Fig. 6.1-24.

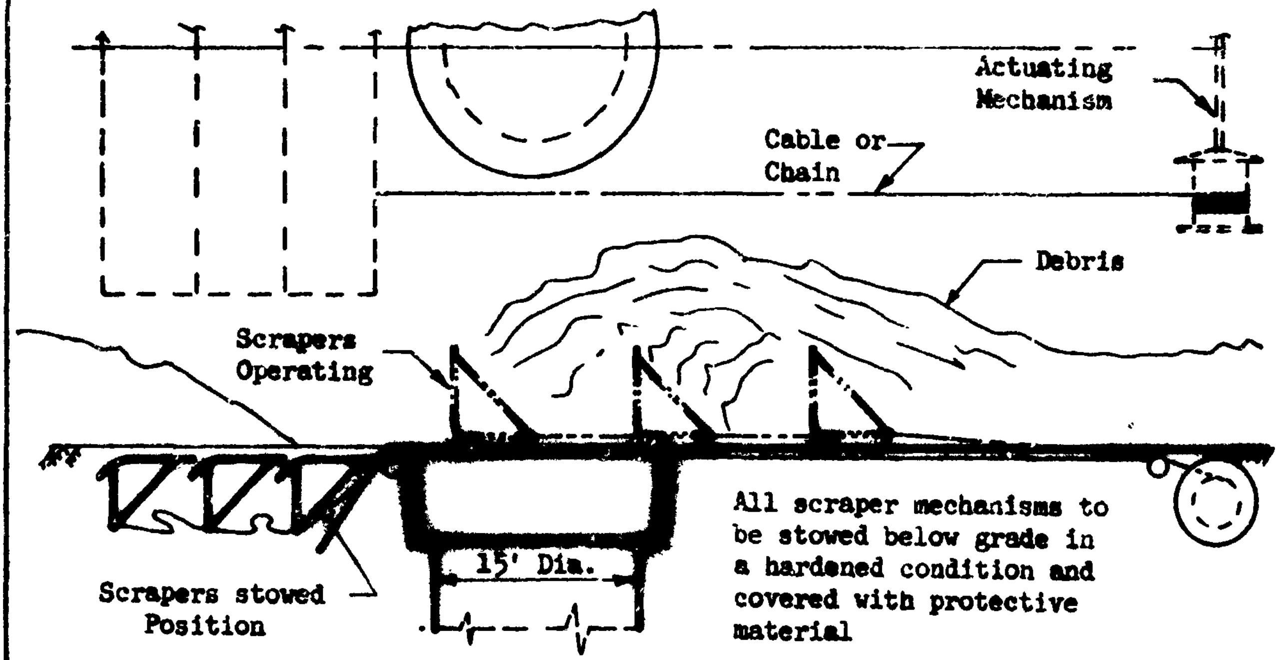


Figure 6.1-26

6.1.26 MECHANICAL DEBRIS REMOVAL CONCEPT

FUNCTIONAL DESCRIPTION: A mechanical scraping system is installed over a flush lid, so that after attack it can be pulled across the lid by a cable and drum system located in a hardened vault. Cable is protected in slots.

ADVANTAGES: The lid can be actuated in a debris free environment.

DISADVANTAGES: The system must be hardened itself so that it can survive. All the mechanical parts must be anchored down during surface erosion.

SUMMARY: Not a good concept except at very low ranges.

USE FOR DRAWING AND HANDPRINTING — NO TYPEWRITTEN MATERIAL

6.2 Additional Concepts and Variations

The following is a discussion of notes and points as to the advantages and disadvantages of different geometrical shapes and support media for silo closure lids:

Shaped Doors (Domes Arches, etc. vs. Flat Slabs)

This type of structure provides:

Increased strength to weight ratio;

No appreciable vertical depth increase;

Requires debris pit, debris removal, or accommodations for debris within the silo structure.

Ductile (Yieldable) vs. Elastic Design

No successful ductile design has been proposed for the closure alone. Most ductile designs involve the total structure. However, some success has been demonstrated in providing a crushable base or yieldable structure under the cap or incorporated in the silo wall. It is possible to introduce sufficient mass in the cap and closure and select a crushing element strength to essentially cut the footing pressure in half for a reasonable cap stroke or displacement (2-7 feet for three attacks). Mass is critical because the overpressure positive pulse is long compared with surface structure yield time. Sufficient mass must be added above the yieldable element to reduce the peak overpressure effects and/or reduce the wave velocity through the structure;

Concept offers considerable protection for remaining silo structure;

This design would handle initial free-field upward displacements;

Structure would have to be restrained horizontally to prevent excessive sideways displacement;

Requires complete knowledge of surface effects relative to time, properties of media and structural materials and extensive analysis.

Buried or Semi-buried Lid Concepts

Some attenuation with depth is expected;

Provides additional protection from flying debris (ejecta);

Requires additional excavation per depth of burial;

Increases maintenance problems and costs;

Provides additional thermal and radiation protection;

Increases final debris depth with increase in lid operating requirements;

Relocates hardened structure away from surface effects (loading may be more uniform and predictable).

Integral and Symmetrical Concepts vs. Separate Lid Design

Loading the same from any direction;

Analysis not dependent on direction;

Compatible with launchable lid or silo extension concepts;

Simplifies lid tie downs/locks;

Compatible with cold launch in-silo debris swallowing concept;

Requires crane(s) for lid removal for maintenance;

Compatible with lid fly-out concepts and lid tethering concept;

Due to undefined negative loading and phasing of directional loading an integral design is more appealing than a separate cap.

Above Ground Shaped Lids and Silo Caps

Some designs supposedly remain above any debris level and automatically shed the debris;

Above ground lid concepts are subjected to overpressure, reflected, refracted and dynamic loading which can be calculated according to present data;

The combination of above ground and below ground launch facility subjects the interface (ground/air) to severe bending along with other loadings.

7.0 DEVELOPMENT OF SUPERHARD CONCEPTS

The configurations on the following pages were evolved from the proposals shown in section 6.0 of this document. The Baseline Criteria used is that which is outlined in section 7.1 below.

7.1 BASELINE CRITERIA

a. Overpressure level at the ground surface of the launch facility is 33 1/3X psi.

b. The launch facility will be sited in competent rock.

c. The closure shall be designed to be opened within one minute, except that up to 15 minutes shall be permitted for maintenance purposes.

d. The silo opening shall be 15 feet in diameter.

e. The survival period shall be two months.

f. The debris level to be considered shall be ten feet per burst, for a total accumulation of thirty feet of debris.

7.2 PRELIMINARY 33 1/3X PRELIMINARY CONFIGURATIONS

The following concepts are an outgrowth of section 6.0 of this document. It shows an attempt to apply new configurations to superhard applications.

Each concept is evaluated and described on the face of the drawings.

It should be understood that no concept is in its ultimate geometrical form and that all configurations could be improved, subject to a more detailed study.

7.2.1 FIGURE 7.2-1 SPLIT SLAB CLOSURE

The split slab construction has three layers, each composed of concentric rings of high density concrete incased by steel. Centered over each of two outside half-lid tracks are two gas-operated actuators which on command separate the lid halves. The half-lid tracks serve only to guide the lid's movement, not to bear the lid's weight. The annular debris pit surrounding the silo and lid collects all debris that is shed from the lid's sloping top.

Th. lid can be transported to the launch site as six separate layer halves.

Splitting the closure lid offers several advantages:

- no adjacent cove is needed to harbor the lid in open position,
- half-lid tracks protected by lid require less hardening,
- actuator force is 50% of that required to move the entire lid horizontally.

Limitations of Figure 7.2-1 include:

- superhard lip necessary,
- superhard seal requirement,
- silo wall's exposure to blast wave.

7.2.2 FIGURE 7.2-2 SPLIT DOME CLOSURE

The split dome lid has two actuators which on command slide the two half-lids on rails. All debris slides from the domed lid into an annular debris pit which is sloped 30°. Thus, the shock traveling down the debris pit is diverted away from the silo walls and expends its large reflection overpressure on rock 20 to 30 ft. away from the silo.

The superhardened lip is simply a concrete donut strengthened with steel bar. The steel liner is thicker near the hole opening and wraps around the concrete donut.

The dome closure is placed 10 - 15 ft. below ground level so that: a. The hole opening can be "necked" by several feet, b. The asymmetrical drag pressure and reflected pressure felt by an object protruding above ground will be eliminated, and thus: c. A nearly symmetrical overpressure is felt by the dome.

A domed closure appears to offer three distinct advantages:

- weight savings
- transportation ease
- efficient structural use.

Basically, the dome closure is a thin steel hemisphere around which are two concentric hemispheres each built of rings of concrete incased by steel. Each ring or half ring can be transported separately to the launch facility site, thus demanding a carrier capable of transporting only 10 - 15% of total lid weight.

At the site the rings are stacked one upon another beginning with the ring of largest diameter. When constructed this dome offers a closure which is very resistant to overpressure, especially a symmetrical loading. In this situation the primary loading felt by each ring is a uniform compressive loading. The interface between any two rings lies along a radius of the dome. Thus, the greater the overpressure the harder the structural rings bind together to bear the load in compression. Because of this compressive binding, fractures or cracks in a ring due to debris penetration or to structural failure should not be as critical as in a silo structure. Also, multiple rings and multiple dome layers promise a high structural reliability.

For a split dome the outer ring-halves overlap like interlacing fingers to bear the meridional loads. The overpressure on the dome sides squeezes the dome halves together.

An interesting possibility in beyond-state-of-the-art materials is the use of Chemcor or Herculite II glass rings incased in a polymeric coating. Used in deep submergeable spheres, these materials show a compressive yield stress of $.8-1.25\times10^6$ psi.

The polymeric coating protects against surface scratches which lead to brittle fracture and allows the glass to bear tremendous compressive loads. Glass, besides supplying a light weight lid, could prove satisfactory as a radiation shield.

Some limitations of Figure 7.2-2 are:

- superhard lip necessary
- superhard seal requirement
- dome loading uncertainty due to variable shock azimuth.

7.2.3 FIGURE 7.2-3 BURIED DOME CLOSURE

At the time of construction the domed lid is buried under 20 - 30 ft.of sand or removable sand bags. Surrounding the lid in a complete circle is an explosively-loaded, expendable arch which on command is obliterated, allowing the sand plus 30 ft. of blast debris to fall into a 30° inclined annular debris pit. Four gas actuators push the dome half-lids up and over the rounded tension ring, leaving the silo open for launch.

Directed explosives in the expendable arch and explosive rope break up the sand and debris that may have hardened due to overpressure, ablation, time or a combustion thereof.

An outside power source is required to close the lid. This could be a truck portable block and tackle attached to the half-lid top and through the neck of the hole opening.

A bruied closure offers a number of advantages:

- The effective mass of the closure is greatly increased by the 20 - 30 ft. of burial sand. Thus, a less massive lid is required.

- The burial material provides radiation and ablation protection for the launch facility.

- Rigidity of the hole walls is increased.

- The filled hole prevents an overpressure shock from traveling down the hole un-attenuated.

- Burial makes enemy detection difficult.

Limitations of Figure 7.2-3 include:

- Greater hole depth required,

- Uncertainty of explosives,

- Removal of burial material for maintenance.

7.2.4 FIGURE 7.2-4 BURIED HARD MOUNTAIN CLOSURE

This hard mountain buried closure functions similarly to Configuration III. Upon command the explosive arch is obliterated allowing the 20 - 50 ft. of burial sand any any hill-side debris to fall into the debris pit. Three actuators withdraw a hinged lid stop allowing the lid, guided by two tracks, to fall into the pit leaving the silo clear for launch.

The lid is constructed of two layers which are made of parallel laid steel I-beams. The lid must be strengthened locally in the area that serves as a support for one base of the explosive arch. An outside power source, such as a block and tackle device, is required to close the lid; however, hole depth and mountain slope could be complications.

The advantages of a buried hard mountain closure are the same as those listed for Figure 7.2-3. Disadvantages include:

- Possible hardening of burial material,
- Removal of burial material for maintenance,
- Construction of a very large debris pit.

USE FOR TYPEWRITTEN MATERIAL ONLY

FIGURES 7.2-5A AND 7.2-5B WATER SUBMERGED CONCEPTS

7.2.5 The water submerged concept consists of an encapulated missile with an integral closure. The missile container is anchored in rock with closure lid submerged in the fluid of the debris pit provided.

Another configuration shows the missile suspended in a fluid where the entire cavity surrounding the missile container is the debris pit.

Advantages: open pit filled with a fluid to protect silo from the effects of the nuclear blast (heat radiation, and shock wave).

Disadvantages: water seals for the pressure vessal, fluid storage and maintenance provisions.

USE FOR TYPEWRITTEN MATERIAL ONLY

FIGURE 7.2.-6 VERTICAL LIFT CONCEPT

7.2.6 FUNCTIONAL DESCRIPTION

The concept shown in Figure 7.2-6 is developed from Figure 6.1-7. The idea in this concept is to vertically push the missile tube through 30 to 35 feet of debris. Once the missile tube closure is above the debris, (about 10 feet), the silo lid would be rotated to clear the missile opening for launch of missile.

The simplicity of the concept is lessened by the vertical thrust required to push through the debris - approximately 12,000,000 pounds.

FIGURE 7.2-7 CLAMSHELL CLOSURE

7.2.7 FUNCTION DESCRIPTION:

After multiple nuclear burst the silo closure is covered with debris. Upon command the missile tube is pushed through to clear the debris level. The closure is opened by an actuator system for missile launch.

Advantage:

This concept allows the closure and missile container to be constructed as a unit. The clamshell shaped closure, after the initial break, will penetrate the debris with less effort than a flat top surface lid. The closure configuration provides a positive-lock device.

Disadvantage:

Power requirements are high. The missile silo and container must be designed as a telescoping system and strong enough to take column action.

NOTE: To push through 35 feet of debris requires a force of 12,000,000 pounds approximately.

Summary:

The clamshell closure concept with silo and missile container buried in soil could be effective for superhard applications.

FIGURE 7.2-8 CYLINDRICAL SILO CLOSURE

7.2.8 FUNCTIONAL DESCRIPTION:

In the cylindrical silo closure the lid rotates 60° clockwise by means of an actuator to align the fifteen foot diameter opening in the lid with the silo opening for missile launch. See Figure 7.2-8A, 8B and 8C.

Advantage:

The concept has good debris control, the debris slides down into the pit by way of the sloping silo lid surface. It is protected from pressure effects. The closure system provides good bearing surface for the lid. Moderate power required - approximately 400 hp.

Disadvantage:

The debris pit must be large and hardened to prevent collapse during several nuclear bursts. The lid must have a large diameter to accommodate the missile launch opening and provide sufficient bearing surface for the closure system.

FIGURE 7.2-9 SPHERICAL SILO LID CLOSURE

7.2.9 FUNCTIONAL DESCRIPTION:

The spherical silo lid function is the same as the cylindrical rotating silo lid closure. See Figure 7.2-8A.

Advantages:

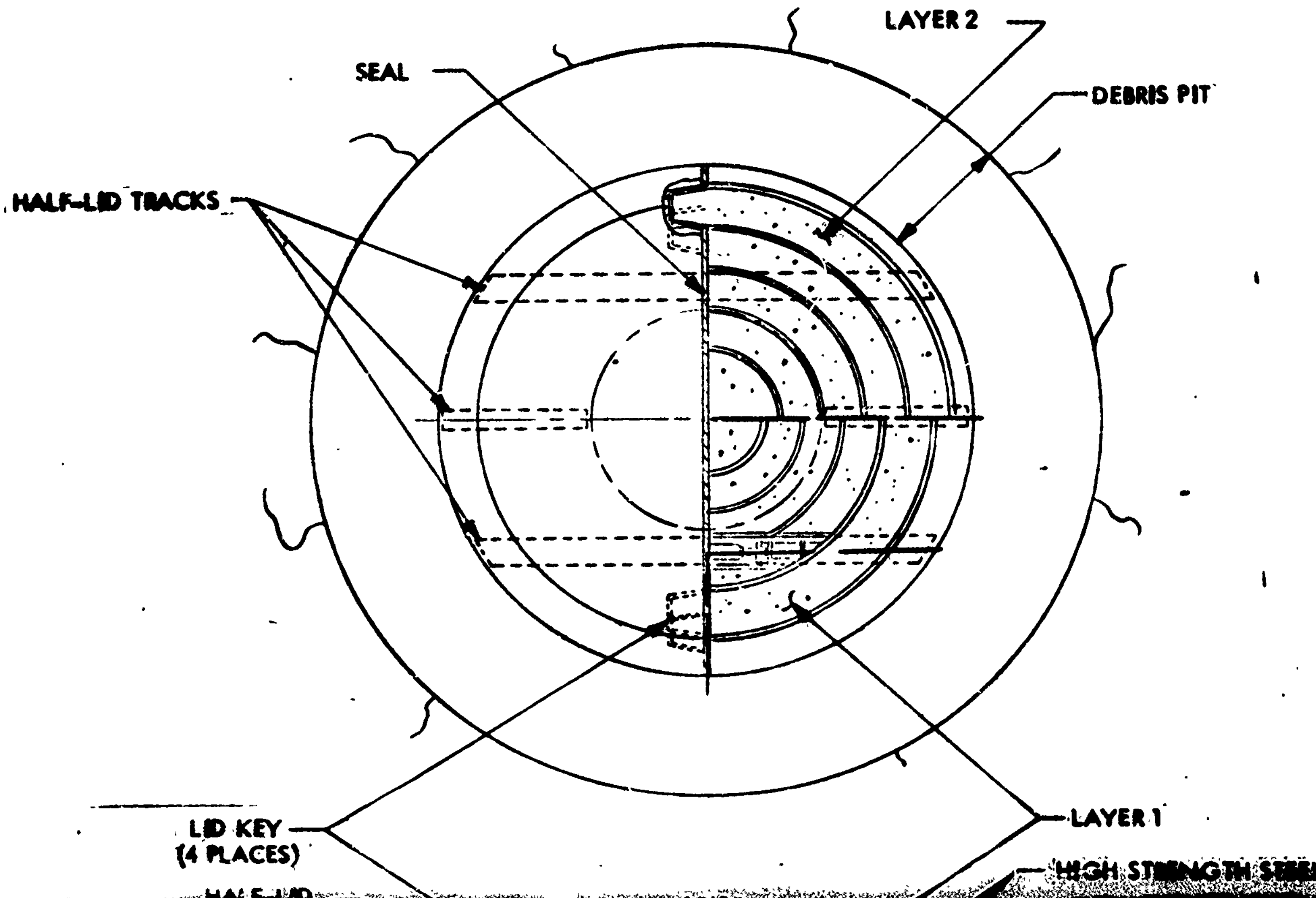
The spherical silo lid concept provides a greater bearing surface and a stronger structural section.

Disadvantages:

Same as Figure 7.2-8A

Summary:

The spherical silo lid could possibly be used in a superhard environment.


LAYER 2
SEAL
DEBRIS PIT
HALF-LID TRACKS
LID KEY
(4 PLACES)
LAYER 1
HIGH STRENGTH STEEL

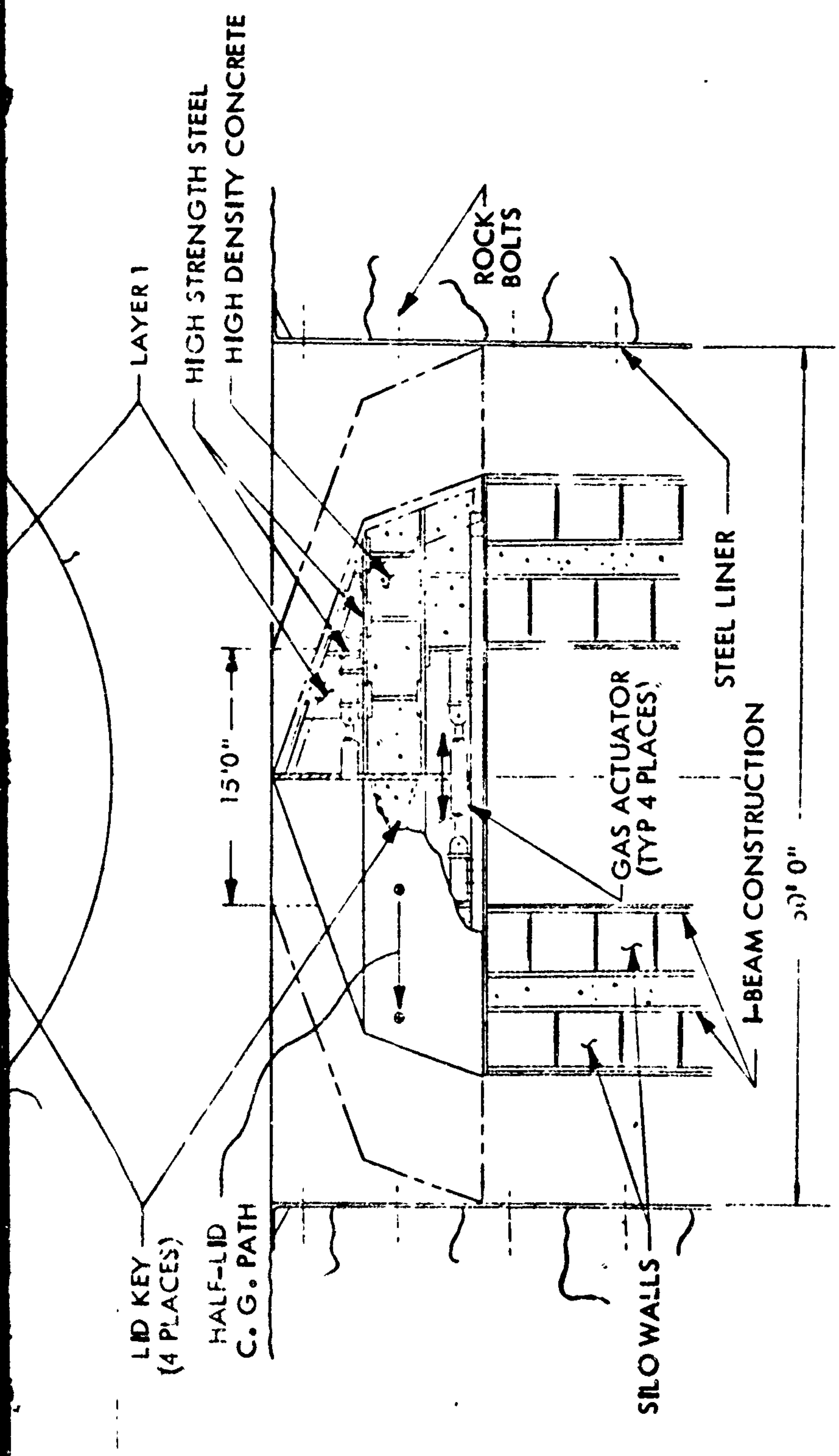
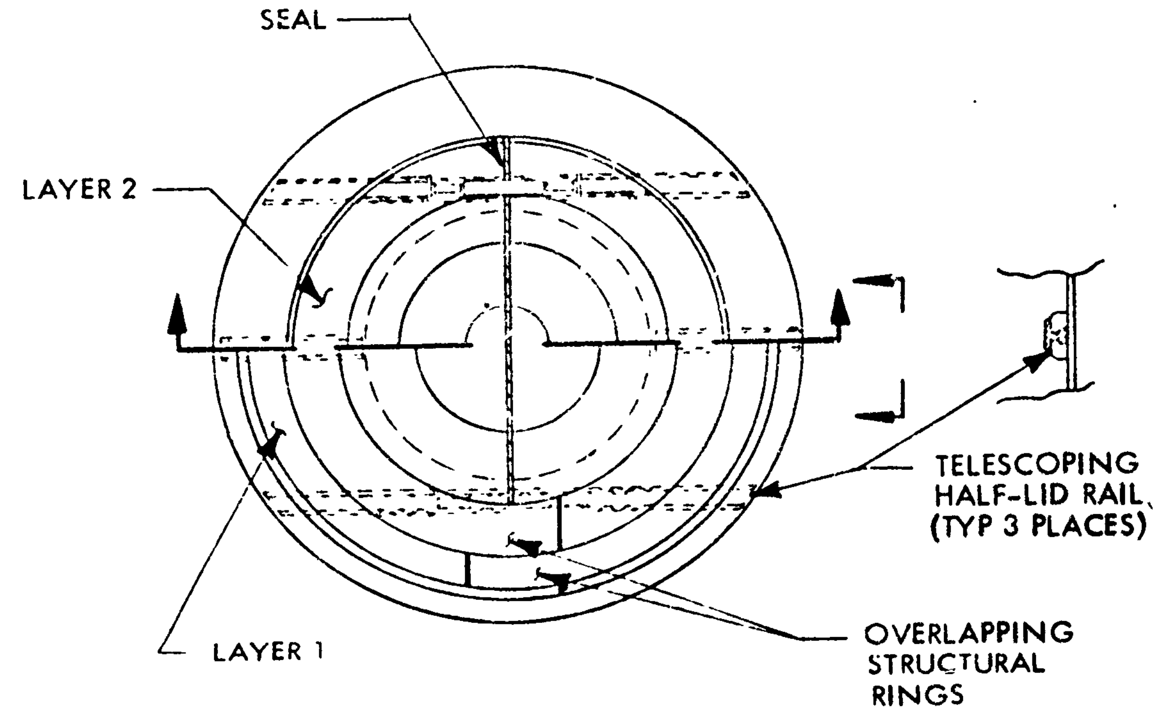
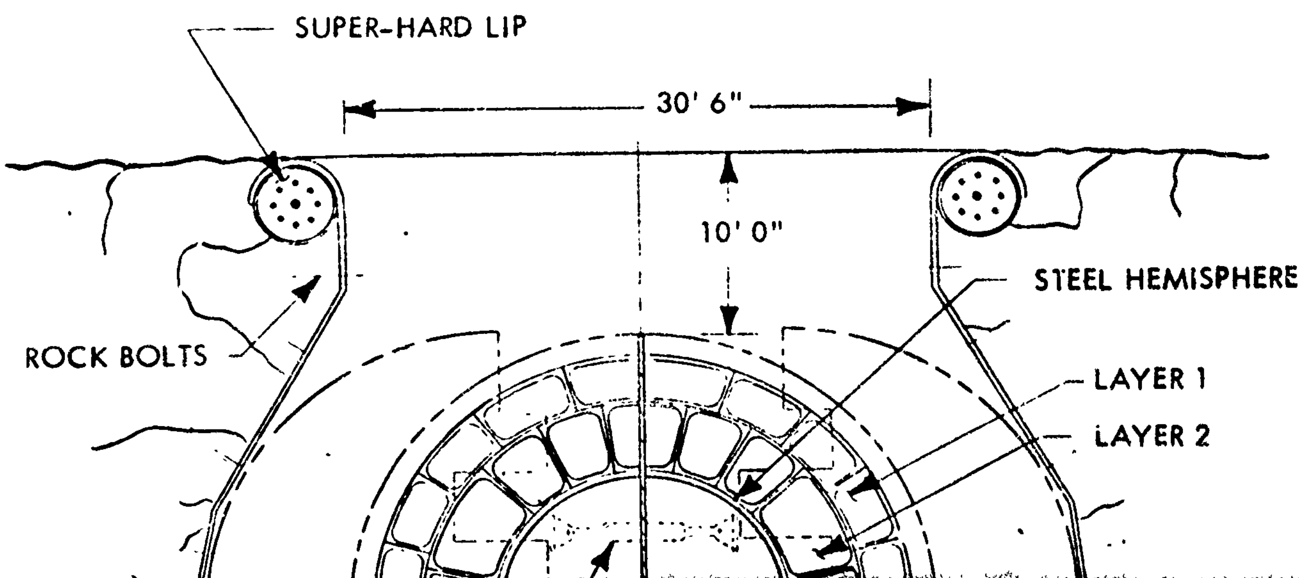


FIGURE 7.2-1
SPLIT SLAB CLOSURE


SEAL
LAYER 2
LAYER 1
TELESCOPING HALF-LID RAIL (TYP 3 PLACES)
OVERLAPPING STRUCTURAL RINGS


SUPER-HARD LIP
30' 6"
10' 0"
STEEL HEMISPHERE
ROCK BOLTS
LAYER 1
LAYER 2

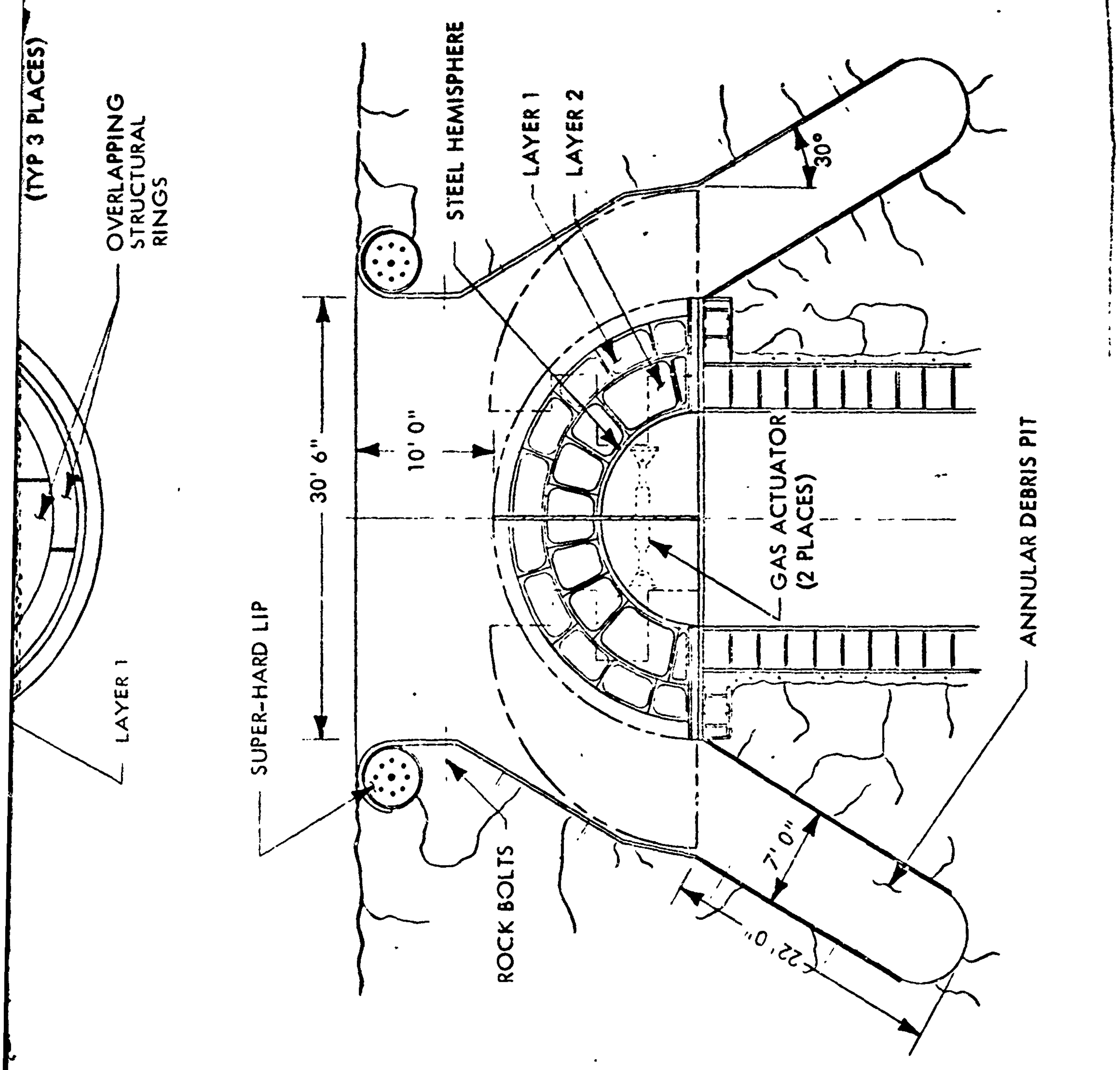
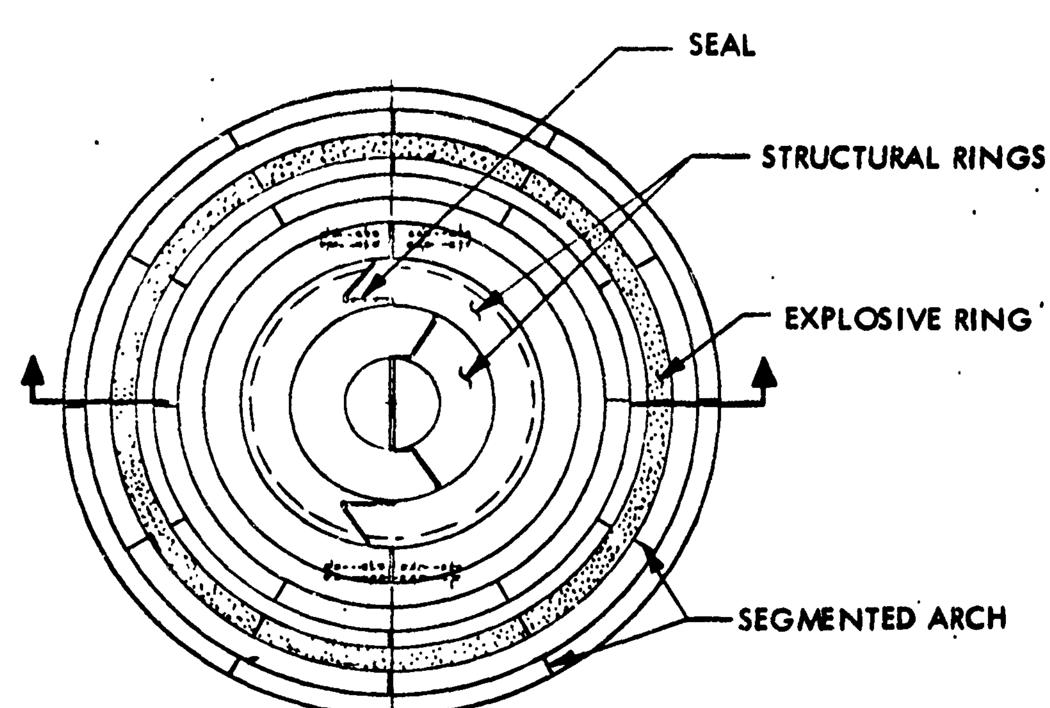
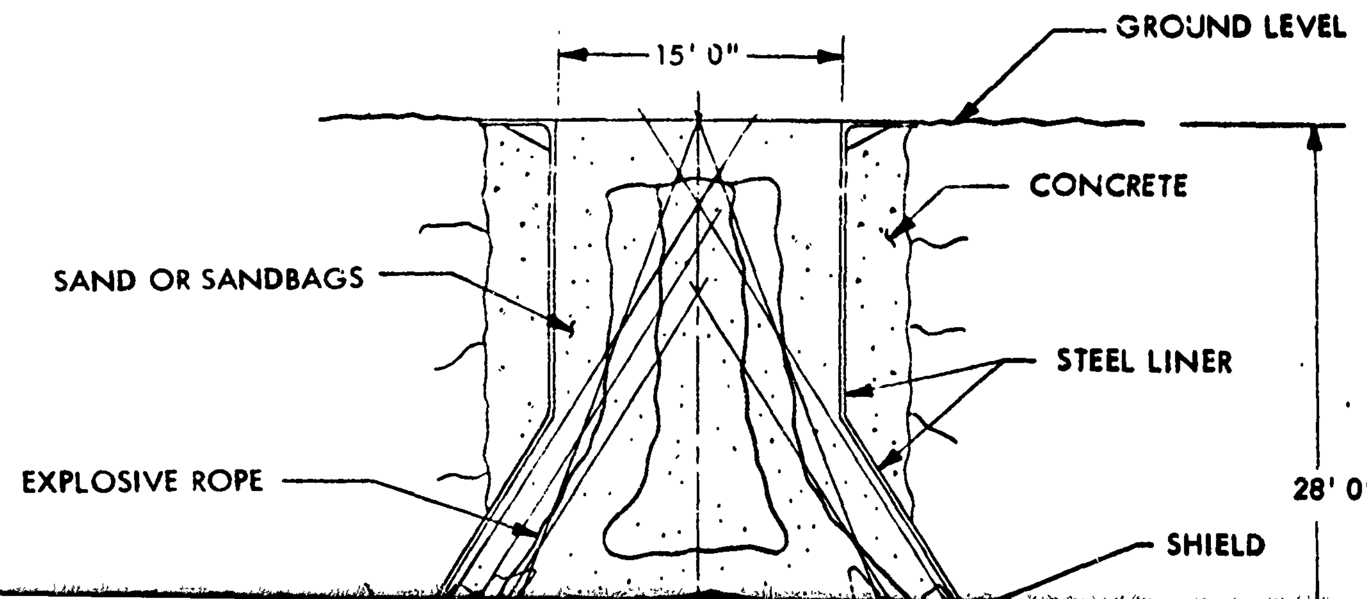


FIGURE 7.2-2
SPLIT DOME CLOSURE



(SHIELD REMOVED)



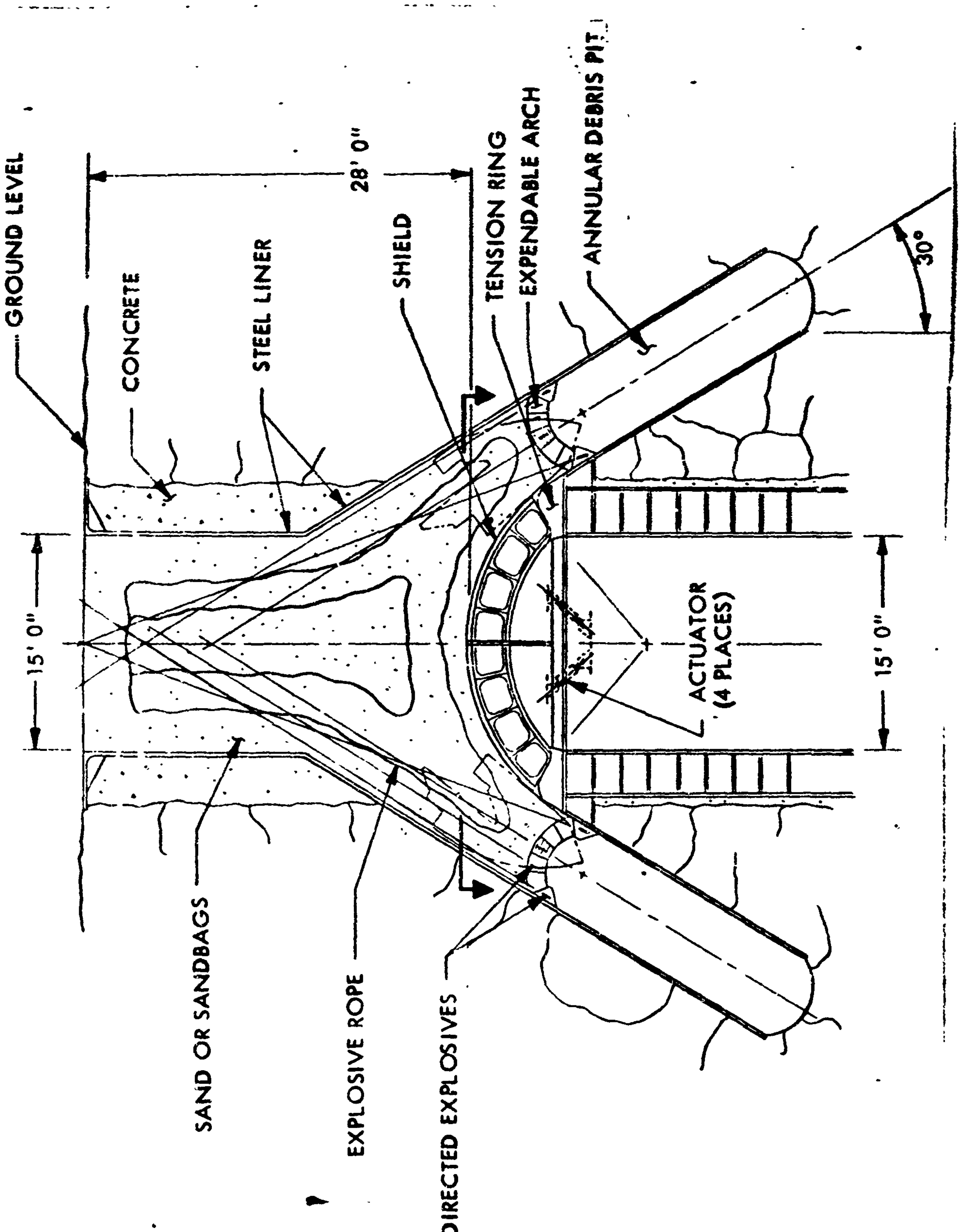
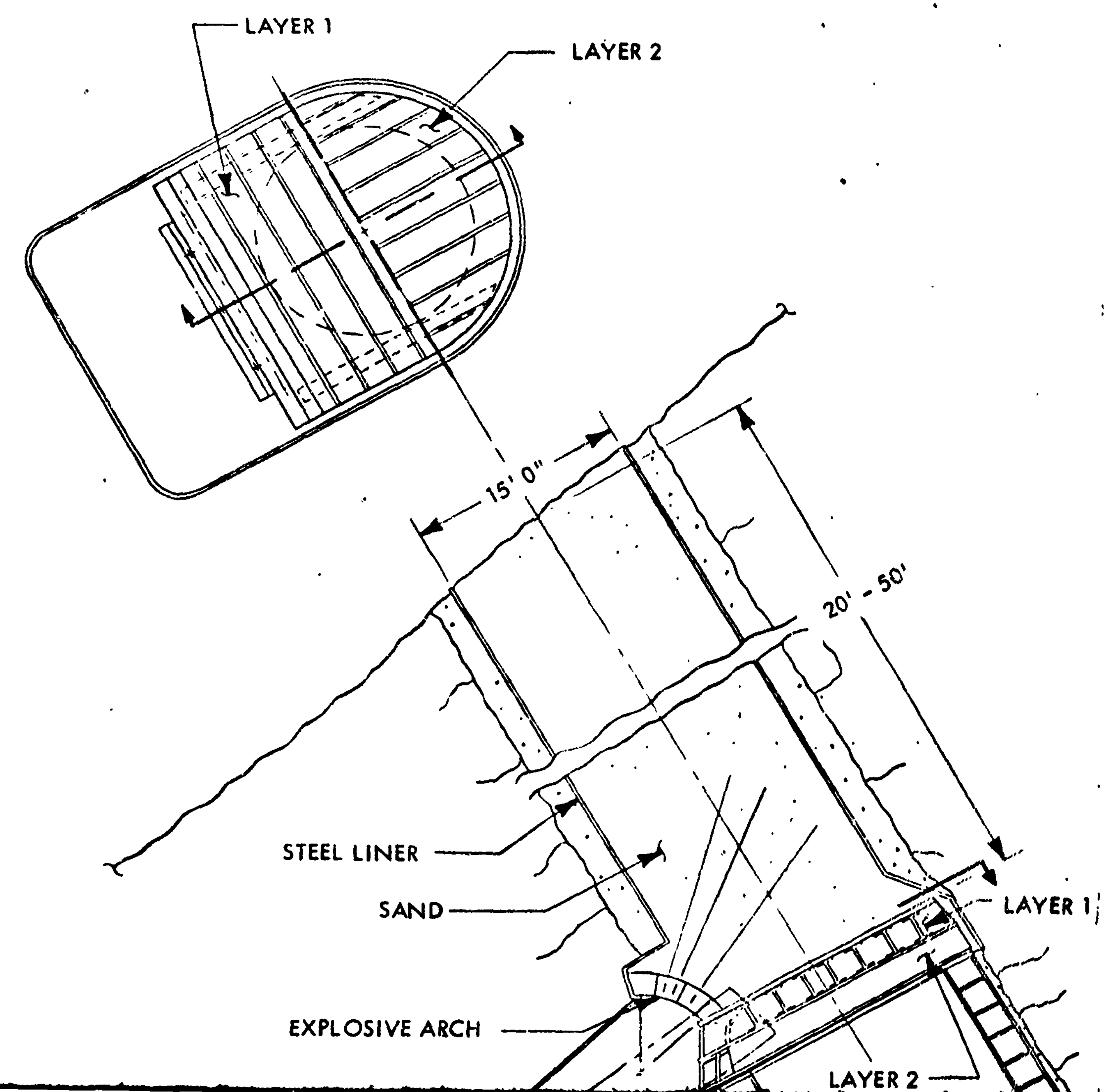


FIGURE 7.2-3
BURIED DOME CLOSURE


LAYER 1
LAYER 2
15' 0"
20' - 50'
STEEL LINER
SAND
LAYER 1
EXPLOSIVE ARCH
LAYER 2

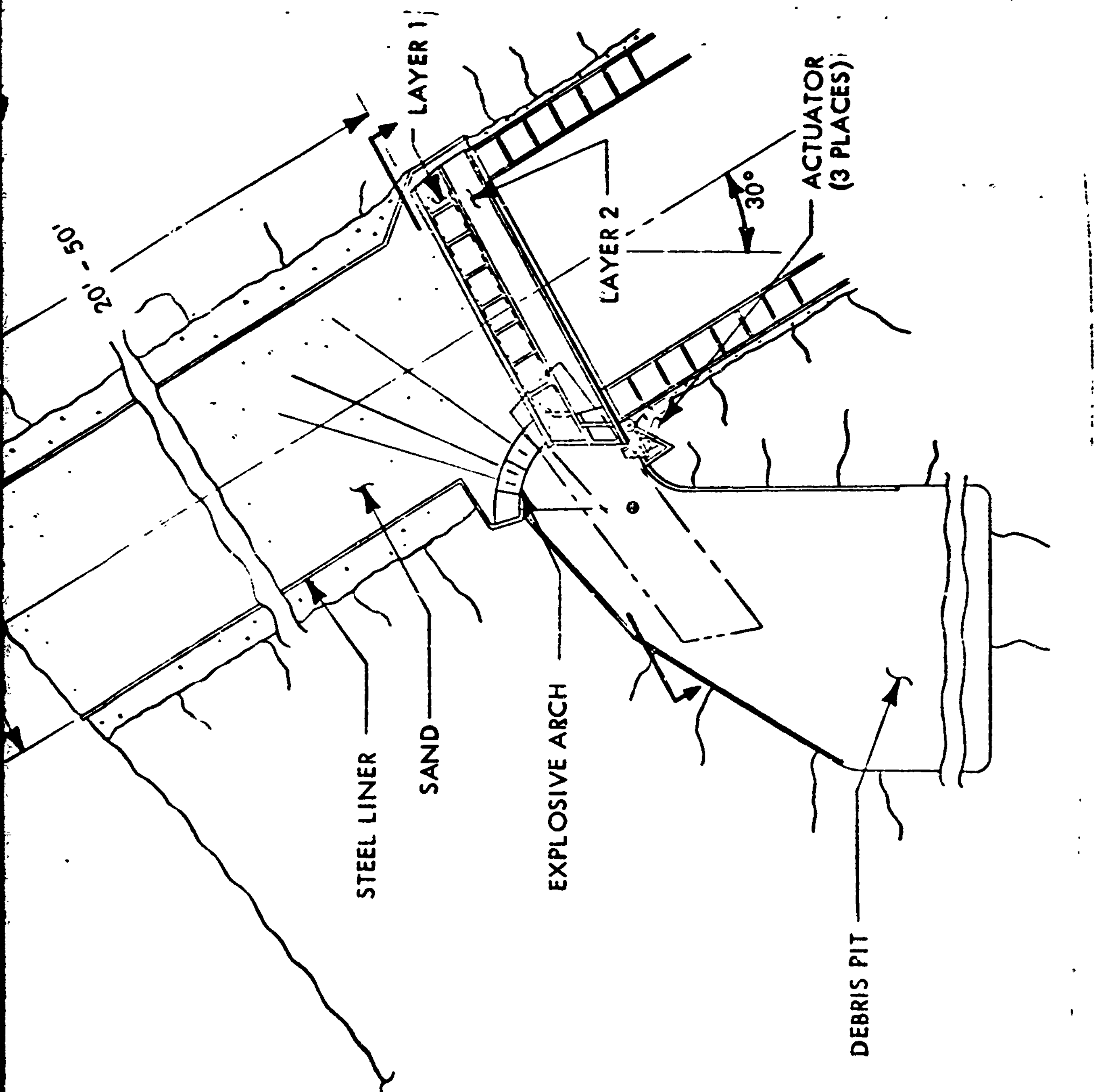
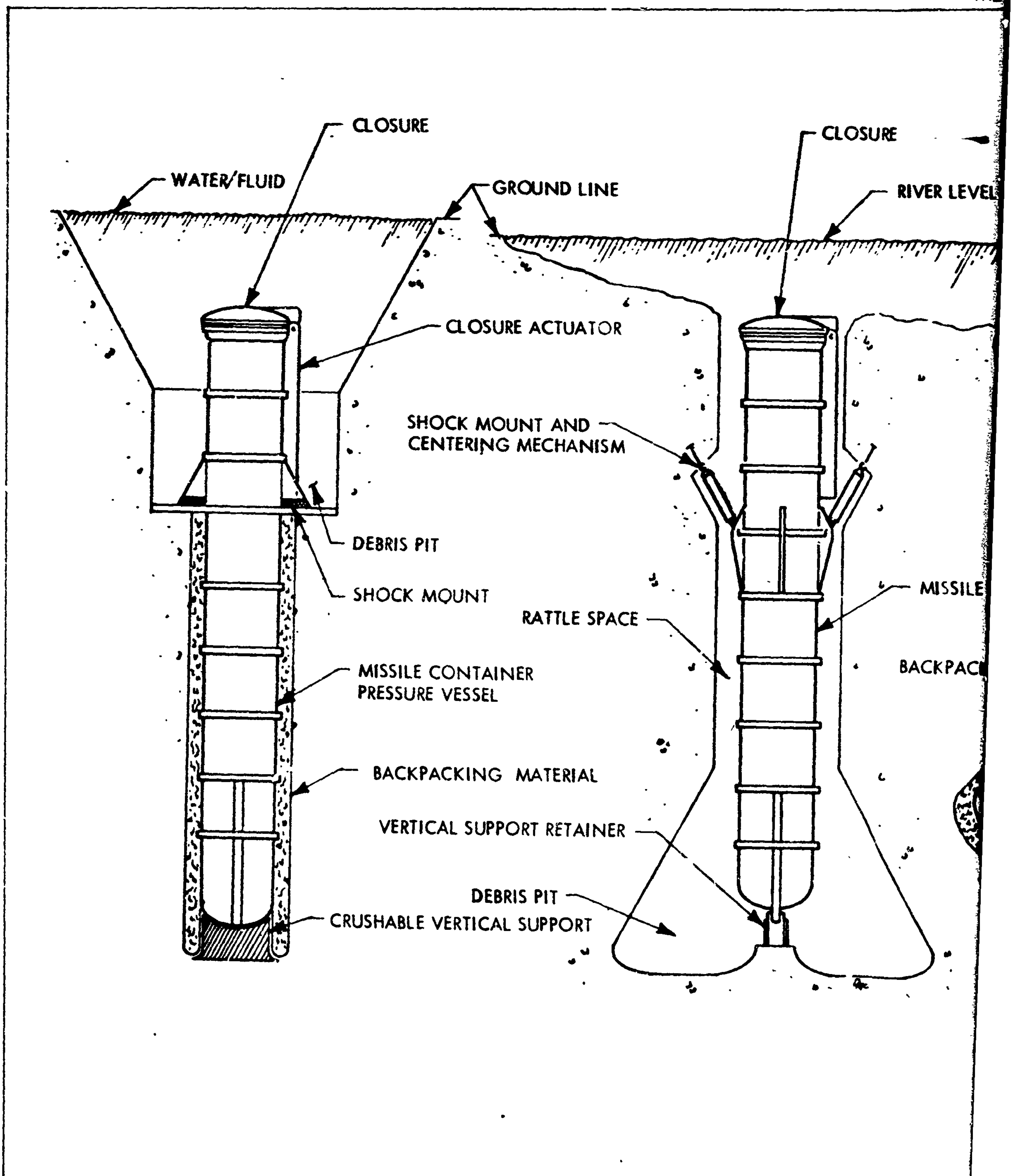
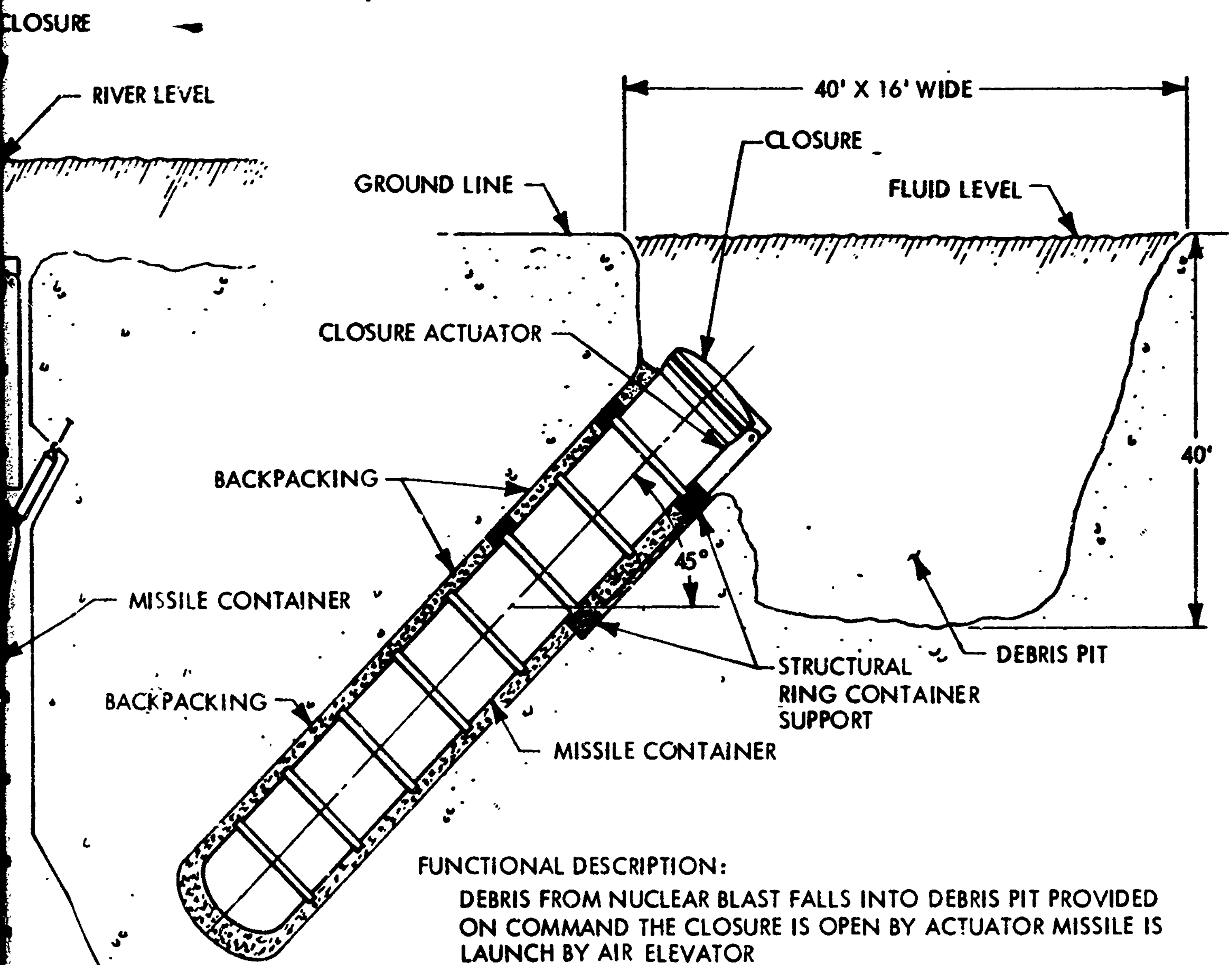


FIGURE 7.2-4
BURIED HARD MOUNTAIN CLOSURE


CLOSURE
WATER/FLUID
GROUND LINE
CLOSURE ACTUATOR
DEBRIS PIT
SHOCK MOUNT
MISSILE CONTAINER
PRESSURE VESSEL
BACKPACKING MATERIAL
CRUSHABLE VERTICAL SUPPORT
CLOSURE
RIVER LEVEL
SHOCK MOUNT AND
CENTERING MECHANISM
MISSILE
RATTLE SPACE
BACKPAC
VERTICAL SUPPORT RETAINER
DEBRIS PIT



FUNCTIONAL DESCRIPTION:

DEBRIS FROM NUCLEAR BLAST FALLS INTO DEBRIS PIT PROVIDED ON COMMAND THE CLOSURE IS OPEN BY ACTUATOR MISSILE IS LAUNCH BY AIR ELEVATOR

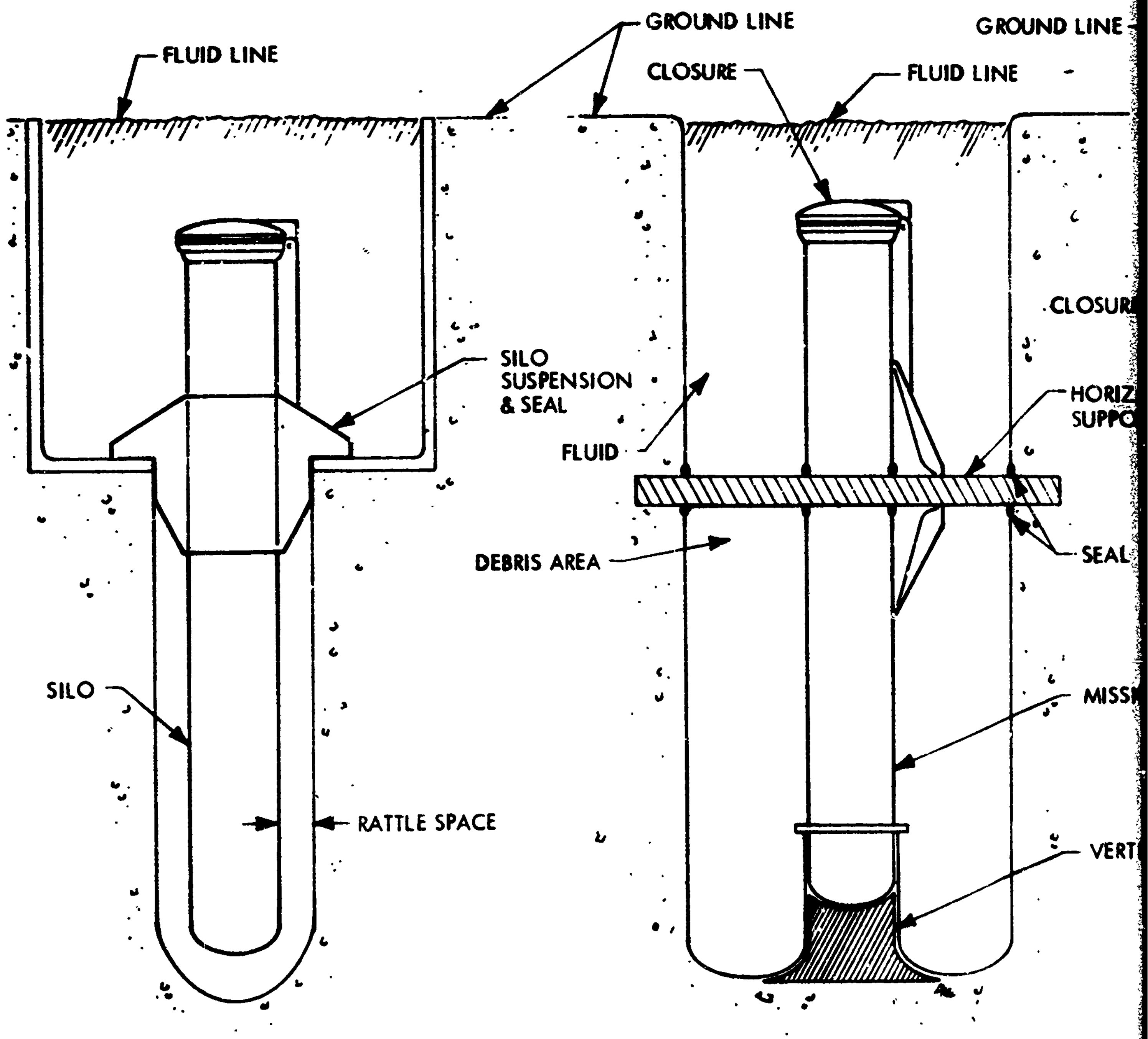
ADVANTAGE

(AS MEANS OF ATTENUATING HEAT AND RADIATION EFFECTS) IN ADDITION TO PROVIDING A DEBRIS PIT FLUID ACT AS BACKPACKING, MODERATE POWER REQUIRED

DISADVANTAGE

MISSILE CONTAINER MUST BE DESIGNED AS A WATER SEALED PRESSURE VESSEL/FLUID MUST BE KEPT IN A LIQUID STATE. CLOSURE ACTUATOR REQUIRED TO OPERATE IN A LIQUID.

FIGURE 7.2-
WATER SUBMERGED CONCEPT



ADVANTAGE & DISADVANTAGE
SAME AS FIGURE 7-5

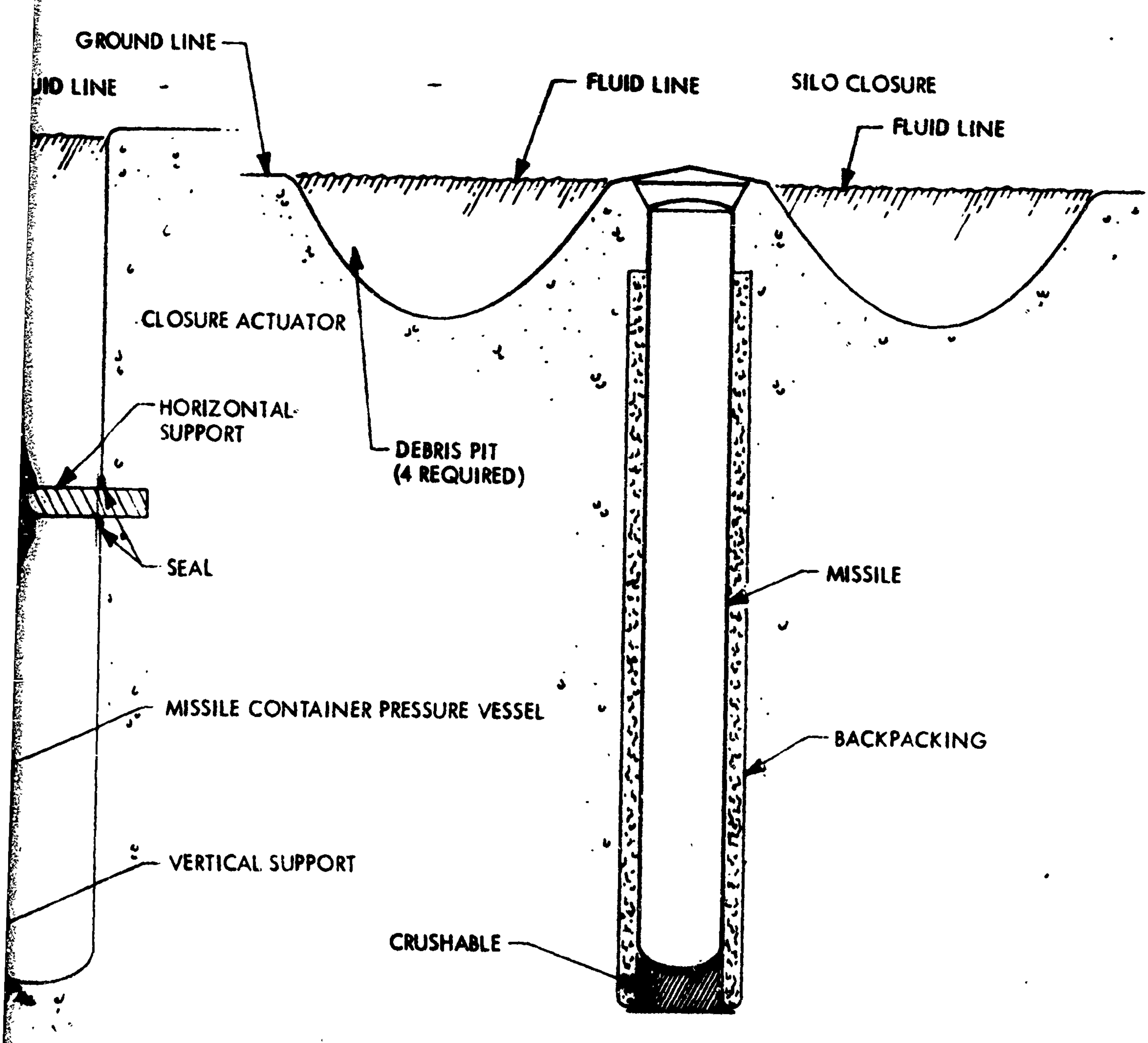
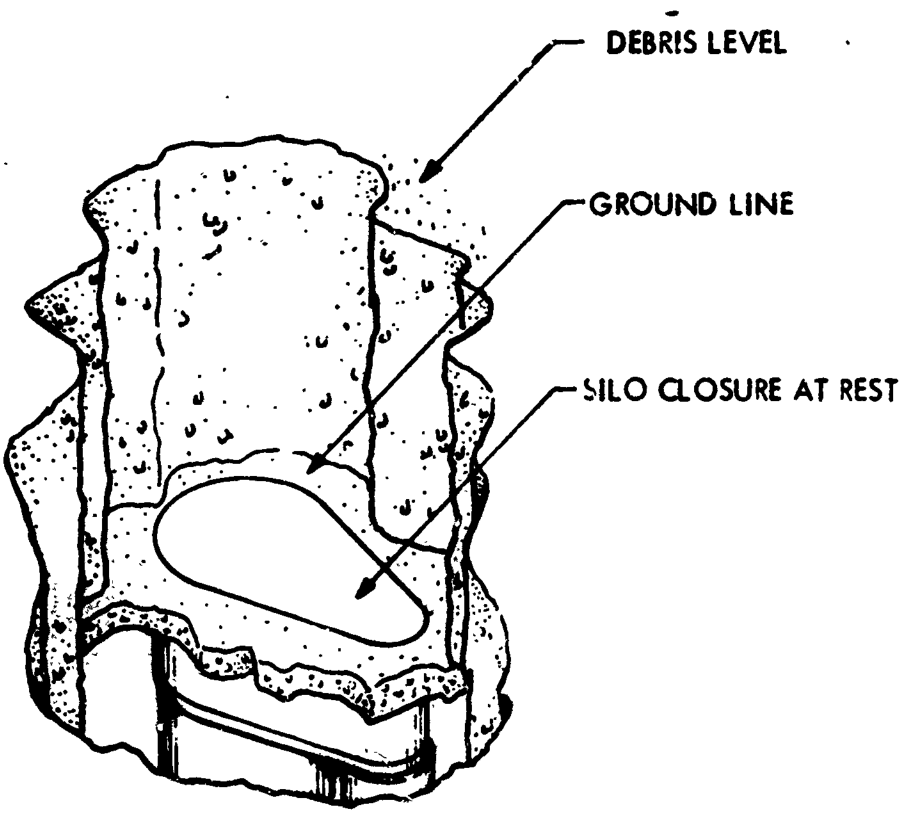
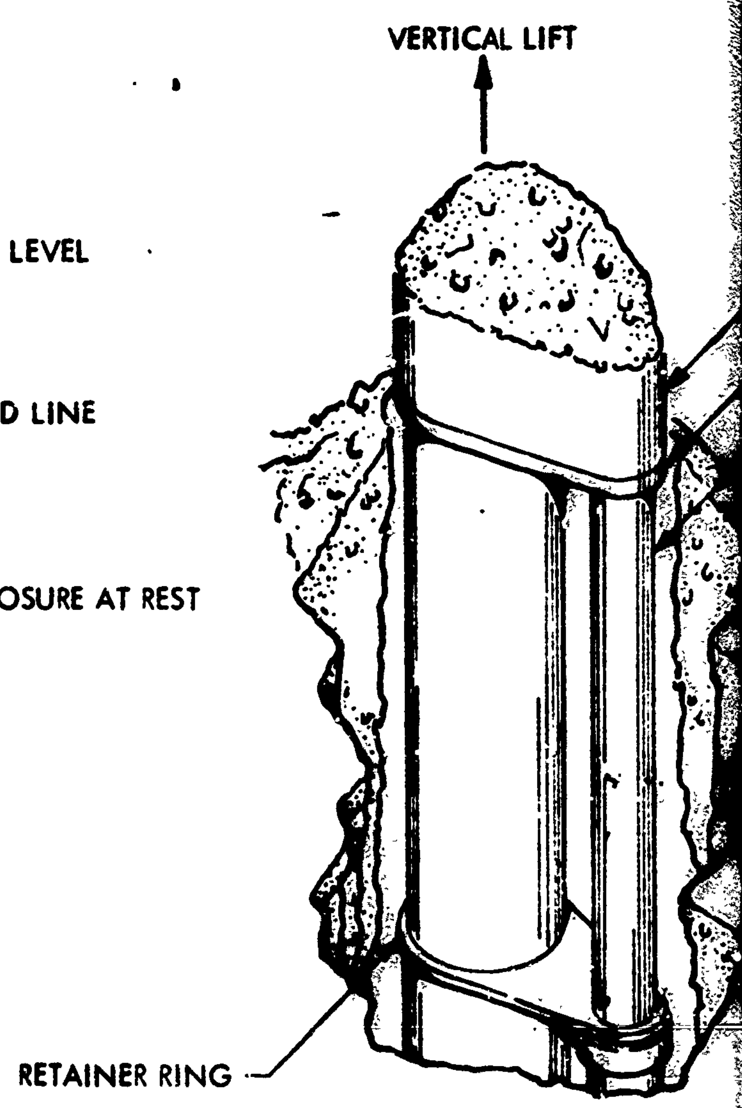


FIGURE 7.[illegible]A
WATER SUBMERGED CONCEPTS

THE



SILO CLOSURE @ REST



SILO CLOSURE AND
MISSILE CONTAINER RAISED POS

FUNCTIONAL DESCRIPTION:

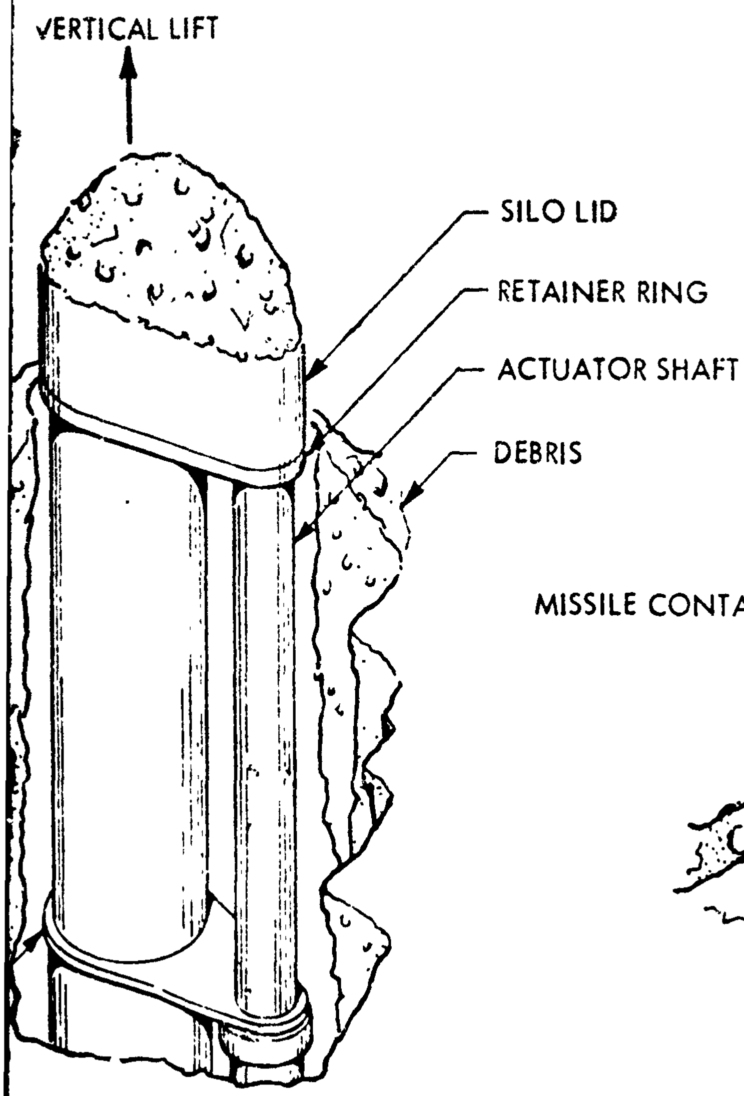
THIS LID IS COMPLETELY FLUSH WITH THE GROUND SURFACE. ON COMMAND THE MISSILE CONTAINER AND ACTUATOR SHAFT IS PUSHED UPWARD THRU THE DEBRIS AND ROTATES LID TO CLEAR THE SILO OPENING.

ADVANTAGE:

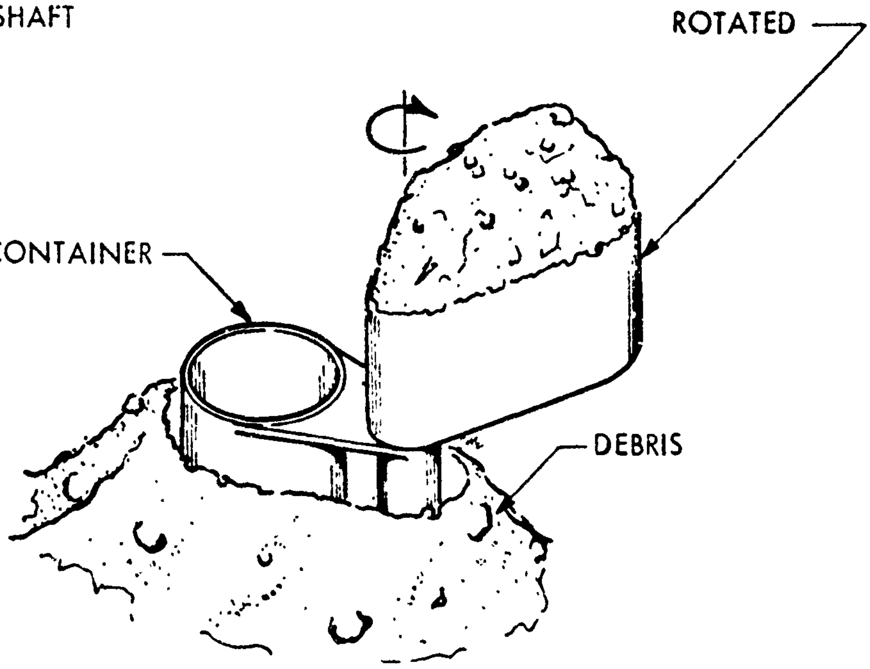
PROVIDES PROTECTION AGAINST DYNAMIC AND REFLECTED PRESSURE.

DISADVANTAGE:

VERTICAL LIFT REQUIRES A LARGE POWER SO ACTUATOR SHAFT AND MISSILE CONTAINER BE DESIGNED TO CARRY CANTILEVER LOADS MISSILE TUBE WILL BE SUBJECT TO LARGE MOMENTS. NO HANDLING OF DEBRIS PROVI THE FLAT SURFACE OF THE CLOSURE MAKES DIFFICULT TO PENETRATE FROZEN OR INTERL DEBRIS.



SILO CLOSURE AND
LE CONTAINER RAISED POSITION



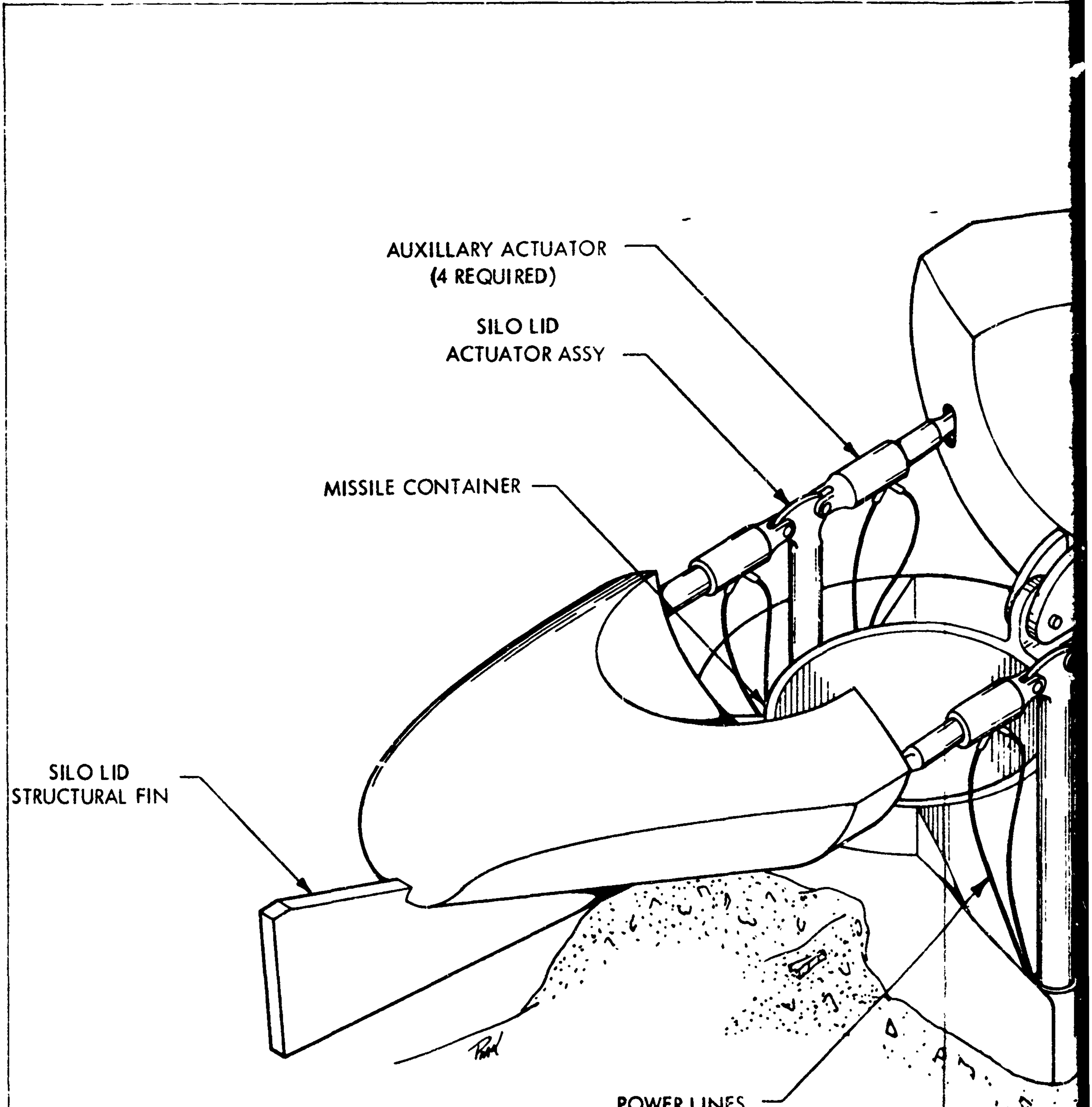
SILO CLOSURE RAISED AND ROTATED

UIRES A LARGE POWER SOURCE.
AND MISSILE CONTAINER MUST
CARRY CANTILEVER LOADS.
BE SUBJECT TO LARGE BENDING
NDLING OF DEBRIS PROVIDED.
OF THE CLOSURE MAKES IT
TRATE FROZEN OR INTERLOCKED

SUMMARY:

A MODIFIED VERSION MAY BE USED TO HANDLE LOWER DEBRIS LEVELS.

FIGURE 7.? -
VERTICAL LIFT CONCEPT


AUXILLARY ACTUATOR
(4 REQUIRED)
SILO LID
ACTUATOR ASSY
MISSILE CONTAINER
SILO LID
STRUCTURAL FIN
POWER LINES
PNEMATIC

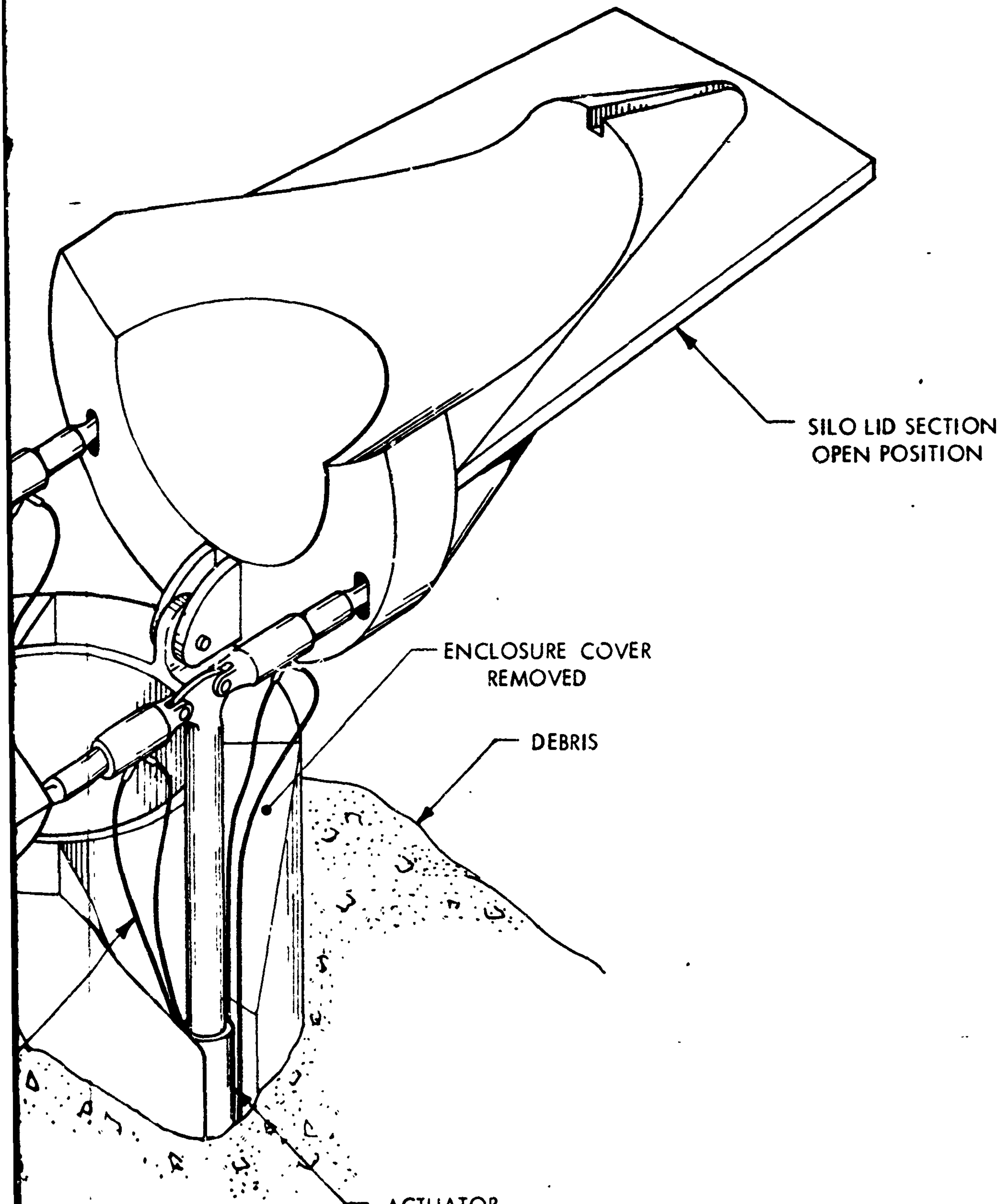
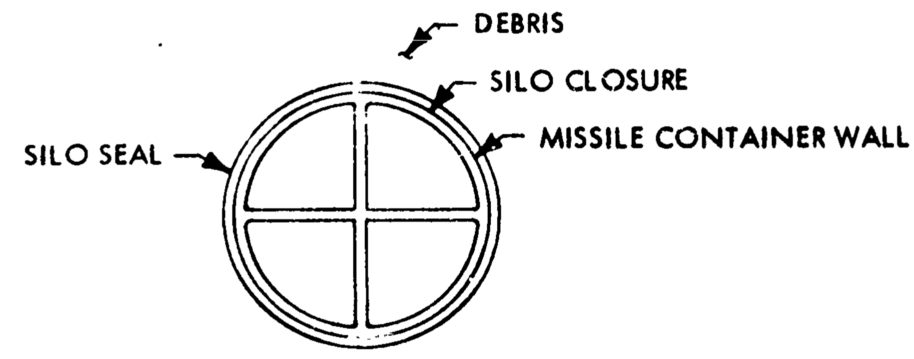
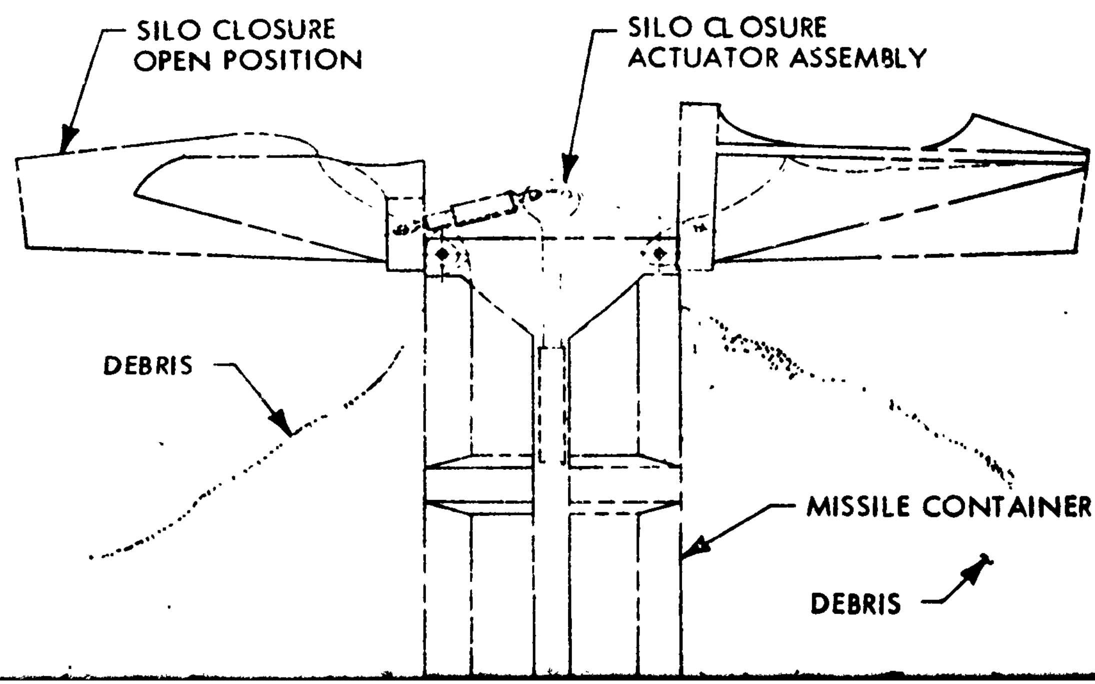


FIGURE 7.. .
CLAMSHELL SILO CLOSURE
(RAISED AND OPENED POSITION)


DEBRIS
SILO CLOSURE
MISSILE CONTAINER WALL
SILO SEAL

PLAN


SILO CLOSURE
OPEN POSITION
SILO CLOSURE
ACTUATOR ASSEMBLY
DEBRIS
MISSILE CONTAINER
DEBRIS

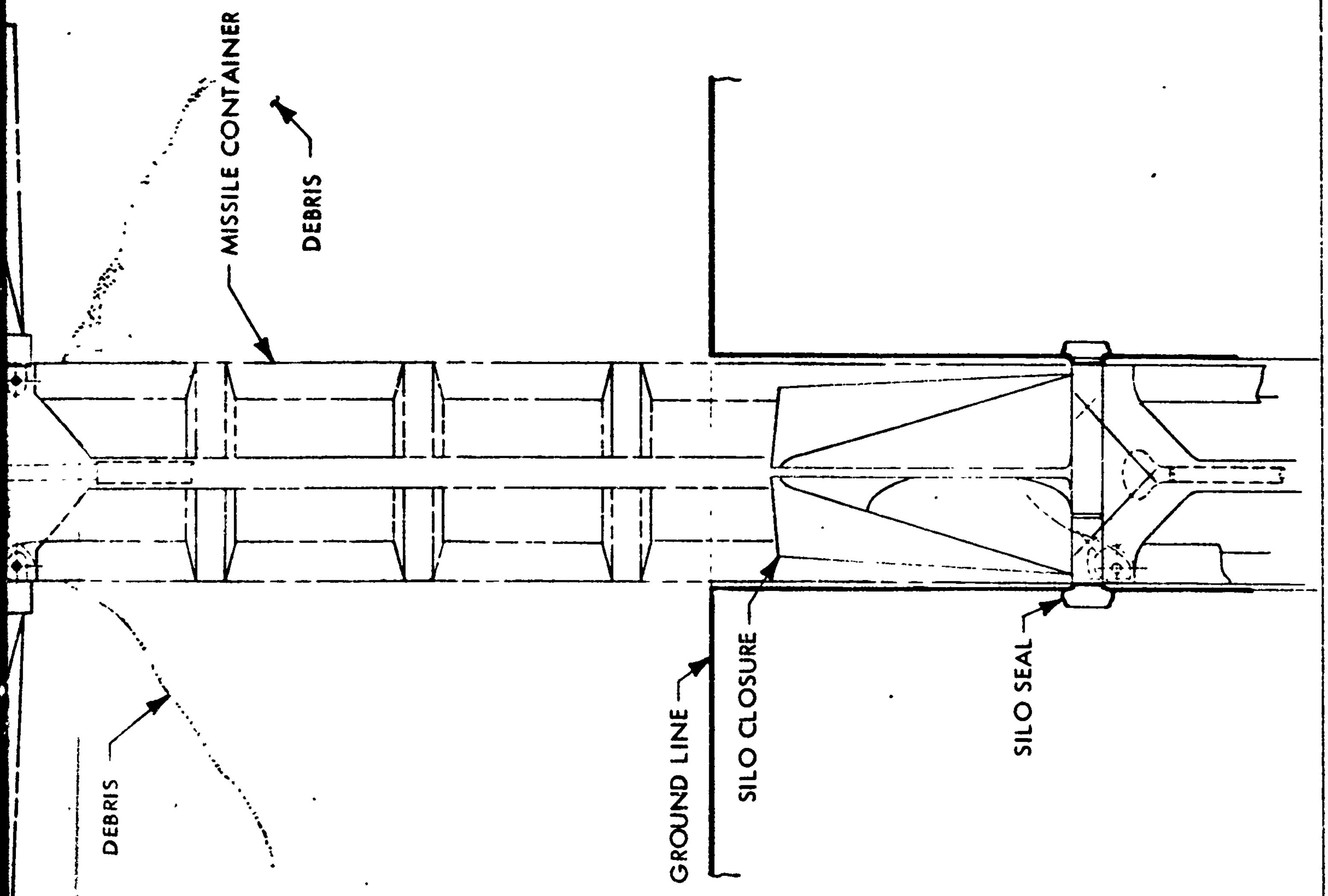


FIGURE 7. 7A
CLAMSHELL SILO CLOSURE

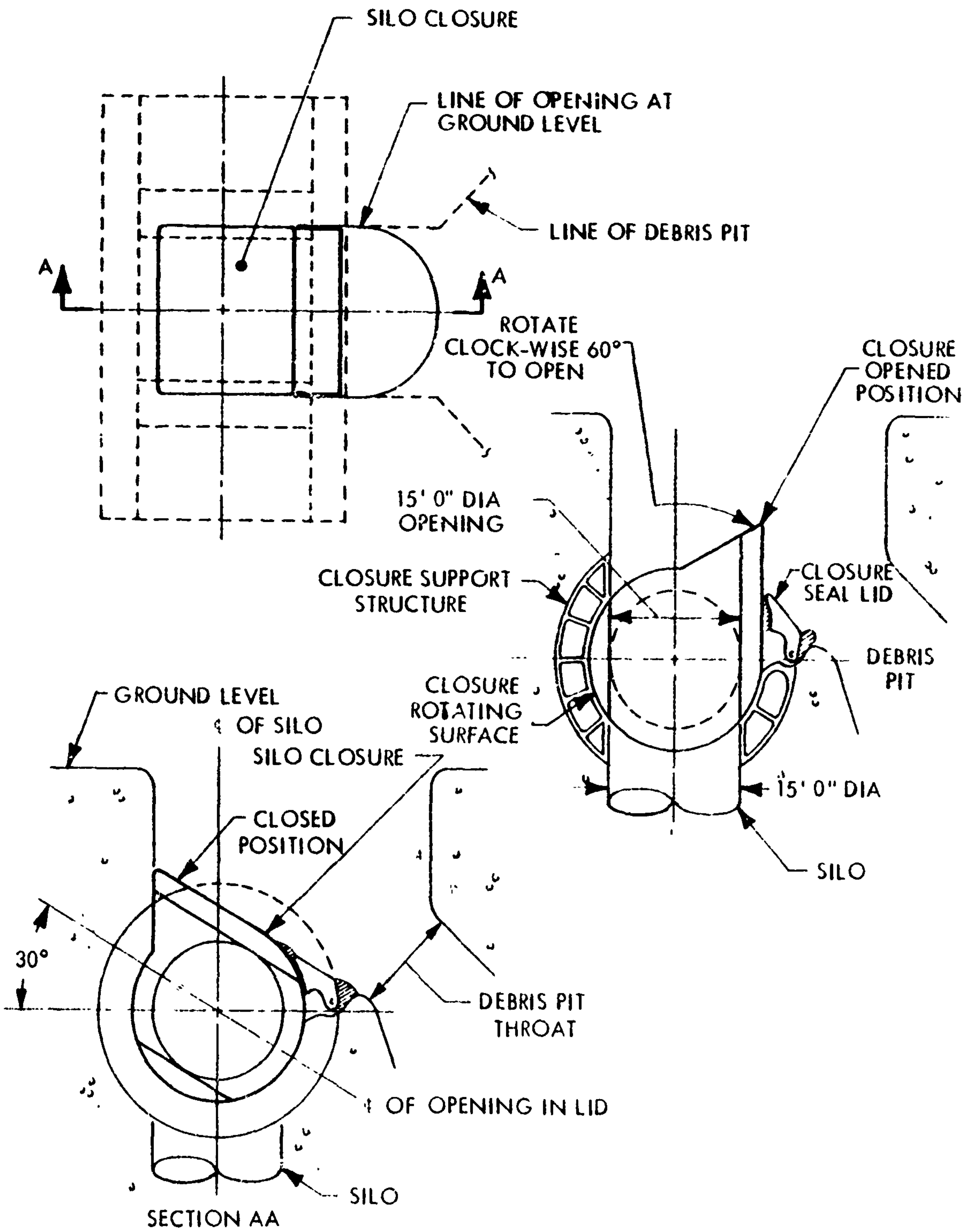


FIGURE 7.2-8A
ROTATING CYLINDRICAL LID CONCEPT

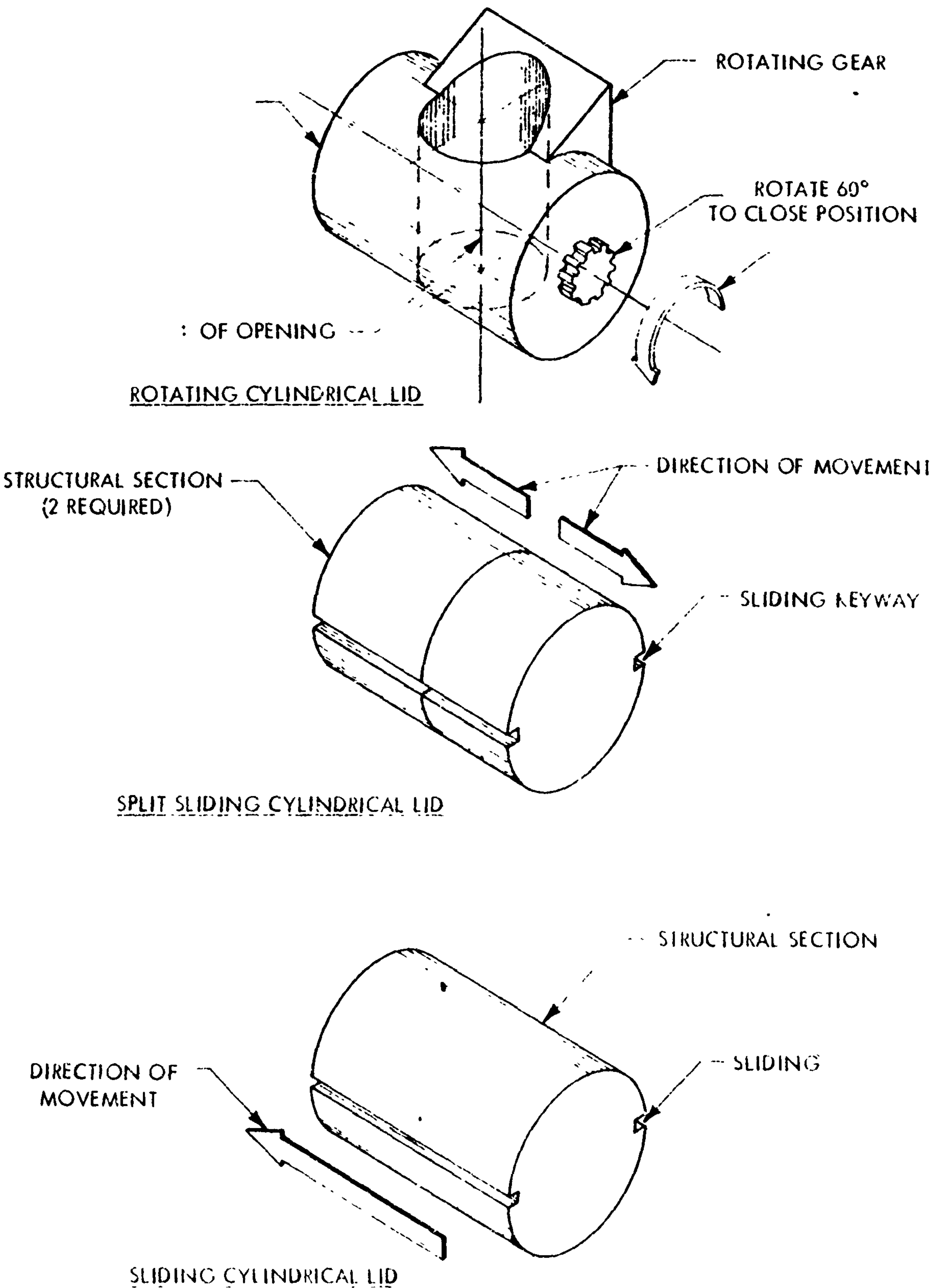
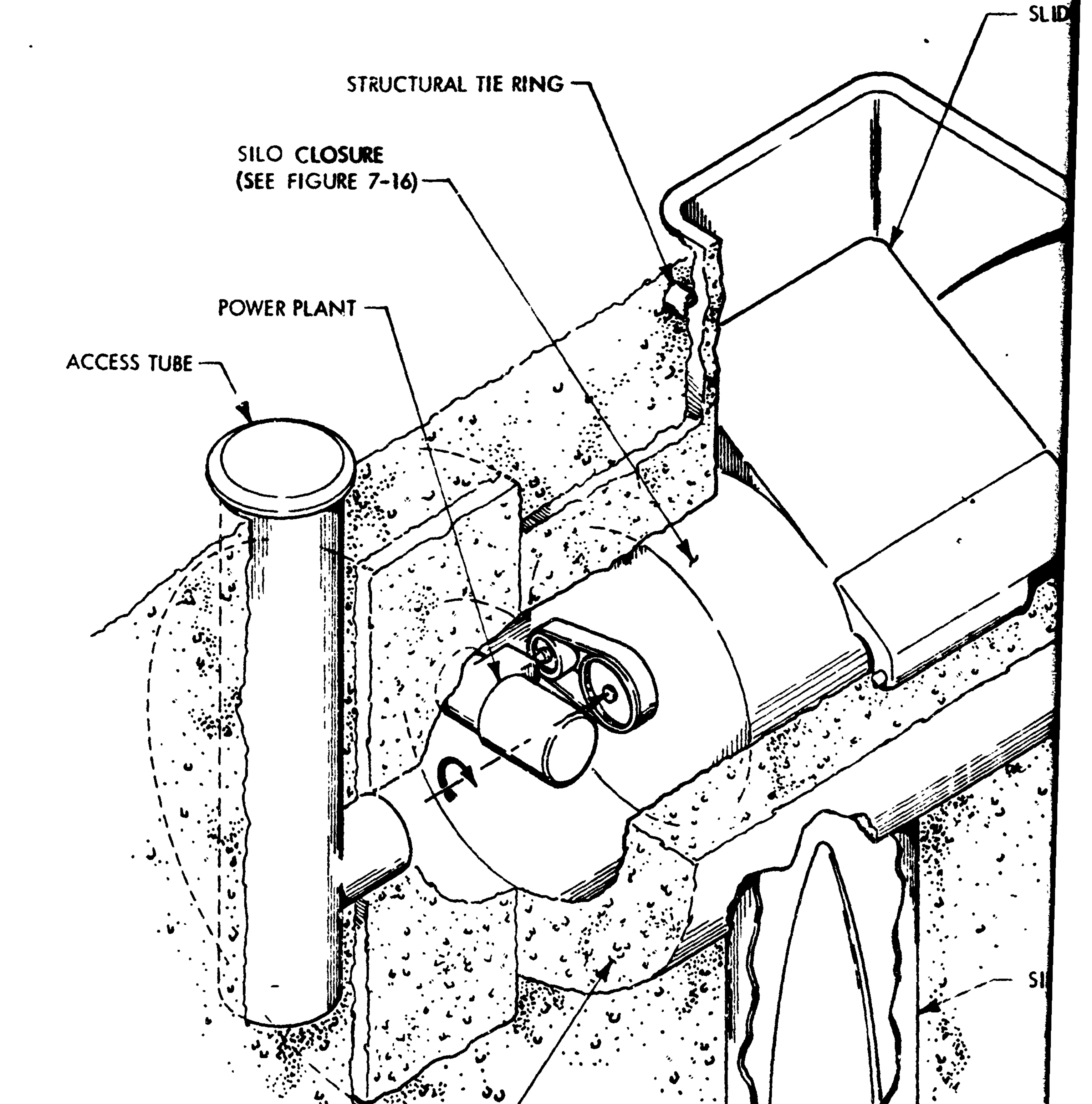


FIGURE 7.2-8B

CYLINDRICAL CLOSURE CONCEPTS


SLID
STRUCTURAL TIE RING
SILO CLOSURE
(SEE FIGURE 7-16)
POWER PLANT
ACCESS TUBE
SI
LID REINFORCE CONCRETE SUPPORT CYLINDER

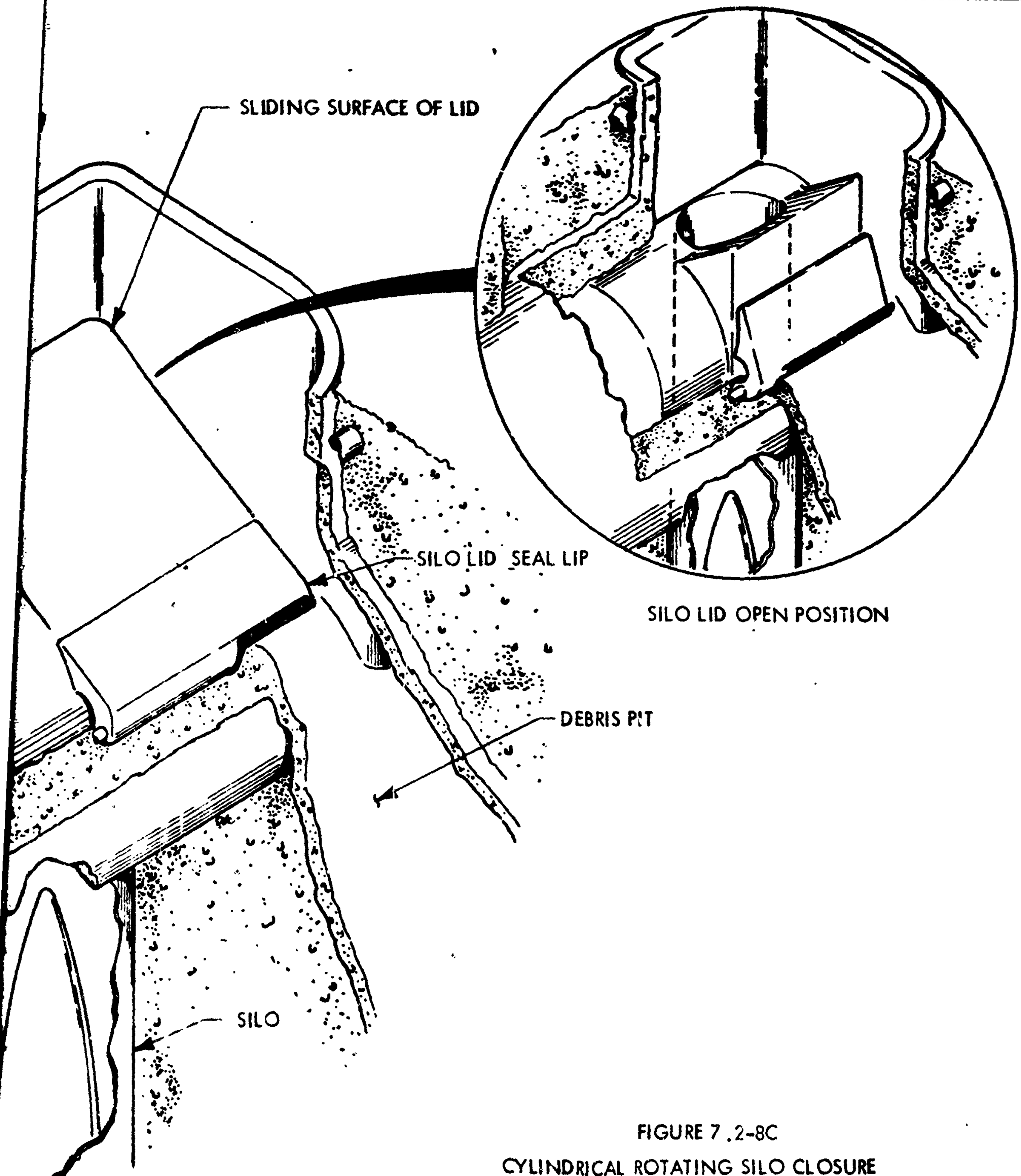
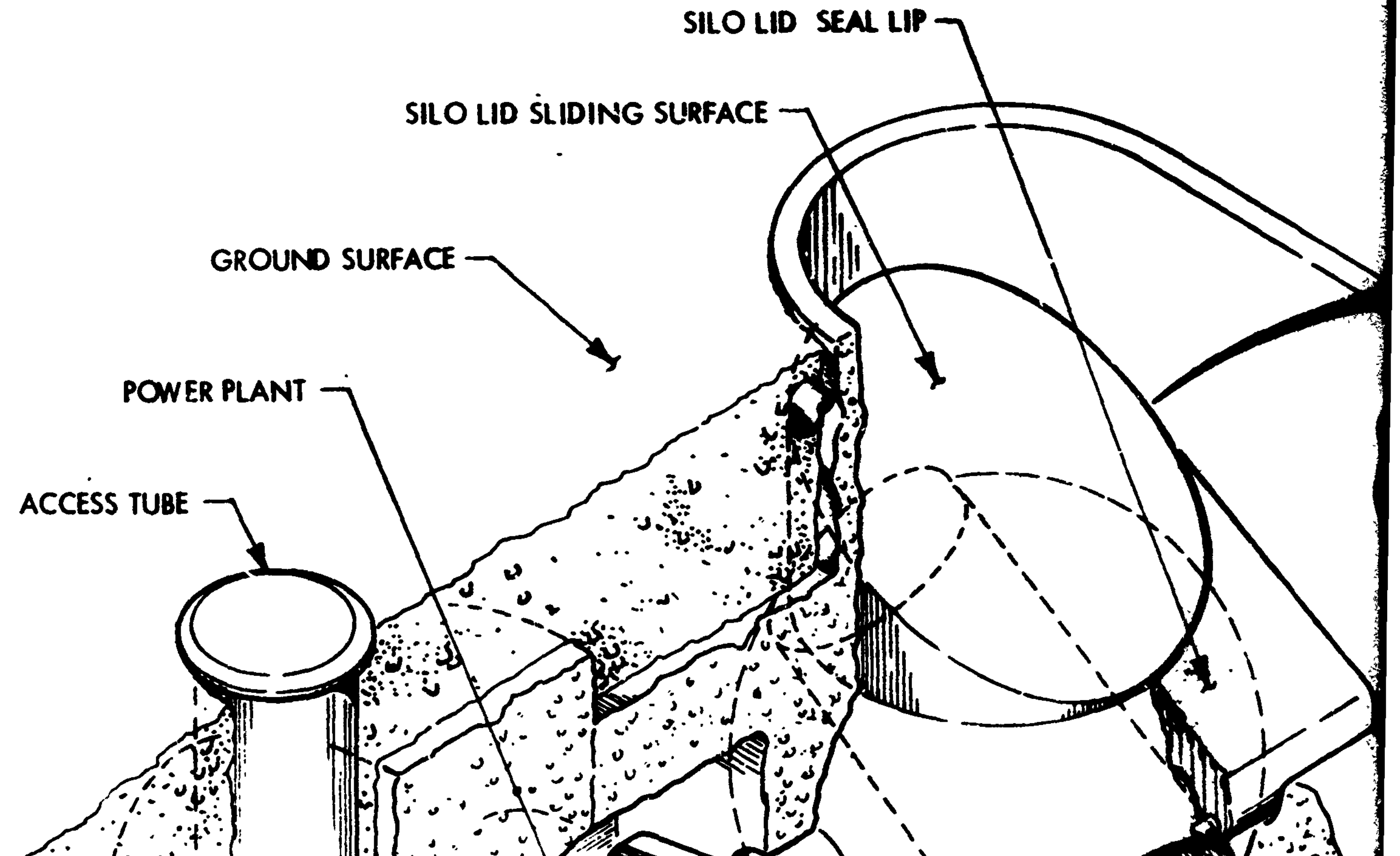


FIGURE 7.2-8C
CYLINDRICAL ROTATING SILO CLOSURE


SILO LID SEAL LIP
SILO LID SLIDING SURFACE
GROUND SURFACE
POWER PLANT
ACCESS TUBE
CYLINDRICAL STRUCTURE SUPPORT RING
ROTA
SILO WAL

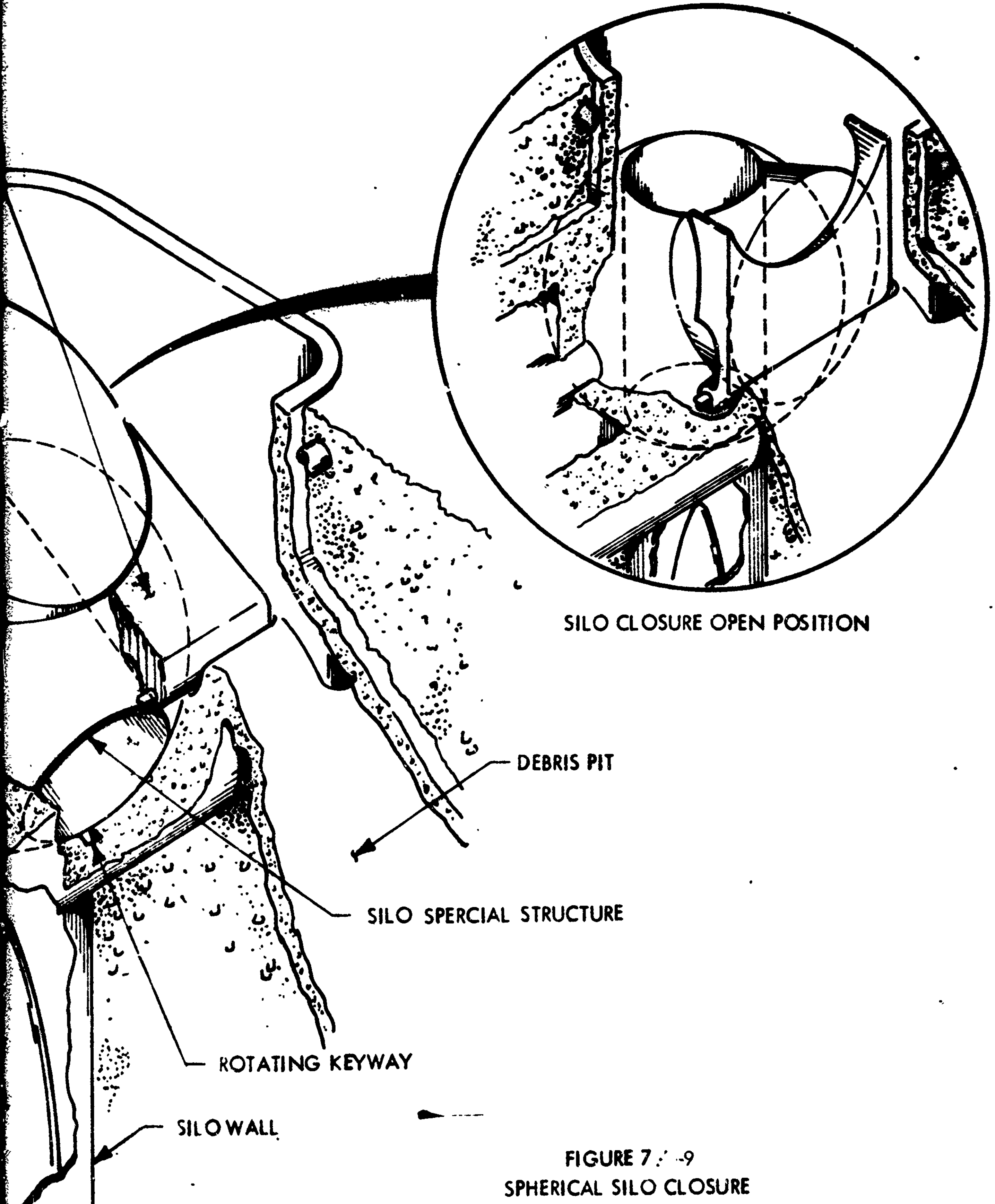


FIGURE 7.[illegible]-9
SPHERICAL SILO CLOSURE

8.0 CONCLUSIONS AND RECOMMENDATIONS - PART I

This closure and debris handling study has concerned itself with closures independently of the launcher structure, and at extreme overpressure levels like 33 1/3X. It is unfortunate that at this point in time (December, 1967) the technical community is still undecided as to survivability limits for cavity type structures constructed in rock. There is promise that such a decision is forthcoming within a few months because of the urgency of implementing a new hardened national weapon system. Survivability of such structures apparently depends mostly on the anticipated rock stress at a given air overpressure level, and the various authorities are in disagreement to such an extent that this rock stress could be predicted anywhere from levels equal to the air overpressure, up to seven times that amount. This being the case, the region investigated in this study could well be outside the realm of practicability because the launcher structures under the closures might not be survivable. In order to benefit from this study, it is imperative that accepted levels of survivability be recognized, and the closure and debris handling study reoriented if required.

The results of the research to date, as represented in Section 7.0, has served to illustrate only some of the difficulties associated with designing at the 33 1/3X pressure level. The problems encountered in the conceptual phase concerning debris accomodation and closure configurations has overshadowed other equally critical design factors including structural dynamics, radiation effects and actuation mechanization.

The problem of debris at the specified level results in two basic methods of accomodation. The first is a debris pit or by ingesting the debris in some manner, and the second is by brute force penetration of the debris by a push out device.

The debris pit scheme is attractive from its conceptual simplicity but it has several serious problems, including the large size required, the structural complication of adjacent cavities in rock, and the undeterminate amount of debris likely in an open debris pit.

A secondary closure or separate closure for the debris pit is the only definable pit concept and is recommended below for further study.

The penetration or brute force concept has the advantage of being predictable and although the power requirements are extremely high, they are still conceivable when taken in context with other requirements of the system. Analytical work is underway within Boeing to define the push out forces for this type of closure. This work should be available for future design effort. The other major complication of frozen debris is not well defined but is estimated to be a fraction of the load due to the debris at high debris levels.

Both concepts are considered feasible functionally with the assumption of structural feasibility and compatibility with other requirements. The penetration method can be identified as the most promising concept to date for the severe design conditions of the study.

The closure configurations illustrated in Section 7.1 have been evaluated from a static overpressure requirement and are considered adequate only for this condition. Actuation schemes are illustrated conceptually and it was not possible to develop latches during the study period. Likewise, specific ablation allowances and shielding schemes were not developed for the closures, as finite requirements were not available. Further development work to include these requirements is recommended below.

All of the concepts which are rated as being feasible (shown in Section 7.0) are concepts which do not account for other possible functional requirements

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of the launchers, such as air breathing for post attack survival power systems. Even without such complications, these concepts, though feasible are generally complicated and obviously will be extremely expensive to fabricate.

The study has progressed to the point of recognizing three configurations which merit further development. The task of developing the next level of detail, evaluating the configurations and making cost analysis as indicated on the study plan were not accomplished in 1967, however, the conceptual evaluation as applicable to high debris levels will apply regardless of the corresponding nominal overpressure level.

The follow-on effort to the study will logically include completion of the primary objectives originally described as a first consideration. Additional effort to further define design factors and limitations can be identified which will add confidence to the results and improve the technical base of the study.

The recommended study can be broken into four areas of effort.

I. Develop new updated configurations of three feasible concepts as follows.

a. Vertical lift concept with debris shield (Fig. 7.2-6). Modify at least to provide multiple actuators.

b. Clamshell closure (Fig. 7.2-7) with capability to raise closure and launcher through debris.

c. Closed debris pit concept using either secondary closure to divert debris to pit or separate debris pit closure.

Develop these feasible configurations to a functional level of detail which includes:

1. Dynamic structural capability for basic structure and components.

2. Operating mechanisms for closures, actuators, latches, debris penetrators and frangible devices. Include power sources in design.

3. Composite structural design of closures for strength and radiation attenuation effectiveness.

4. Ablation allowances and high temperature strength loss for exposed surfaces.

II. Perform Cost and Material Analysis for the concepts developed above.

Costing to be limited to a first estimate based on material quantities and unit costs. Material analysis to include availability, sources, lead times, fabricators and production capacity. This research also is to be done to a first level of definition with the objective of recognizing problem areas associated with the large size components and quantities of materials involved.

III. Improve the technical base of the study by:

a. Further research into the total environment to provide specific currently acceptable ground rules for the design effort involved in I. above.

b. Seek further staff support for design evaluation and development in critical areas. Useful work to promote design confidence could be done in the areas of structural analysis, dynamic loads analysis, composite structure analysis for strength/radiation shielding optimization, debris penetration analysis and actuator power sources.

c. Maintain surveillance of expected advancements in survivability limits, rock/structure interactions, and weapons effects criteria including debris levels and ablation effects.

d. Study the effects of other functional requirements including air entrainment components, maintenance access and missile emplacement.

IV. Continue development of other concepts which can be shown to have feasibility similar to those recommended above. Suggested approaches which have not been worked to date include:

a. Combination approach to debris handling. An undersized debris pit would reduce the debris level to a point where a simple closure could penetrate the remaining debris.

b. A dynamic method of debris removal has been suggested using explosives or a large gas generator to blow the debris aside.

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1. Air Force Design Manual - AFSWC TDR-62-138 dated December 1962 (U)

2. IIT Research Institute, Final Report No. M6086, Survivable Launch Facilities for Ballistic Missiles - dated August, 1965

3. D2-20202-1 - Weapons Effects for Preliminary Design of Hardened Structures (SRD)

4. DASA 1836, Ground Shock and Survival or Kill of Military Systems (S)

5. Appendix "A" of D2-36186-1, Hardened Antenna Configuration Study (SRD)

6. 2-7900-00-222, Dated 12-15-66, G. L. Keister to O. C. Boileau, et al, Subject: Nuclear Weapon Criteria Panel Report for Crater and Ejecta Scaling (SRD)

7. Project Rand Report R-425-PR - A Review of Nuclear Explosion Phenomena Pertinent to Protective Construction, H. L. Brode, May, 1964 (U)

8. Timoshenko, S, "Theory of Plates and Shells", McGraw Hill Book Co. Inc., 1940

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CLOSURES AND DEBRIS HANDLING CONCEPTS

FOR SUPERHARD MISSILE LAUNCH FACILITIES

PART II (1968 STUDY)

TABLE OF CONTENTS (PART II)

U 4802 1434 REV. 5-65

1.0 INTRODUCTION

The purpose of this document is to present the 1968 results of a Company funded study of survivable "super-hard" launch facility closure systems and debris handling methods.

This document is a continuation of the work performed in 1967 under TRP 363 (Technical Research Program) directed toward "Superhard (Cold Launch) Missile Launch Facilities.

The work performed in 1968 and presented herein is basically a direct follow-up of the recommendations and conclusions made at the end of the 1967 effort. (D2-125499-1) (PART I)

1.1 OBJECTIVES AND SCOPE OF STUDY

The prime objectives of the 1968 effort were to develop preliminary designs for three launch facility closure concepts which will function at the limits of survivability, to define and evaluate the weapons effects parameters at the limit of survivability, and to provide a basis for a cost analysis for the closure systems.

The closure designs were intended to be developed to a high confidence level and in sufficient detail to allow a realistic cost analysis to be performed. The objective configurations as a result of the previous work include three concepts as follows:

A. Debris Penetrating Closure

In this concept the facility closure only is pushed through the accumulated debris from the specified attack model.

B. Debris Penetrating Launcher

In this concept the entire launcher assembly as a unit is pushed through the debris before launch.

C. Debris Pit Concept

This concept includes a closed facility with a primary blast closure and a secondary closure over the launcher to deflect the falling debris into a debris pit when the primary closure is opened.

Debris penetrating closures were to be developed as the most promising functionally for the extreme conditions assumed. The debris pit concept was to be developed to illustrate the limitations of this approach and to evaluate cost of the system when exposed to the total environment at high overpressure conditions. The weapons effects were to be further investigated and defined to provide quantitative data on all parameters which could be utilized in the design effort.

A cost analysis was to be performed only to a first level, based on material quantities and unit costs. The objectives were to provide a cost magnitude

1.1 (Continued)

for superhard closure systems for future system cost efforts, and to provide cost comparison among the developed concepts.

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2.0 SUMMARY OF 1968 RESULTS

The 1968 effort has resulted in an evaluation and interpretation of recent weapons effects information, the identification of additional critical design parameters applicable to "superhard" concepts, and the development of preliminary designs for launch facility closures which have a good probability of surviving the total environment as interpreted in this study. In addition, quantitative design data for debris penetration has been obtained and reproduced for reference.

The study effort has resulted in five closure configurations being developed to a first level of definition. The configurations are variations of the three concepts identified above as study objectives. Included are one penetrating closure configuration, two versions of the penetrating launcher concept, and two versions of the debris pit concept. The debris penetrating launcher identified as No. II will survive all of the weapons effects postulated for this study (Section 5.3), however, further design should not be pursued without first developing a more definitive environmental model.

During the study effort, the most recent data on the effects of nuclear bursts of high megaton yields and the response of the emplacement medium (soil and rock) to the bursts were obtained and interpreted. Selected maximum values of the weapons effects parameters for a range of postulated attack conditions were utilized as design criteria in developing the study configuration. The debris environment definition used in the study has resulted in the debris penetration forces, the debris particle size, and the impact velocity at the facility becoming key parameters. Previous studies have not included a critical evaluation of these parameters and the resulting design influence is significant.

Limitations

In order to proceed with preliminary design of closures and components, certain assumptions were necessary in areas outside of the scope of the study:

1. It was necessary to assume that a basic launch facility structure can be designed which will survive. The design of the facility is far beyond the scope of the study and in fact the technical community cannot yet define a structure which will survive the attack conditions when located at the ground surface. In addition to basic survival capability, the facility structure would be required to simultaneously withstand the dynamic reactions of the massive closure end components.

2. The study configurations are developed around a particular model for debris quantity and particle size distribution, which is noted below to be a compromise between models proposed by various researchers. Examination of the configurations will show them to be highly dependent on the debris model utilized in the areas of debris depth and debris impact parameters. The configurations and even the concepts can change if the debris environment is made less demanding. Likewise, any significant increase in the requirements due to debris would require new concepts.

2.0 (Continued)

3. The scope of the designs has been limited by assuming steel shell closure structures for consistency of approach. The development of a small diameter closure as shown in Figure 5.3-2 would allow consideration of other materials, such as reinforced concrete for this closure if further work were considered.

4. An accurate analysis of the dynamic response of the closure components was not accomplished. As noted in later paragraphs, many of the closure components cannot survive elastically if the free-field dynamic shock spectrum is used to define loadings.

3.0 WEAPONS EFFECTS - FURTHER DEFINITION

Recent work performed in the area of weapons effects has identified new conditions that must be considered. For this reason a restatement of the review of Weapons Effects included in the 1967 documentation is offered here, expanding the description.

The following discussion is intended to provide a broad picture of weapons effects from high yield weapons, including some specific considerations that are possible but unproven.

At the present time there appears to be reasonably good agreement on many of the nuclear weapons effects that might result from a nuclear attack involving a true surface burst of some megatonnage over competent "rock". Most of the differences of opinion arise with respect to the consequences of the effects within a particular rock-site environment. The descriptions being furnished for crater formation, resulting debris, and magnitude of direct transmitted ground stress show wide variation. Debris dimensions vary up to an order of magnitude and direct transmitted stresses vary up to a factor of four.

This is understandable when the sources of test data and analysis are considered. All data and analysis currently being used derives from various interpretations of past detonations of high explosive devices and nuclear devices. None of these are exactly appropriate to explosions that would be expected from current threats. From the many interpretations the extreme interpretations have been collected into a "big crater school" and a "small crater school" with debris descriptions differing by an order of magnitude, or more, dependent upon range. (Once crater size has been established by any of the authors the geometric proportionment of debris to crater is reasonably consistent with that of the other authors.) Currently, Boeing personnel charged with responsibility for definition of weapons effects criteria are endorsing an intermediate position as the description against which designs might logically be performed.

Since specific testing to resolve the differences in crater and debris descriptions is denied by the existence of the nuclear test ban treaties, there can not be any certainty that the weapons effects description will remain constant. Indeed, the experience of the past year has shown that description to be quite fluid and greatly influenced by degree of conservatism assumed by others with respect to probability of particular threats and particular weapons effects. For this reason it is a necessity within this study, to select some reasonable combination of weapons effects, for purposes of establishing design criteria. Since the combinations of weapons effects that can result from various yield weapons, varying site conditions, and varying ranges are very numerous, selected maximum values were used for the study.

3.1 DESIGN OVERPRESSURE LEVEL AND AIR BLAST EFFECTS

Previous work was performed using a somewhat arbitrary nominal overpressure level as a design point for evaluating launch facility requirements. Advances in the definition of weapons effects parameters and in soil/structure interaction studies have demonstrated that there is a location with respect to the weapon crater, inside of which it is impractical to define a survivable facility. As with other parameters, this location is variable with weapon yield, siting,

3.1 (Continued)

burst height, etc., however, it can be associated with a nominal overpressure less than that used for previous work.

Accordingly a new arbitrary nominal design overpressure of 20X psi. has been selected as a reasonable design point for the present study. The other weapons effects parameters assumed are roughly the corresponding values considered a reasonable design maximum from various attack possibilities.

The build-up of pressure from the detonation and its subsequent decay in the form of a rapidly moving spherical shock front result in the primary peak over-pressure wave felt at the facility as the shock front passes over it. For larger weapons and higher overpressures, this effect will be felt at the facility within two hundred milliseconds. The velocity of the front could approach tens of thousands of feet per second. Decay of the overpressure after passage of the shock front is very rapid. However, conservative design indicates that the surfaces of interest be exposed to the full overpressure effects. This results in a very severe loading on the facility and adjacent site medium. Positive overpressure will continue for several seconds after the passage of the shock front. The result of impingement of the shock front on protrusions or indentations on the surface will produce reflected shock values significantly greater that the incident overpressure value.

From the time of arrival of the shock front there will be transient wind condition existing at the facility, through the positive phase of the overpressure, and continuing through the negative phase. The initial wind velocities will be in the order of tens of thousands of feet per second and will then decay in more or less direct proportion to the overpressure decay. The later winds in the period of negative overpressure and final stages of the positive phase, while not high in velocity, will be sufficiently strong to cause displacements of any unattached projecting surface materials. The influence of wind on debris movement, deposition, and abrasive erosion of surfaces must be considered.

3.2 RADIATION EFFECTS

The first effects felt at a facility from detonation of a nuclear device will be the nuclear radiation. This is accompanied by an intense thermal radiation pulse from the initial burst, and followed by a longer thermal pulse as the site is engulfed by the fireball.

Within the first few milliseconds there will be a bombardment of the facility surface by X-rays, prompt gamma rays, neutrons, secondary gammas, as well as the effects of neutron capture. Sufficient shielding must be provided by the closure system to attenuate the initial radiation pulse to a level which will not affect the equipment within the facility.

The same radiation energy also results in damage to the structural and natural materials that comprise the surface as a consequence of the conversion of that radiation energy to heat. The heating effects will be a function of the material absorption properties, dimensions of the materials, and their thermal characteristics. This heat may be sufficient to cause ablation of some materials

3.2 (Continued)

through vaporization and melting, sufficient to cause degradation of the mechanical properties of some materials to significant depths below surface, and possibly sufficient to result in thermal shock of the materials. Further, the consequences of differential heating to differing components of composite materials, such as steel-reinforced concrete, could result in additional damage.

From the initial forming of the fireball at detonation, heat is radiated in all directions, the first radiant heat arriving with the radioactivity. As the fireball develops, the heat radiated to the facility increases. The maximum heating at the facility occurs when the fireball has grown to sufficient size to envelope the facility surface, radiating to and conducting heat to that surface. This will occur immediately following passage of the overpressure shock front. It continues in existence with high input to the facility throughout the period of the positive phase of overpressure. The negative phase, with ground wind reversal will force the rising of the fireball from direct contact with the surface. However, for many seconds the heat of the once again remote fireball will be sufficient to cause very significant radiant heat reaching the facility. The total effect of all of these phases of the heating of the facility will be sufficient to cause vaporization and melting of many of the structural and natural materials that might exist at the facility. The degree to which this ablation might occur should, perhaps, be estimated conservatively since it is conceivable that the ablation would be occuring at the heat of melt rather than at the higher heat of vaporization, particularly during periods in which either wind or debris might be eroding the surface as rapidly as it reaches a fluid state.

In addition, the direct heating of the surface of the facility combined with high temperature molten deposits carried by the dynamic wave could result in a fused layer which may in effect weld adjacent surface components together.

The additional phenomena of heating to significant depth, followed by ground shock, thermal shock, or steam from ground water can produce loose debris which can be carried over the facility by later winds. High velocity projectiles from this source can cause severe damage to surface structures.

For the developed configurations the closure mass and over-burden required by the overpressure level and debris impact criteria provide protection from all radiation and surface effects including heating, ablation and spallation.

3.3 GROUND SHOCK-DATA AND INTERPRETATION

Within an interval of about 100 milliseconds after the arrival of the air overpressure shock wave, the effects which are transmitted through the ground will reach the facility. Since shocks transmitted through the ground do not get the same form of spatial attenuation with range that occurs in the air, the ratio between shock induced by air overpressure and the direct ground transmitted shock is variable. In general, the nature of air shock is predictable while that of ground transmitted shock is not. The structure of the medium through which ground shocks are transmitted is generally variable and the resulting reflections can cause either magnification or attenuation of the transmitted shock.

3.3 (Continued)

The facility is subject to severe loadings due to both the ground stresses, which can be several times the air overpressure, and the motions induced by the shock phenomenon. The definition of the basic facility is beyond the scope of the study and it must be assumed that a basic facility can be designed to survive. The ground shock effects to be considered for the closure designs are the motions experienced by the facility at its location with respect to the crater.

The ground shock criteria is presented as a "free field" shock spectrum which represents the maximum expected values of displacement, velocity and acceleration to be experienced in the ground at the facility due to the ground shock effects.

From the free field spectrum a "response" spectrum is prepared by applying suitable factors and this represents the corresponding displacement, velocity and acceleration response of an object (a simple spring mass system) to the ground shock.

Data are usually presented for vertical and horizontal components and for both air induced and direct induced (ground transmitted) effects.

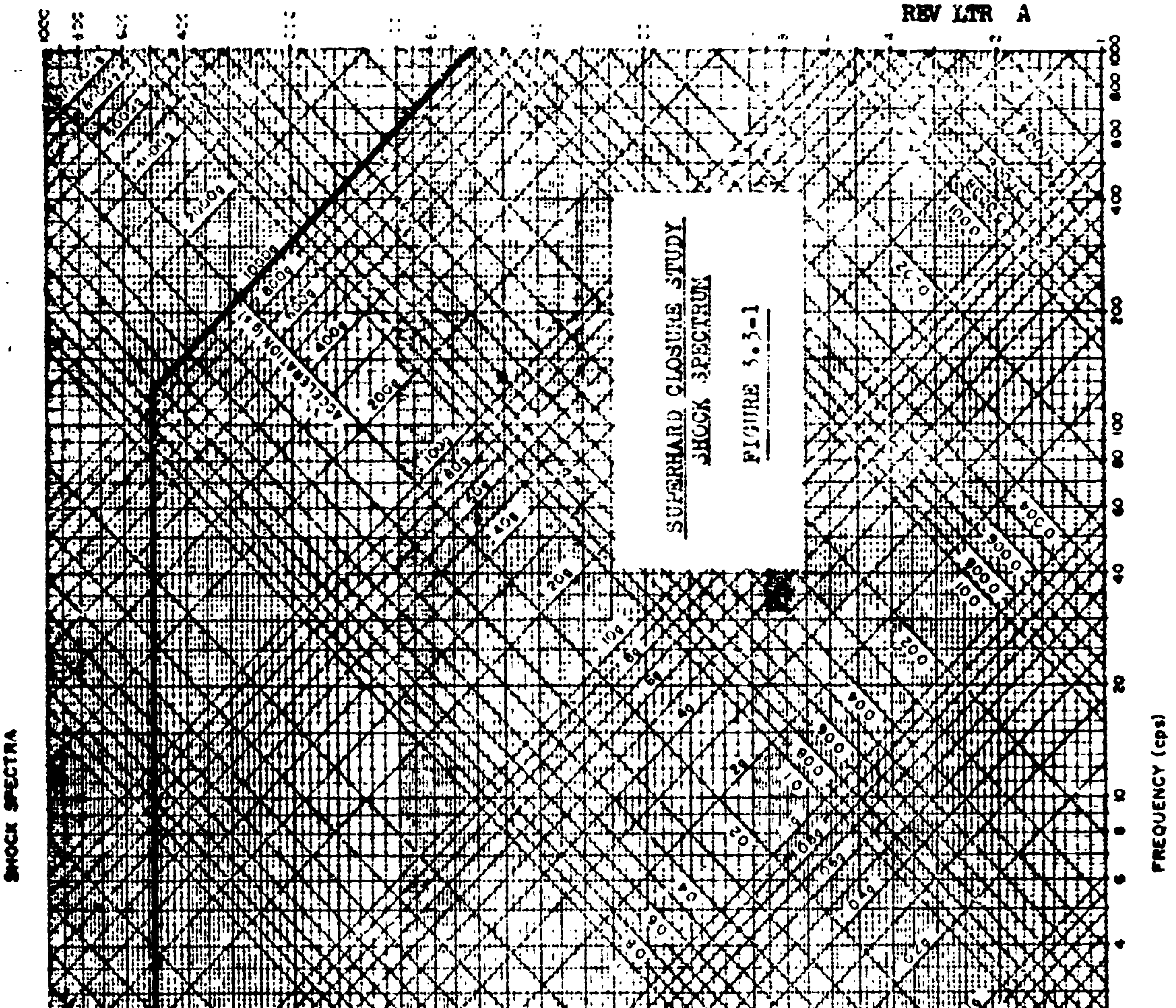
The available shock spectra for the high overpressure regions from nuclear bursts of high yield weapons are many and greatly variable. The shock spectra are a rather imprecise definition of the actual ground motions experienced at a facility. This is due mainly to the variability of the transmission in the earth. However, the spectra are the only practical method of describing the effects and are satisfactory for preliminary design purposes. For the present study a single response spectrum representing a probable maximum environment has been used for both horizontal and vertical components. This is presented in Figure 3.3-1.

Interpreting a shock spectrum for design purposes can only be done by assuming the component under consideration as a simple harmonic oscillator. The spectrum presents the maximum displacement, velocity, and acceleration response of the component to the event represented by the spectrum (by definition). The component is then analyzed to a displacement, velocity, or acceleration, and stresses calculated accordingly. This procedure is generally suitable for preliminary design purposes and is the method utilized in evaluating the response of the developed designs.

More exact analysis requires that finite components and groups of components be subjected to a specific driving pulse and their response calculated. This work requires the support of technical specialists, beyond the scope of this study.

3.4 DEBRIS ENVIRONMENT

In addition to the weapons effects of radiation, thermal pulse, shock, ground motion, peak overpressure, and dynamic pressure, a very severe and uncertain debris environment will exist at the facility. The debris environment includes high velocity "wind swept" early debris, large quantities of bulk debris and large particle impact effects.


SUPERHARD CLOSURE STUDY
SHOCK SPECTRUM
FIGURE 3.3-1
SHOCK SPECTRA
VELOCITY (in/sec)
FREQUENCY (cps)
DISPLACEMENT (in)
ACCELERATION (g)

3.4 (Continued)

Previous work in debris definition has paid scant attention to the mechanism of debris depositions or the effects of the debris particle size on the survival and functioning of the facility in the debris environment. (The particle size as noted below can vary from dust to large boulders.) This lack of identification has not been significant so long as the levels of debris predicted have been low. For the regions nearer the crater that are currently being explored in attempting to achieve the greatest possible hardness, debris levels are becoming significant and the predicted distribution of debris in the final deposition is such that this factor is becoming of prime importance in design. In addition, further evaluation of the probability of large debris particles arriving at the facility in free flight from the crater has resulted in the damage due to impact becoming important.

Various models for debris quantity, size distribution, and arrival mechanisms are being proposed and the definition is at least as uncertain as the ground shock descriptions. The possibilities of changes in site conditions, level of burst for nuclear detonations, and changes in the required probability of survival for a facility, dictate that designs be conservative in debris considerations.

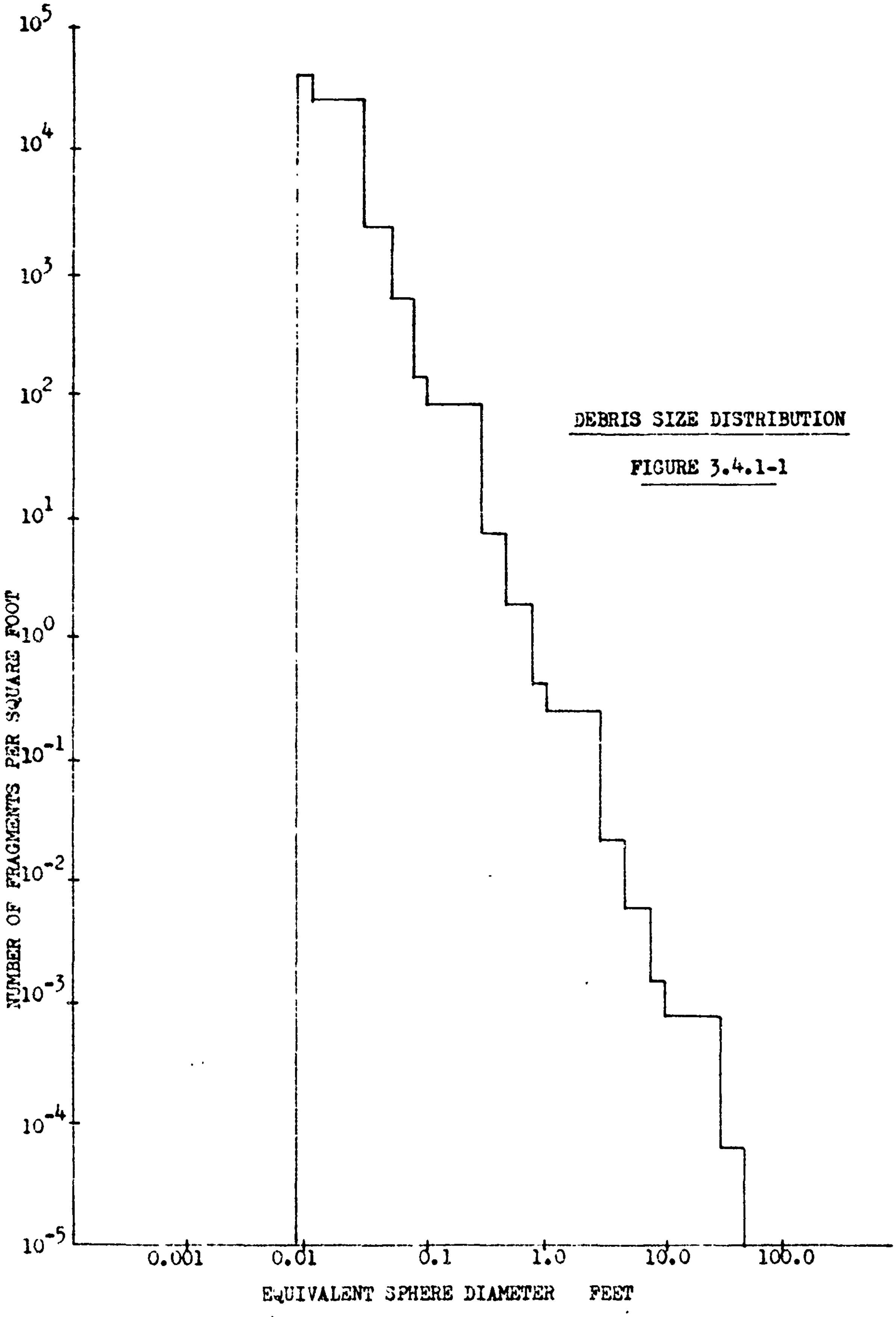
For large weapons, high debris levels are being predicted with rather high probabilities. In addition, the debris is described as having a significant number of large particles on the order of 10 to 40 feet equivalent sphere diameter. When this description is coupled with the minimum conditions by which ejected debris could reach the facility in free flight, velocities of several hundred feet per second result and the impact damage can be potentially more severe than the damage caused by the earlier mentioned effects. The present study has been performed on the basis of a relatively severe debris model to illustrate the order of magnitude of the possible effects and the type and size of components required to accommodate these debris levels.

Previous design efforts in the 1967 study have already defined the debris handling problem as a controlling design factor and suggested that brute force penetration of the debris or a large debris receiver are the most probable successful concepts available. The evaluation of debris impact to a first level of definition has been performed during the present effort. The debris model assumed for the study is defined below.

3.4.1 DEBRIS DISTRIBUTION AND SIZES

The currently favored (by Boeing) debris model is considered to be a conservative one with a finite percentage of the debris volume being of a particle size comparable to the nominal debris depth.

A typical size distribution definition is shown in Figure 3.4.1-1 and this represents the assumed conditions. The curve represents the distribution of various particle sizes within a given area and can be interpreted to estimate the size distribution in the bulk debris, and also to estimate the probability of having to push aside a large particle at any given site. It is significant to note that the bulk of the debris is in fairly large particle sizes (on the order of the closure radius) and that the probability of



DEBRIS SIZE DISTRIBUTION
FIGURE 3.4.1-1
NUMBER OF FRAGMENTS PER SQUARE FOOT
EQUIVALENT SPHERE DIAMETER FEET
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.001
0.01
0.1
1.0
10.0
100.0

3.4.1 (Continued)

having a large particle on top of any facility is relatively high. The bulk debris condition is reflected in the penetration requirements below. The effects of the very large particle sizes possible cannot be fully evaluated without further information but it is presently felt that the direct lifting of the particle is no problem and side thrust is the effect which may be critical to a push out member. Practical judgement suggests that the very large particles are unlikely to come to rest at any remote location in one piece even if they do exist as the crater is formed. Accordingly, a maximum particle size of about 15 ft. equivalent sphere diameter has been used for evaluation on the basis that this is a somewhat critical size for clearance reasons in debris pit concepts and also for impact conditions assumed.

3.4.2 QUANTITY RELATED TO PIT CONCEPT

The bulk depth of debris anticipated for the present study makes the concept of a debris pit untenable at the nominal level. However, the uncertainty of the model and siting variability indicates that it is indeed conceivable that the amount of debris to be handled could be reduced. This would allow reconsideration of debris pit concepts and accordingly the requirements have been investigated.

Because of the nature of volume requirements for a debris pit when high levels are considered, an arbitrary upper limit was established for the study and the concepts developed around this limit. The maximum volume of debris to be considered was assumed to be that which could be accommodated in a receiver of the same diameter and maximum depth as the missile facility. This results in a pit 25 ft. in diameter and 108 ft. maximum depth having a nominal volume of 53,000 cubic feet.

The debris depth which corresponds to this volume is based on a conical depression in the bulk debris formed at a nominal angle of repose of 35° from the horizontal.

Figure I-C-2 (APPENDIX I) presents the volume of the depression as a function of nominal debris depth when the facility opening is 15 feet in diameter. This results in the debris pit configurations shown having the capability of handling a 23 ft. nominal debris level. This is much less than the required capability of 36 ft. which would require 149,000 cubic feet of receiver.

3.4.3 DEBRIS PENETRATION

The direct penetration or "Push-out" concept has been taken as the most definable and most likely method of designing a facility which will function for high debris levels. The magnitude of the push-out force required is readily recognized as being high just from the overburden effect at the depths under consideration.

Previous work has been hampered by lack of information on the properties of the bulk debris as they resist penetration from below.

3.4.3 (Continued)

Recent work by Boeing has provided theoretical and non dimensional quantitative data which provides further definition of debris penetrating forces for large irregular particles. This data has been used for sizing the penetrating closures of the study. The data is based on a theoretical model of sand and experimentally determined factors for the variation with size. This is shown in Appendix I. The resulting debris penetrating forces are extremely high and while they require mechanical systems which are near the limits of the state of the art, they are considered feasible functionally.

3.4.4 DEBRIS IMPACT

The possibility of large boulders arriving in free flight at the facility has been discussed above and is considered a positive design requirement for the debris environment under consideration.

Very little work has been done in this area because the previous design debris levels have not required it. The effects of large masses of alluvium (unconsolidated silt, sand, and gravel) being ejected from a test device have been observed and studied in connection with the Sedan Test in Nevada and is described in Reference 1. The very significant damage caused by these masses of unconsolidated material when they impacted a structure and the craters or ground depressions formed when they impacted the ground suggest that this phenomenon is of some importance.

The referenced paper proposes a model for impact phenomenon which is based on an equivalent pressure pulse of triangular shape which is developed by an Impulse-Momentum approach with given mass, velocity and time parameters. This model is shown in the appendix with a 15 foot diameter particle arriving at the facility at 300 feet per second. The resulting 10,000 psi equivalent pressure on a non yielding surface is modified for the present designs by providing a gravel overburden on the facility. This will allow less rapid deceleration of the impacting particle which will reduce the peak pressure on the closure. The reduction has not been evaluated and the overburden is shown as a possible method of attenuating the effects below the nominal 20X psi design capability.

It must be noted that while the assumed particle and velocity represent the limit of the design capability under the assumed conditions, they also represent a relatively small particle in the illustrated debris model and the minimum energy trajectory for arrival at the facility. Further consideration of the possible particles and high velocity trajectories can result in an impact consideration which is nearly impossible to design for.

The conditions assumed have been chosen for illustration of the magnitude of the phenomenon and the sensitivity of the designs to the debris model.

4.0 DESIGN CONSIDERATIONS

The total weapons effects environment results in the recognition of three primary design factors which will determine the basic configurations of closure systems. These are:

1) Nominal overpressure and air blast effects

2) Debris environment

3) Ground shock environment.

The concepts selected for study were categorized with the debris handling methods being the most significant difference between approaches. Two basic debris handling methods are recognized. The first is a brute force penetration of the debris by mechanical means. The second is a debris pit concept where the debris is allowed to fall into a pit, leaving the closure exposed and unobstructed for opening.

The basic functional requirements considered for the development of the designs were limited to survival of the weapons effects and providing a post-attack functioning system for opening the facility to allow missile launch. A one attack criteria was assumed, however the conservative elastic approach used in the design definition will provide an inherent multiple attack capability if this objective is met, with the limitation that the total deposited debris depth cannot exceed the nominal value.

The penetration approach has been developed to the point of defining three configurations, each having unique features and problems. The first, most direct approach is to push the silo closure and a debris shield assembly alone through the debris (Fig. 5.1-1). The second approach is basically to push the entire launcher through the debris. This is accomplished by essentially making the closure, debris shield, and missile system into a single unit which is pushed through the debris (Fig. 5.2-1). The third approach is a refinement of the second, wherein a much smaller closure is utilized to minimize materials and to enhance substantially the survivability of the basic structure. (Fig. 5.3-1)

Two conclusions have been reached in previous studies of debris pit concepts, the first is that a closed structure must be provided to prevent the pit from overfilling by interception of a horizontally moving mass of debris, and the second is that a secondary closure system is required to protect the missile from the debris as it falls into the pit.

The primary problem with debris pit concepts is the size required when high debris levels are encountered. The required volume increases very rapidly with depth because of the nature of the 35 degree conical shape of the cavity formed as the loose debris falls into the pit.

4.0 (Continued)

The sheer size of a debris pit for the assumed conditions, in addition to the structural complexity of adjacent cavities in a highly stressed medium, indicates that this concept has a very low confidence and high cost. The concept is developed however in order to illustrate the problems encountered and to provide a reference for future evaluation.

The debris pit size for the nominal debris quantity is considered to be impractical, and for the study an arbitrary upper limit to the debris pit size has been set by defining the debris pit as having the same diameter and maximum depth as the facility. For the assumed missile configuration this results in a pit which will handle approximately 23 feet of debris.

4.1 SURFACE EFFECTS AND DEBRIS IMPACT

Evaluation of weapons effects at high overpressure levels has resulted in the definition of effects which occur in the surface layers of any medium present. The effects of nuclear radiation, thermal radiation, ablation, and debris impact have been discussed in Section 3.4. The requirements to survive a severe debris impact condition are such that the other surface phenomena become secondary problems. Protection for debris impact will also provide protection from radiation, heating, and ablation.

The assumed condition of a 15-foot diameter particle arriving at 300 feet per second when evaluated as an effective maximum impulse pressure will result in a 10,000 psi pulse when the particle strikes a non-yielding surface (see Appendix I.B.). By allowing the particle to penetrate a slightly softer surface the pressure pulse can be reduced to a value below the design capability of the closures. Neither data nor analysis were available during the study to define these requirements, and the approach taken was to provide a finite depth of gravel cover when would both allow some penetration and which would distribute the load over a larger area at the depth of the closure. Further investigation will be required to define the fill material properties and dept required.

Again this requirement is sensitive to the debris model utilized and a change in the criteria can reduce the impact problem to secondary significance, with surface spalling and radiation shielding governing the requirements of the surface layers.

The study configurations have been made consistent by providing approximately 15 feet of gravel cover for surface protection. The obvious maintenance problem using a shield of this type has not been resolved, however several approaches are apparent and it is not considered a primary problem.

The overburden approach as utilized in the present designs will have three positive effects on the survivability of the facilities. The first is the surface protection and radiation shielding as noted above. The

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4.1 (Continued)

second is that the overburden will allow the steel shell closures to be designed as fully buried structures according to the Air Force Design Manual TD 62-138 (Reference 7). The third positive factor is the removal of the structural elements of the closure from the ground surface, thereby increasing the general survivability.

4.2 PENETRATION REQUIREMENTS

The debris levels and particle size criteria used as design requirements result in extremely high forces being required to penetrate the debris layer.

Recent testing within Boeing has provided usable data and a method for evaluating the push-out force required. This is shown in the Appendix and results in a force requirement of 40 million pounds for the large closures shown in Fig. 5.1-1 and 5.2-1. The smaller closure shown in Fig. 5.3-1 has a push-out force requirement of 20 million pounds. The equivalent peak power requirement for the large closure if a time of two minutes is used for push-out is of the order of 60,000 horsepower. This can be considerably reduced if the system is programmed to increase the rise rate as the load drops off or if a longer overall time is allowed. The reduced value will remain in the thousands of horsepower range and for the study it is assumed that any motor or pump system is unsuitable for the purpose. Accordingly, the actuation system is considered to be hydraulic cylinders with the required pressure being developed by directly pressurizing the oil storage reservoir by a gas generator.

Hydraulic actuation is utilized to maintain positive control of the system and to allow operation for maintenance by using an external power source.

The required gas generator sizes have been estimated by assuming a final pressure and temperature and calculating the mass of combustion products based on an approximate molecular weight, and the volume of the system. The resulting 8 ton propellant requirement for the large closures presents a design problem beyond the scope of the study and a volume requirement only has been incorporated in the configuration. It is further assumed that a generator can be designed which will withstand a 40 g dynamic reaction with rattle space and a suspension implied accordingly. The hydraulic cylinders required for the large closure configurations are considered to be within the state of the art even though they must operate at a maximum pressure of 7100 psi to provide the required maximum force. The cylinders for the small push-out closure operate at 3600 psi.

4.2 (Continued)

The required fluid storage volume for the large closure concepts is approximately 33000 gallons. The fluid is stored in an integral, hard mounted, baffled tank at the bottom of the facility. A cubical grid baffle system fabricated of heavy plate has been shown by previous studies to be desirable for the extreme dynamic environment expected. This type of reservoir has been shown in the figures, although specific requirements were not evaluated.

The horizontal forces encountered during push-out due to uneven distribution of the anticipated large debris particles are an undefined loading condition. The resulting structural deflections are accommodated for in the small closure concept by providing a positive (approximate 6 in.) clearance between the supporting structure and the missile canister and a two-location support to allow the structure to deflect without straining the missile canister.

The horizontal load capability required for the telescoping debris shield in Figure 5.1-2 is undefined, however, a finite capability has been built into the system by overlapping the shield sections and providing bearing blocks to transmit radial loads between sections. The overlapping sections have been estimated to be able to withstand a horizontal reaction of approximately 2×10^6 pounds as the closure projects just above the original ground surface.

4.3 DYNAMIC LOADS

The ground shock environment definition is variable with attack criteria as discussed elsewhere, and a single maximum criterion has been used for the designs developed. The variations due to lesser values will in general only reduce the material thicknesses of structural members. The design configurations developed will be of the general type required for a finite range of less severe criteria.

The shock criteria are presented in a form intended to cover all cases in a simple manner. This is the shock spectrum. This is the only criterion available to the designer and it must be noted that the data in this form cannot be interpreted literally for any real system. The data is however, an upper bound to the likely response of an elastic member and has been interpreted in this manner.

The general assumption made is that any finite system, particularly a distributed mass system, will have a lesser response to the shock than an ideal simple oscillator which is what the spectrum represents. More realistic design on a preliminary basis could be made if a damped response spectra were calculated and also if response spectra were calculated for types of members likely to be encountered such as uniform beams, axially loaded members, flat plate members, and shells. In general stiff members are desirable and for the resulting higher natural frequencies the maximum loads occur at the restraint or loading points and are equivalent to the maximum "g" loading of the simple oscillator response spectrum.

4.3 (Continued)

The most critical problem arising from the assumed conditions are the ground shock inertial loads on the large components which must be reacted by the latching mechanisms and hinge pins. The high peak accelerations when applied to the closures and other large components result in reactions which make it difficult to provide sufficient latch area for restraint. In addition the reactions on the facility will be a significant factor in its survivability and a more realistic analysis must include a detailed description of the facility response, including the closure.

In general, the dynamic loads as interpreted above are very high and for very large components required in some study concepts, latching devices could not be defined which will survive elastically. The large dome closures are the most notable example and the concepts are limited in this respect.

There are four areas of conservatism in this approach which indicate that further development may allow the structures to survive.

1) Observed maximum response spectra in weapons testing programs are lower than the calculated values used for current criteria and these high values may be modified.

2) The response of finite systems as compared to the theoretical simple oscillator will result in improved survivability.

3) Preliminary calculations have assumed elastic response to the shock. A yielding structure can withstand considerably more severe conditions than an elastic structure.

4) The spectra used to date are the "free-field" response spectra which result in a maximum response at all frequencies. In fact, the closure and interior components are secondary structure, and elastic systems of two stages can allow design to minimize the response of the second stage components by controlling resonant frequencies.

The configurations developed are not thoroughly analyzed designs, but are presented as logical preliminary designs which recognize the critical design problem areas and illustrate the proper order of magnitude of structural and mechanical components which will be required to provide a functional closure system near the limits of survivability.

4.4 DESIGN CRITERIA

For the preliminary design work performed during the study typical maximum values of the critical parameters have been used. In general the values used represent a reasonable maximum expected for the parameter. However, the maximum particle size and debris impact parameters are defined by the limitations of the configurations as shown.

4.4 (Continued)

The values used are as follows:

Nominal Peak Overpressure	20X psi
Maximum Bulk Debris Depth	36 ft.
Maximum Debris Particle Size	15 ft.
Maximum Ground Deplacement (Horizontal & Vertical)	48 in.
Missile Canister Dynamic Clearance Space (Horizontal & Vertical)	72 in.
Shock Spectrum Values	
Displacement	48 in.
Velocity	500 in./sec
Acceleration	1000 g
Maximum Particle Vertical Impact Velocity	300 Fps
Closure Actuating Time	5 - 10 minutes
Debris Penetration Loads	(See Appendix I.A.)

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5.0 CLOSURE CONFIGURATIONS

During the study period five closure concepts have been developed to a first level of definition. These include three debris penetrating or "push-out" concepts and two debris pit concepts. These are described in the following paragraphs.

The concepts are called closure concepts, however, the functional requirements dictate that the closure design is an integral part of the facility design in all configurations and the entire facility is shown. A cold launch, canister emplaced, large solid fuel missile has been used as a baseline for facility definition. The requirements for a system using a hot launch system have not been considered.

The five configurations developed during the study have certain common features as a result of the interpretation of the environment criteria. The penetrating or push-out closures are basically a shell design based on membrane stresses with stiffening and edge reinforcing as required. The debris pit closures include a grid type structure and a modified shell structure with an exterior shape configured to interface with the facility structure and are concrete filled.

The debris impact criteria as developed in Section 3.4.4 result in a uniform 15 foot depth of gravel cover being utilized as surface protection for all concepts.

The study is limited to closure concepts and the layout of the facility is developed only as it is affected by the requirements of the closure and equipment. The configurations as shown neglect the other facility functional requirements such as access, maintenance, missile emplacement, power supply systems, etc. It is assumed that the impact of these requirements would be nearly the same for all concepts and are subordinate in any event to the very difficult primary functions of survivability and debris penetration for launch.

The general considerations of structural survivability result in factors which will favor certain configuration features. A smooth cylindrical cross-section is the best basic configuration. Increased depth of the closure below grade will minimize the ground shock surface effects by providing a confining overburden. A minimum diameter facility neck will also increase survivability.

The facility configurations are shown as cylindrical structures for maximum survivability with deviations only where necessary.

Further, the basic facility structure is beyond the scope of this study and must remain completely undefined. The interaction of closure system components with the facility structure is likewise undefined.

5.0 (Continued)

The mechanical details associated with the concepts are developed only to a first level of definition and are typical of the size and type of devices which may be used

The latching devices illustrated for example, show various ways which these latches may be made. Both shear and compression loaded latches are shown and have similar load carrying capacity. It is to be noted that the latch loads have not been fully evaluated and the latches shown for the closures may not withstand the maximum conditions that can be postulated. This is however, consistent with the uncertainty of the basic structural capability of any member in the extreme shock environment.

The requirements for supporting each of the major components independently as shown on the figures, and for supporting debris shield sections by tension members from the facility wall are fundamental under the extreme conditions and are typical of the design requirements. The resulting complexity of numerous latching devices, guide rails, and bearing blocks to carry compressive reactions into the facility structure, are also typical of the design requirements

A suspension system configuration has been assumed for the missile canister and this has been used in all five concepts. The missile suspension system is assumed to be an 8 point cable suspension symmetrical about the C.G. of the assembly. The response of this suspension has not been evaluated and is only assumed to be within the nominal 72 inch rattle space provided. A pneumatic spring system is postulated having a nominal 3 g response. The spring units are mounted on the missile canister (or Thrust Structure in Section 5.3) and reinforcing rings and cable guides are provided at the desired support locations.

5.1 DEBRIS PENETRATING CLOSURE CONCEPT

This closure concept is the development of the basic "brute force" penetration of a large quantity of debris from the specified attack criteria

The basic requirements for overpressure, rattle space, debris accumulation, and an assumed flyout clearance diameter result in a configuration as shown in Figure 5.1-1.

The radial space requirements for debris shields, actuating cylinders, and flyout clearance result in a diameter at the closure which is very close to the basic facility diameter. Accordingly, the silo is configured as a continuous diameter structure up to the closure, with the debris shield assembly and hydraulic actuating cylinders located directly below the main closure assembly The missile and canister are located below the closure actuator components on a suitable suspension system. At the botton of the facility the hydraulic power system is installed.

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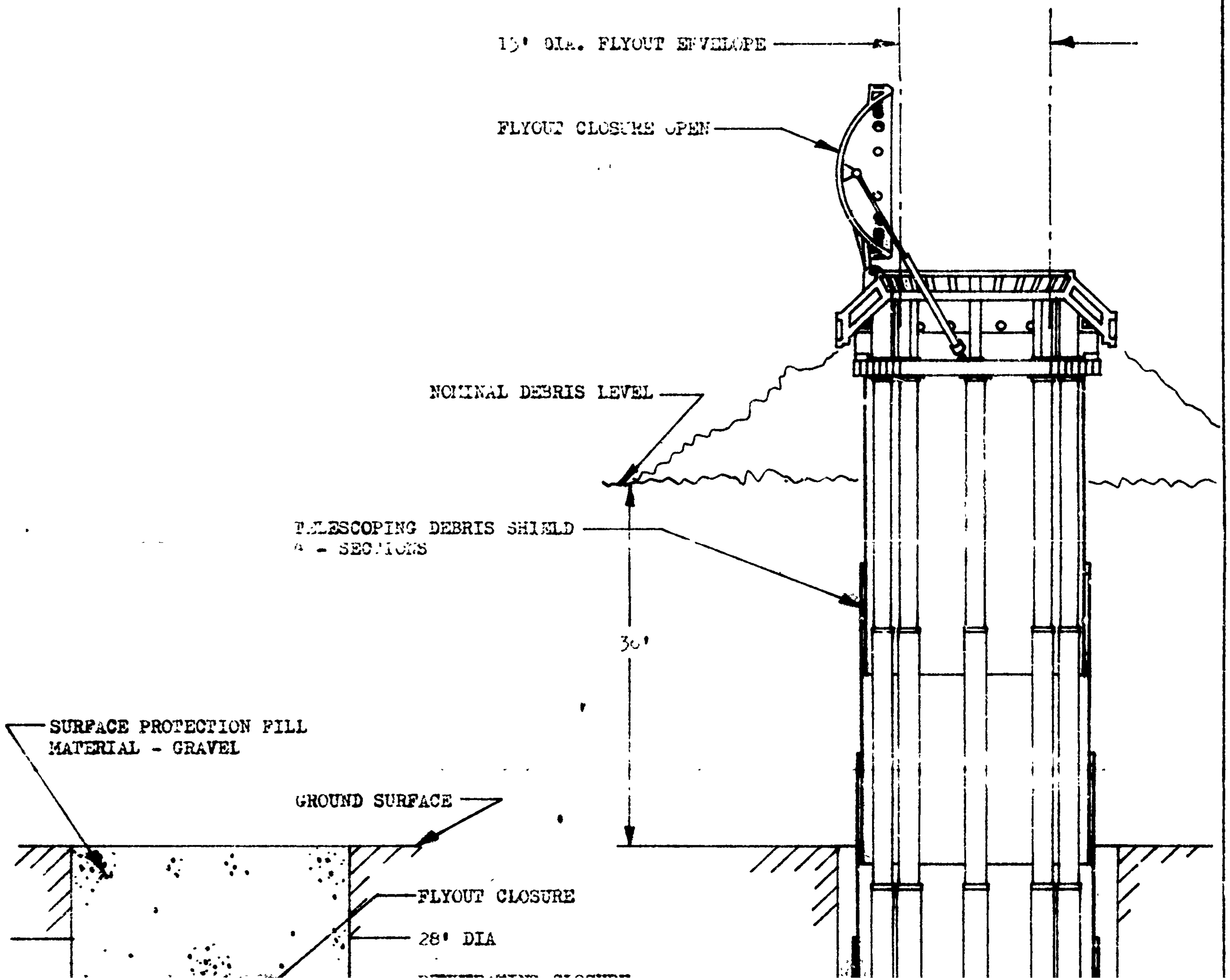
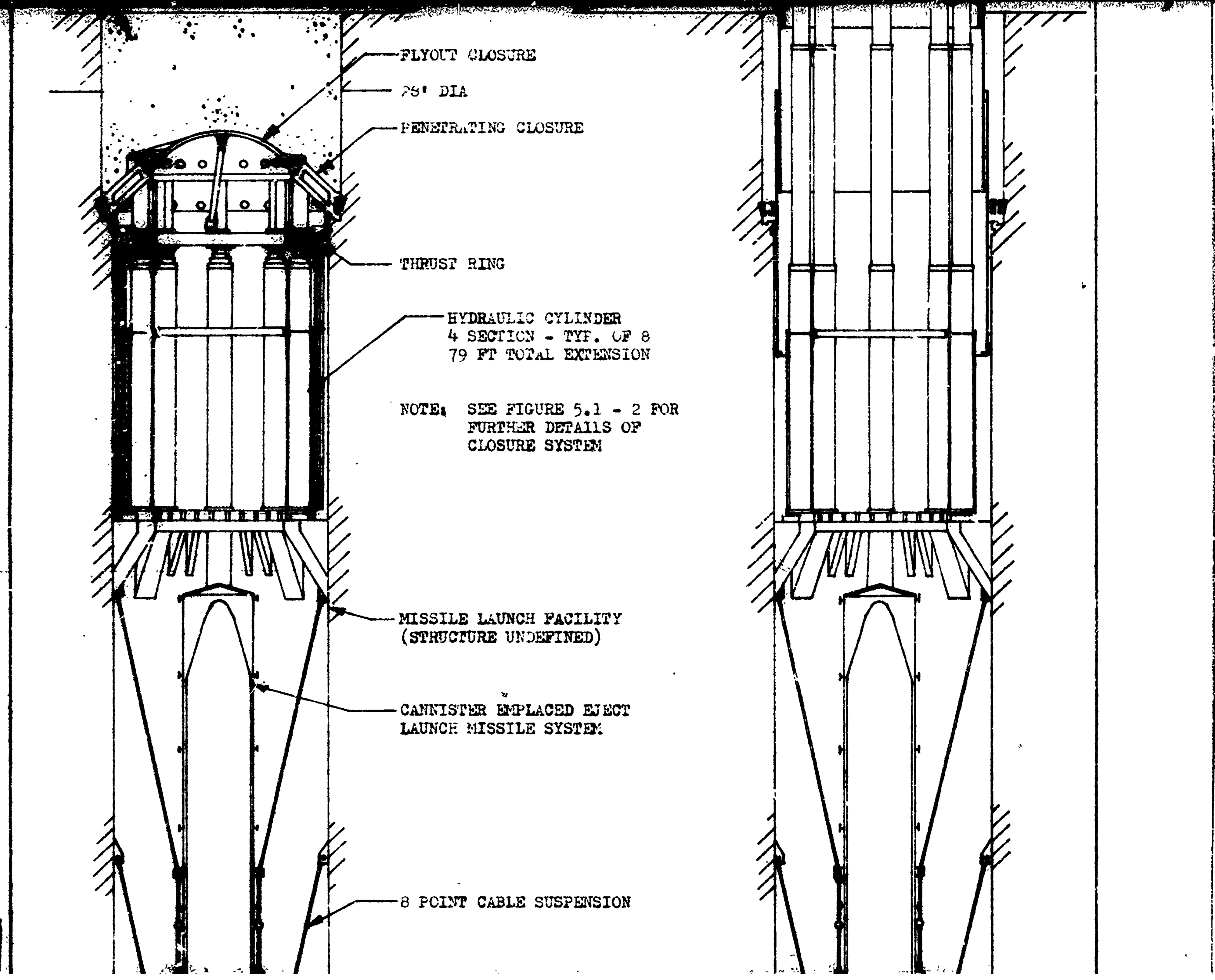


15' DIA. FLYOUT ENVELOPE
FLYOUT CLOSURE OPEN
NOMINAL DEBRIS LEVEL
TELESCOPING DEBRIS SHIELD
4 - SECTIONS
30'
SURFACE PROTECTION FILL
MATERIAL - GRAVEL
GROUND SURFACE
FLYOUT CLOSURE
28' DIA


FLYOUT CLOSURE
28' DIA
PENETRATING CLOSURE
THRUST RING
HYDRAULIC CYLINDER
4 SECTION - TYP. OF 8
79 FT TOTAL EXTENSION
NOTE: SEE FIGURE 5.1 - 2 FOR FURTHER DETAILS OF CLOSURE SYSTEM
MISSILE LAUNCH FACILITY
(STRUCTURE UNDEFINED)
CANNISTER EMPLACED EJECT
LAUNCH MISSILE SYSTEM
8 POINT CABLE SUSPENSION

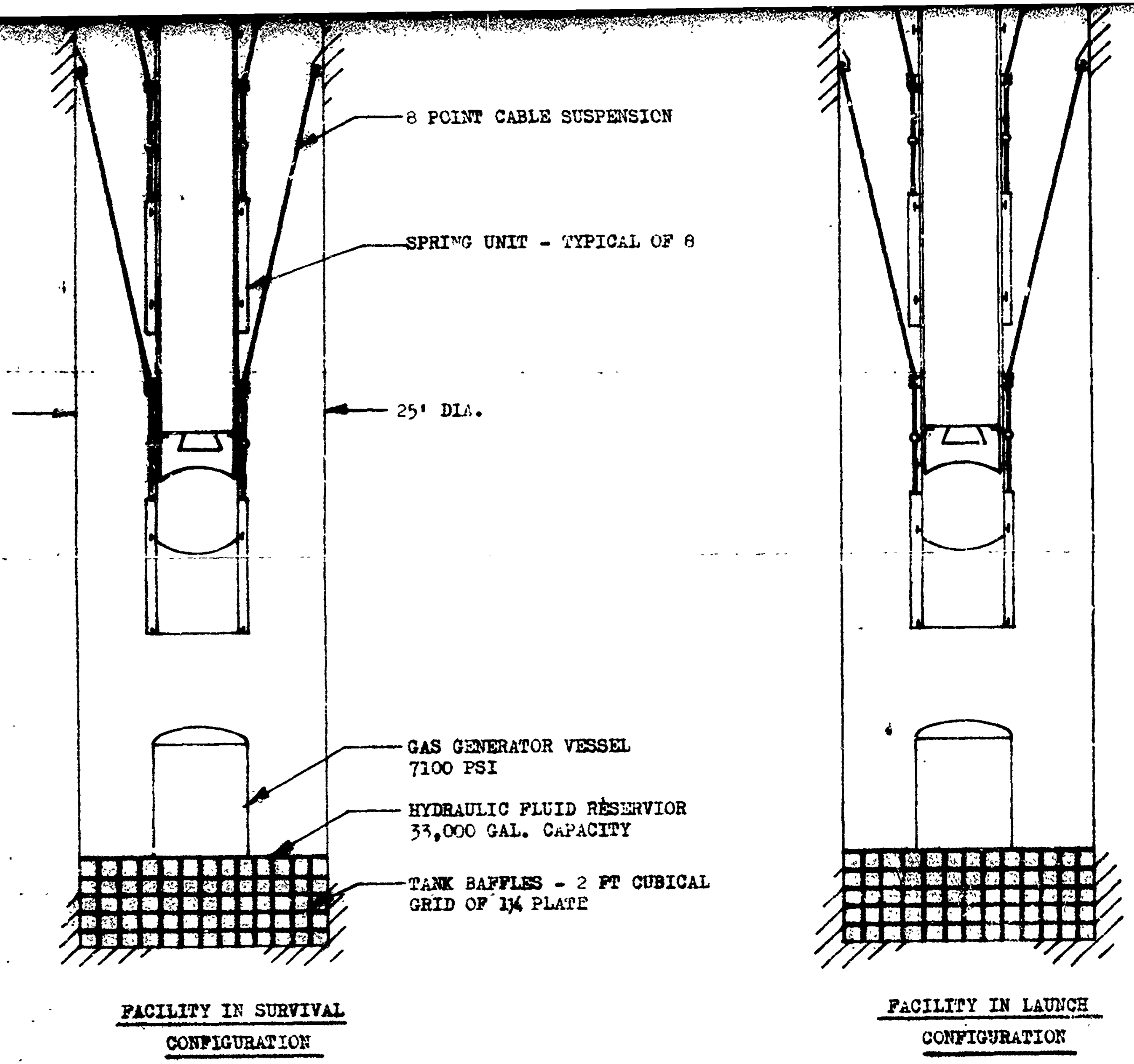


FIGURE 5.1 - 1

DEBRIS PENETRATING CLOSURE

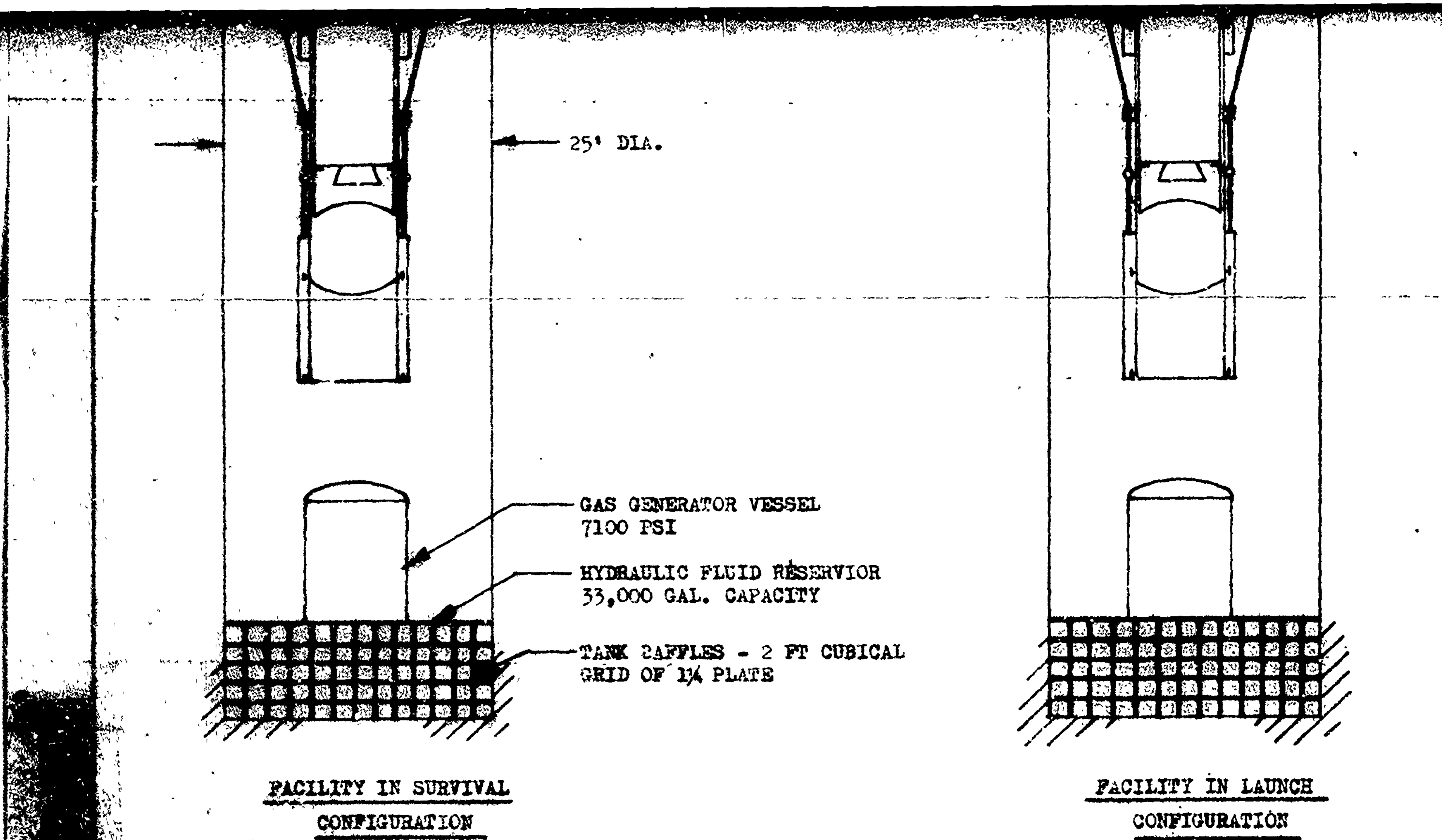
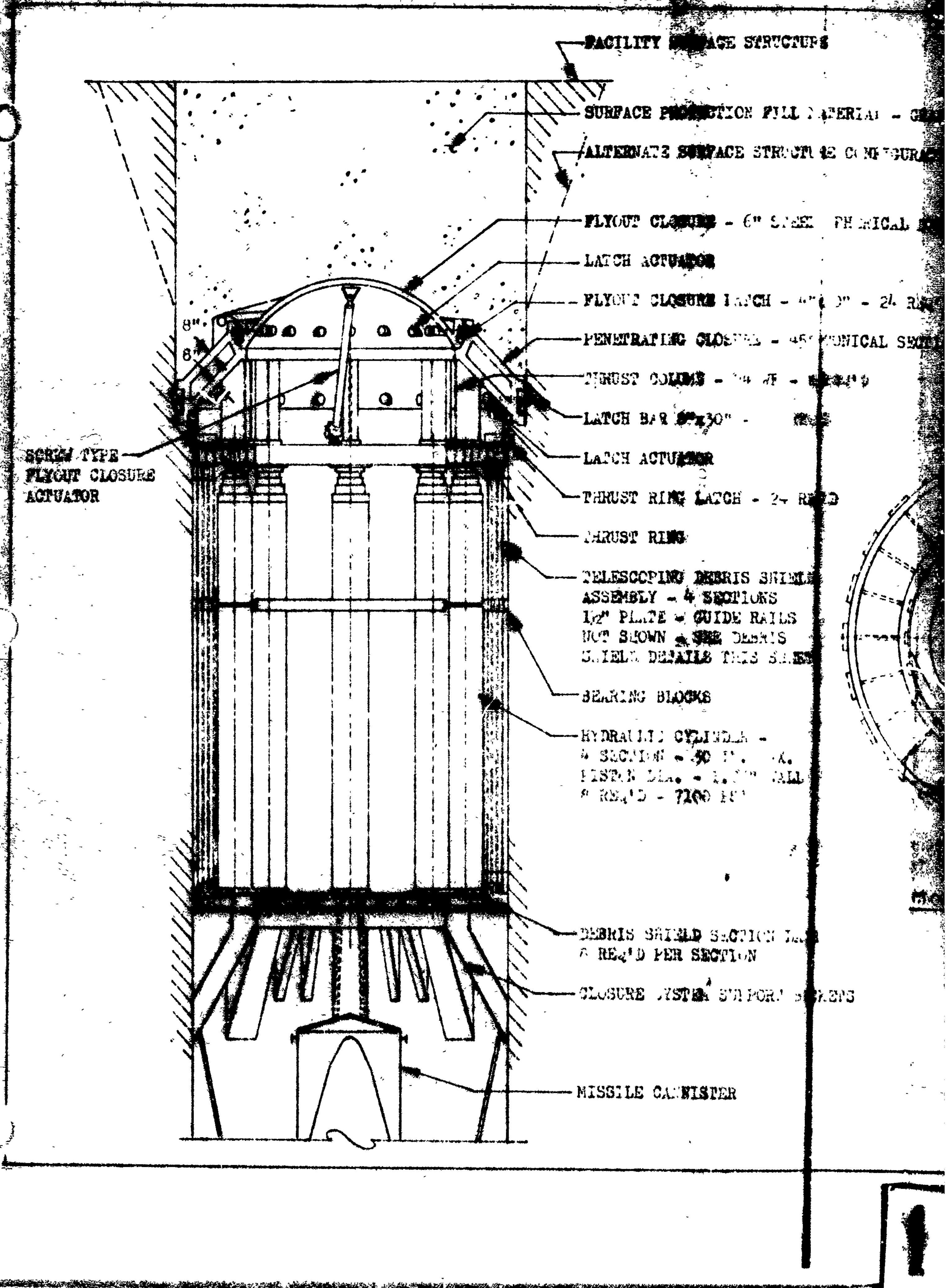


FIGURE 5.1 - 1

DEBRIS PENETRATING CLOSURE

(REF. DWG. 2-5166-0-173)

FACILITY
SURFACE
FLYOUT
LATCH ACTUATOR
FLYOUT CLOSURE
PENETRATING
THRUST
LATCH BAR
LATCH ACTUATOR
THRUST RING LATCH
THRUST RING
TELESCOPING DEBRIS
ASSEMBLY - 4 SECTIONS
1/2" PLATE - GUIDE RAILS
NOT SHOWN
BEARING BLOCKS
HYDRAULIC
DEBRIS SHIELD
REQ'D PER SECTION
CLOSURE
MISSILE CANISTER
SCREW TYPE
FLYOUT CLOSURE
ACTUATOR
8"
8"

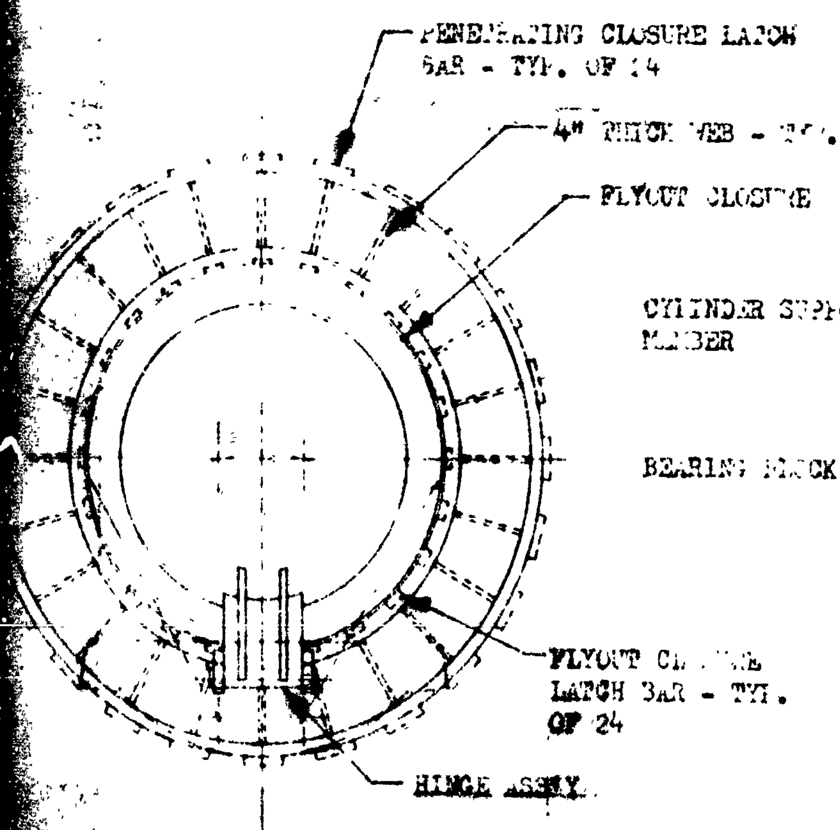
L - GRAVEL 15' DEPTH

IGURATION

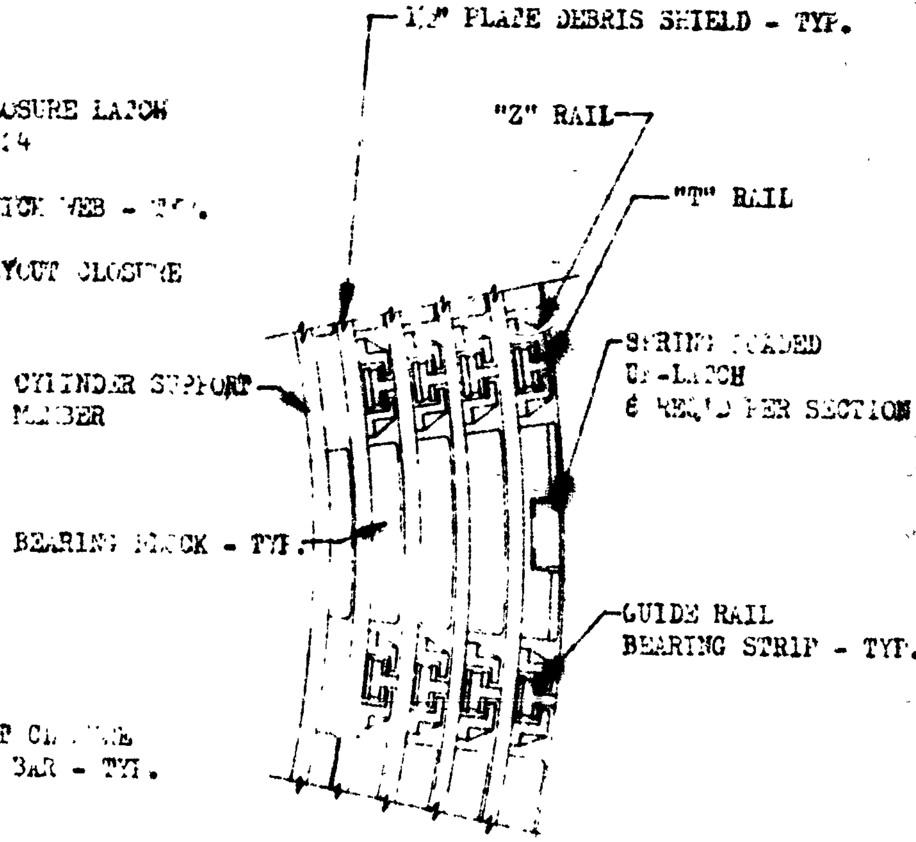
ICAL DOME

24 REQ'D

AL SECTION - TWO SHELLS



CLOSURE TOP VIEW



DEBRIS SHIELD DETAILS

FIGURE 5.1 - 2

DEBRIS PENETRATING CLOSURE DETAILS

5.1 (Continued)

To launch the missile, the main closure latches, the thrust ring latches, and the debris shield latches are released, and the solid propellant gas generator is fired to pressurize the hydraulic fluid reservoir. Hydraulic pressure raises the closure and attached debris shield section. The hydraulic control system will regulate the rate of rise and a level sensor system will control the pressure in each cylinder to equalize the relative displacement between cylinders and compensate for uneven loading conditions. As each stage of the debris shield reaches its extension limit, spring loaded up-latch devices engage to lock the sections together. When the maximum height is reached, the hydraulic pressure is bled off and the debris shield assembly supports the closure assembly.

The flyout closure is then unlatched and the linear actuators open the closure 90 degrees. The environmental cover on the missile canister remains in place to protect against the loose debris which will fail as the flyout closure is raised. When the closure is in the full open position the canister environmental cover is opened and the missile may be launched.

CLOSURE ASSEMBLY

The silo closure is a two-part assembly consisting of a primary closure for debris penetration and a smaller flyout closure. The two closure approach is used to eliminate the problems associated with the opening of a single massive closure for flyout. The primary closure is a truncated conical structure of two 8 inch thick steel shells separated by webs with heavy ring sections at the inner and outer edges to reinforce the edges and carry the latching devices. The nominal O. D. is 28 feet and an inner diameter of 16 feet 8 inches provides a nominal 15 foot flyout clearance and radial clearance for the flyout closure actuators.

The entire closure assembly is restrained against dynamic loads by hinged compression latch bars which engage a latch receiver in the facility wall structure. Twenty-four latch bars, having an 8 inch by 30 inch nominal cross section are provided. Each latch bar is individually operated by a motor driven screw jack.

The flyout closure is configured as a 6 inch spherical shell with an edge reinforcing ring which also carries the latching devices. The closure is hinged for opening and is operated by two screw type actuators. The closure rotates 90 degrees on opening and stands vertical in the open position. The closure is provided with 24 latch bars of 4 in. by 10 in. cross section. The latches are operated by individual screw jacks similar to the primary closure latches.

The primary closure is provided with eight thrust columns which interface with the thrust ring for push-out. An interface is provided by a resilient or crushable member between the thrust ring and closure assembly to allow relative motion between the components during dynamic loading.

5.1 (Continued)

THRUST ASSEMBLY

The thrust assembly consists of the thrust ring and the hydraulic cylinders. The thrust ring is a plate weldment nominally 24.5 feet outside diameter, 15 feet inside diameter and 18 inches deep. The ring ties together the eight hydraulic cylinders, provides the interface with the closure thrust columns, and provides support for the upper end of the cylinders during dynamic loading. The configuration of the ring is such that the upper surface provides a work platform for access to the closure actuators and latching devices.

Twenty-four shear type latches are provided on the thrust ring to provide vertical-up restraint for the thrust ring and the hydraulic cylinder sections. Vertical-down reactions are taken by the cylinder sections bottoming in the cylinder. Bearing blocks are provided around the outer edge of the thrust ring to provide horizontal support during dynamic loading.

The thrust ring is actuated by eight 30 foot long hydraulic cylinders having four sections to provide a total extension of 79 feet. The cylinders have a maximum stage diameter of 30 inches and operate at a maximum pressure of 7,100 psi to provide approximately 40 million pounds of thrust for debris penetration. An intermediate support ring is provided approximately 9 feet below the top of the cylinders to minimize the lateral end reactions and to provide a support structure for installation. The cylinders are tied together by a large ring structure and horizontal reactions are carried through the debris shield assembly by compression bearing blocks on each shield.

The lower end of the cylinders rests on heavy brackets which are to be integrated with the facility structure.

DEBRIS SHIELD

The debris shield assembly consists of four concentric shield sections each approximately 32 feet long fabricated of 1 1/2 inch plate. The largest shield is 24 feet 4 inches O. D. and the nominal spacing is 5 inch. The inner shield is attached to the thrust ring and is carried upward with the thrust ring for push-out. The inner shield alone raises until there is approximately 12 feet overlap with the next shield. At this point the two sections engage and the inner shield pulls up the next section. As the closure raises the other shield sections engage and lock together to form a cylindrical structure which can support the closure assembly when hydraulic pressure is relieved. Bearing blocks are provided at the upper and lower end of each shield section to transfer the radial compression forces which occur from dynamic loads and from side thrust due to uneven debris distribution during push-out.

The debris shield assembly is designed to withstand horizontal dynamic loadings by supporting the relative thin wall shields on a guide rail system which is attached to the facility wall. Radial inward loads are taken by the guide rail system in tension and radial outward loads are taken by the rail system and the bearing blocks.

5.1 (Continued)

Vertical dynamic loads require that each debris shield section be individually restrained by latching devices. Eight shear type latches are provided for each section and these are located at the lower end of the shield between the base of the hydraulic cylinders and the supporting brackets.

HYDRAULIC SUPPLY SYSTEM

The hydraulic supply system is located at the bottom of the facility and consists of an integral baffeled fluid reservoir which is directly pressurized by a solid propellant gas generator. Hydraulic actuation is provided to insure control during push-out and a gas generator is utilized as the only available power source which will produce the high horsepower required for penetration and launch in a short time.

The tank baffling is nominally a two foot cubical grid of 1-1/4 inch steel plate. The fluid quantity required is approximately 33,000 gallons.

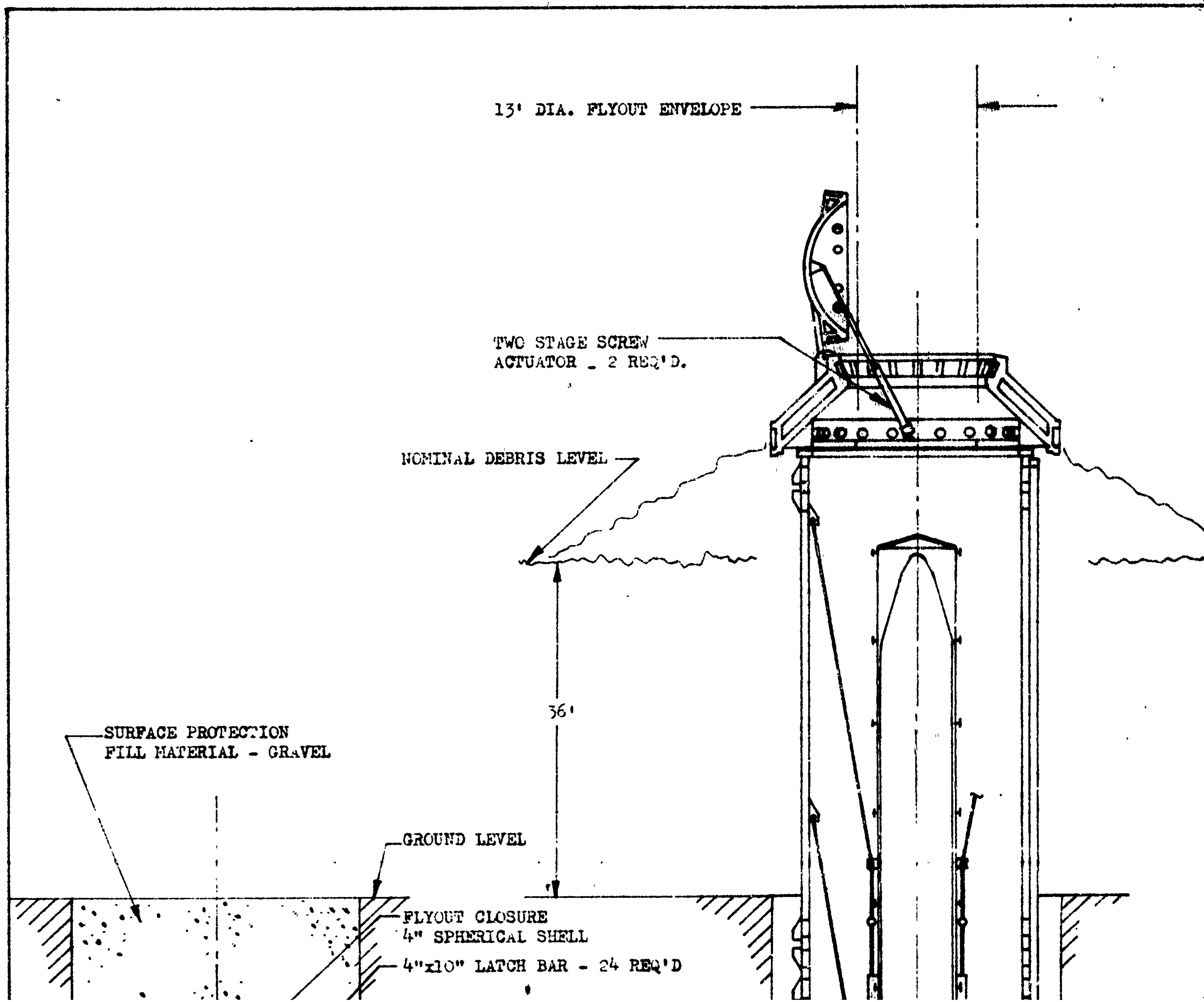
The gas generator contains an estimated 16,000 pounds of propellant and is configured as a pressure vessel integral with the fluid reservoir with the propellant grain assembly shock mounted within the vessel.

5.2 DEBRIS PENETRATING LAUNCHER CONCEPT 1

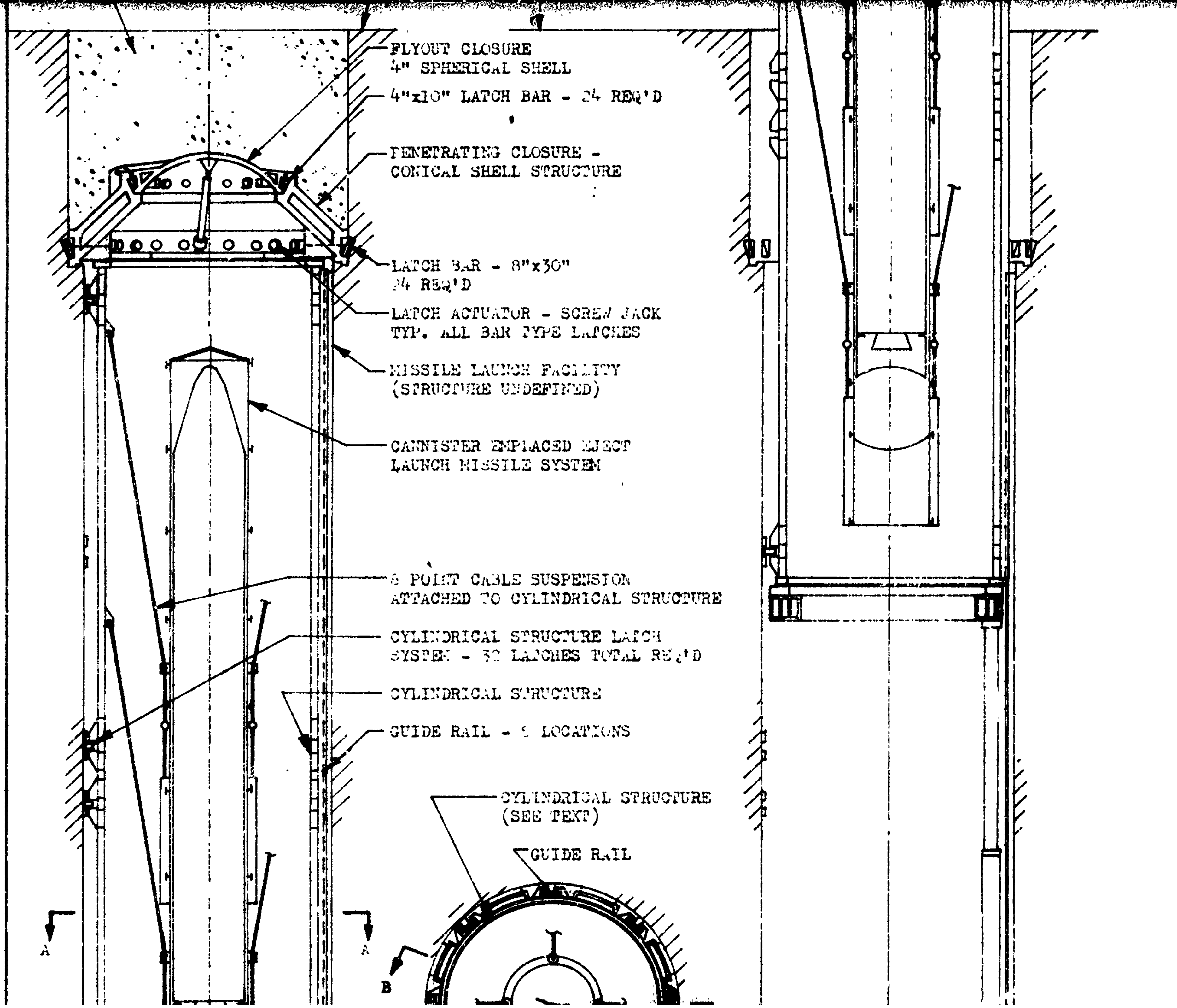
This concept develops the basic idea of attaching the missile canister to the silo closure and debris shield and pushing the entire launcher through the accumulated debris from the assumed attack. The advantages of this concept are to eliminate a complex telescoping debris shield assembly and to get the missile canister nearer the surface to eliminate the problem of ejecting or flying the missile 200 feet to clear the fly-out opening.

The resulting configuration is shown in Figure 5.2-1. The launcher consists of three basic sections. The first is the silo closure, the second is the inner cylinder structure with the attached missile canister, and the third is the thrust ring and hydraulic actuator assembly.

In the launch sequence, the hold down latches of all sections are released and the hydraulic actuator assembly raises the entire inner cylinder assembly and closure assembly with sufficient force available to push through the granular shield material and the accumulated attack debris. After the assembly is latched up, the fly-out closure is opened for launch. The canister cover remains in place during closure opening to protect the missile from loose debris which may fall during opening.



13' DIA. FLYOUT ENVELOPE
TWO STAGE SCREW
ACTUATOR - 2 REQ'D.
NOMINAL DEBRIS LEVEL
36'
SURFACE PROTECTION
FILL MATERIAL - GRAVEL
GROUND LEVEL
FLYOUT CLOSURE
4" SPHERICAL SHELL
4"x10" LATCH BAR - 24 REQ'D


FLYOUT CLOSURE
4" SPHERICAL SHELL
4"x10" LATCH BAR - 24 REQ'D
PENETRATING CLOSURE -
CONICAL SHELL STRUCTURE
LATCH BAR - 8"x30"
24 REQ'D
LATCH ACTUATOR - SCREW JACK
TYP. ALL BAR TYPE LATCHES
MISSILE LAUNCH FACILITY
(STRUCTURE UNDEFINED)
CANNISTER EMPLACED EJECT
LAUNCH MISSILE SYSTEM
POINT CABLE SUSPENSION
ATTACHED TO CYLINDRICAL STRUCTURE
CYLINDRICAL STRUCTURE LATCH
SYSTEM - LATCHES TOTAL REQ'D
CYLINDRICAL STRUCTURE
GUIDE RAIL - LOCATIONS
CYLINDRICAL STRUCTURE
(SEE TEXT)
GUIDE RAIL
A
A
B

2

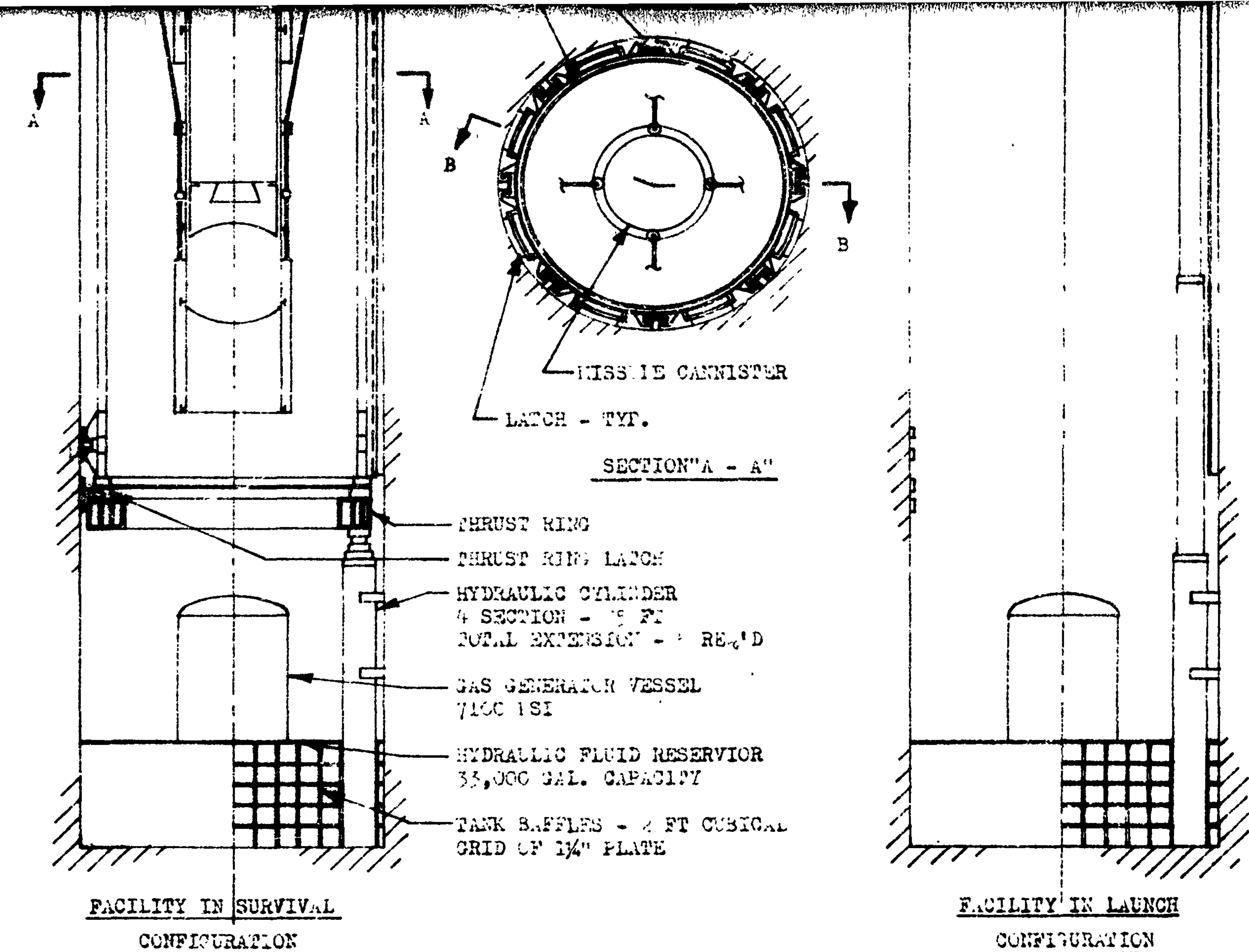


FIGURE .2 - 1

DEBRIS PENETRATING LAUNCHER I

(REF. DWG. -5166-)

REV LTR

3

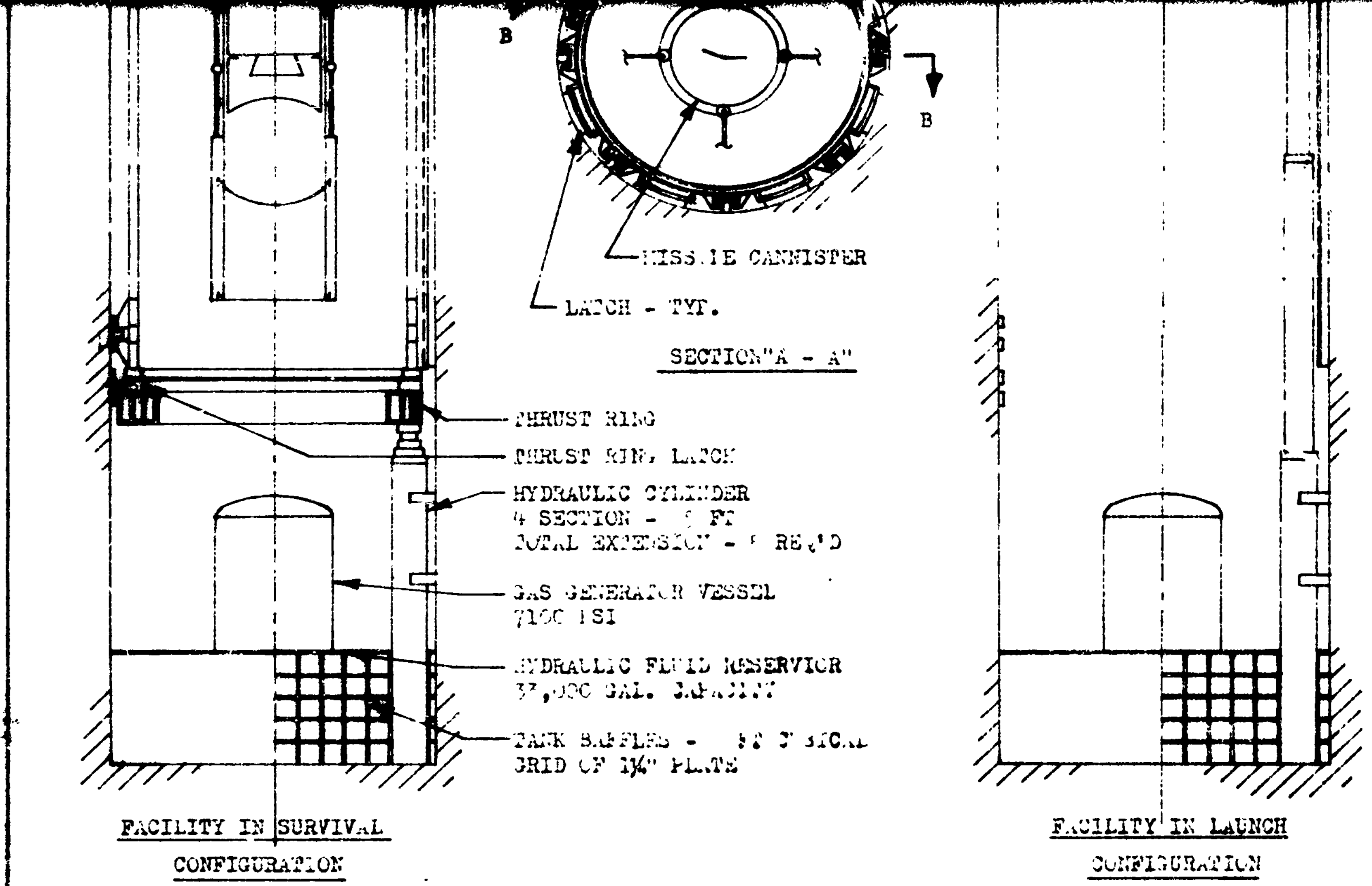


FIGURE [illegible].2 - 1

DEBRIS PENETRATING LAUNCHER I

(REF. DWG. [illegible])

REV LTR A

5.2 (Continued)

CLOSURE ASSEMBLY

The silo closure is a two-part assembly consisting of a main debris penetrating closure and a smaller flyout closure. The two closure approach is used to eliminate the problems associated with the opening of a single massive closure. The main closure is a truncated conical structure of two 8 inch thick shells separated by webs with heavy ring sections at inner and outer edges to reinforce the edges and carry the latching devices. The nominal O. D. is 31 feet, and an inner diameter of 15 feet provides the necessary 13 foot flyout envelope and radial clearance for the flyout closure actuators.

The entire closure assembly is restrained aginst dynamic loads by hinged compression latch bars which engage a mating latch receiver in the facility wall structure. Twenty-four latch bars, having an 8- x 30-inch nominal cross section, are provided. Each latch bar is individually operated by a motor driven screw jack.

A thrust structure is provided below the inner surface of the missile conical shell to provide an interface with the inner cylinder during pushout. A positive clearance is to be provided by a resilient or crushable layer to allow relative motion between the components during dynamic loading.

The flyout closure is configured as a 4 inch thick spherical shell with an edge reinforcing ring which also carries the latching devices. The closure is hinged for opening and actuated by two screw type actuators. The closure is rotated 90 degrees on opening and stands vertical in the open position. Twenty-four bar type latches 4 in. by 10 in. cross section are provided to restrain the closure during shock loading. The latch bars are actuated by screw type jacks similar to the main closure latches.

INNER CYLINDER STRUCTURE

This section consists of a 24 foot I.D. by approximately 112 foot long cylindrical structure which is mounted on guide rails attached to the silo structure. The missile canister suspension is attached to the inner wall of the cylindrical structure. The structure consists of 1/2 in. inner and outer sheets with stiffeners to form a shell 6 in. deep. The structure is supported radially by continuous vertical guide rails on the wall of the facility. The rails support the structure in tension during dynamic loading to prevent an inward collapse.

The inner cylinder assembly is independently supported vertically by latching devices at the upper end, lower end, and the center. Thirty-two shear type latch members of approximately 5 in. by 36 in. cross section are required. Latch configuration has not been defined in the study.

5.2 (Continued)

THRUST ASSEMBLY

The thrust assembly consists of a thrust ring, the hydraulic cylinders and the hydraulic power supply. The thrust ring is approximately a 27 feet O.D., 19 feet I.D., 3 foot thick welded plate fabrication which ties together the top of the hydraulic cylinders and provides the interface with the cylindrical structure. Bearing blocks are provided on the facility wall to carry the guide rails. There are 8 latching devices provided to restrain the thrust ring and the upward reactions of the hydraulic cylinder sections. The hydraulic cylinder downward reactions are carried by bottoming the cylinder sections within the cylinder. A positive clearance is to be provided by a resilient or crushable layer to allow relative motion between the components during dynamic loading.

The thrust ring is actuated by eight 30 foot long hydraulic cylinders having four sections to provide a total extension of 75 feet. The cylinders have a maximum stage diameter of 30 inches and operate at a maximum pressure of 7,100 psi to provide approximately 40 million pounds of thrust for debris penetration. The hydraulic power supply consists of an integral baffled fluid reservoir which is directly pressurized by a solid propellant gas generator. Hydraulic actuation is provided to insure control during push-out and a gas generator is utilized as the only available power source which will produce the high horsepower required for penetration and launch in a short time period.

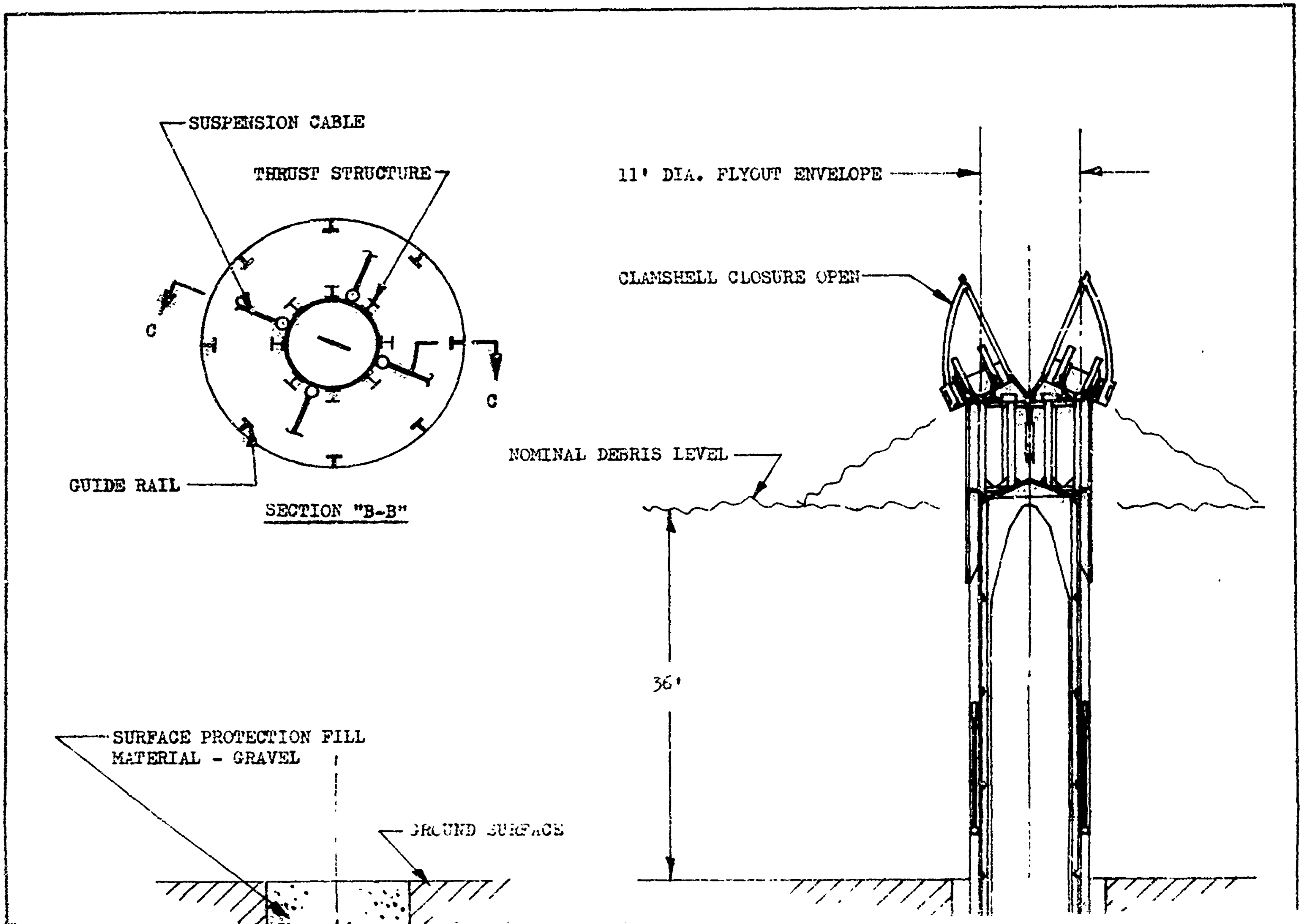
Approximately 16,000 lb. of propellant and 33,000 gallons of fluid are estimated to be required.

The tank baffling consists of approximately 1-1/4 inch thick plates in a two-foot cubical grid. The gas generator is configured at a pressure vessel integral with the fluid reservoir with the propellant grain assembly shock mounted within the vessel.

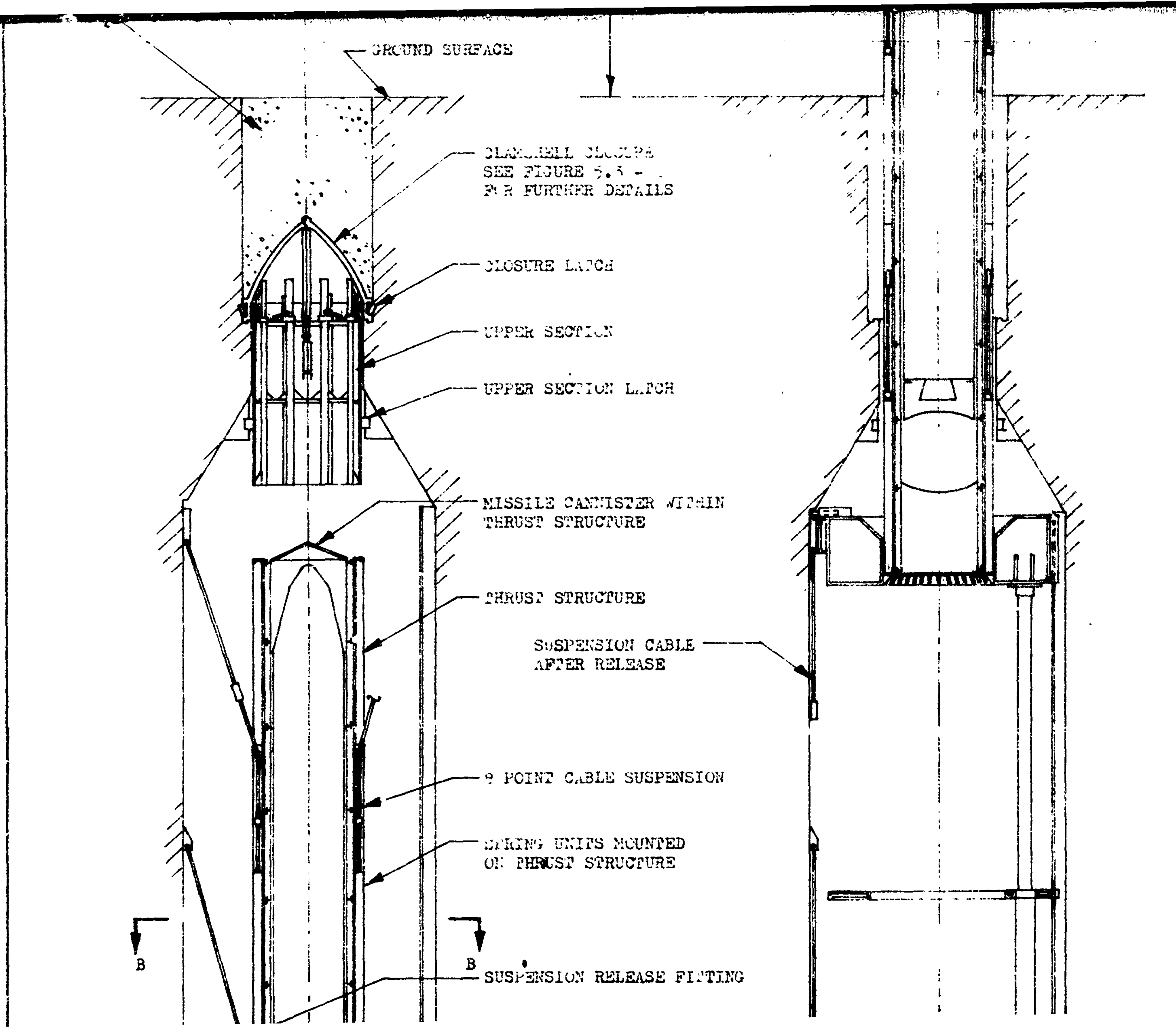
5.3 DEBRIS PENETRATING LAUNCHER CONCEPT II

This concept is designed to use the smallest possible surface opening and closure diameter in order to minimize push-out force requirements and to increase the survivability of the basic silo structure. This is accomplished by utilizing the missile support structure as the push-out member, with a hudraulically powered thrust platform providing the necessary thrust.

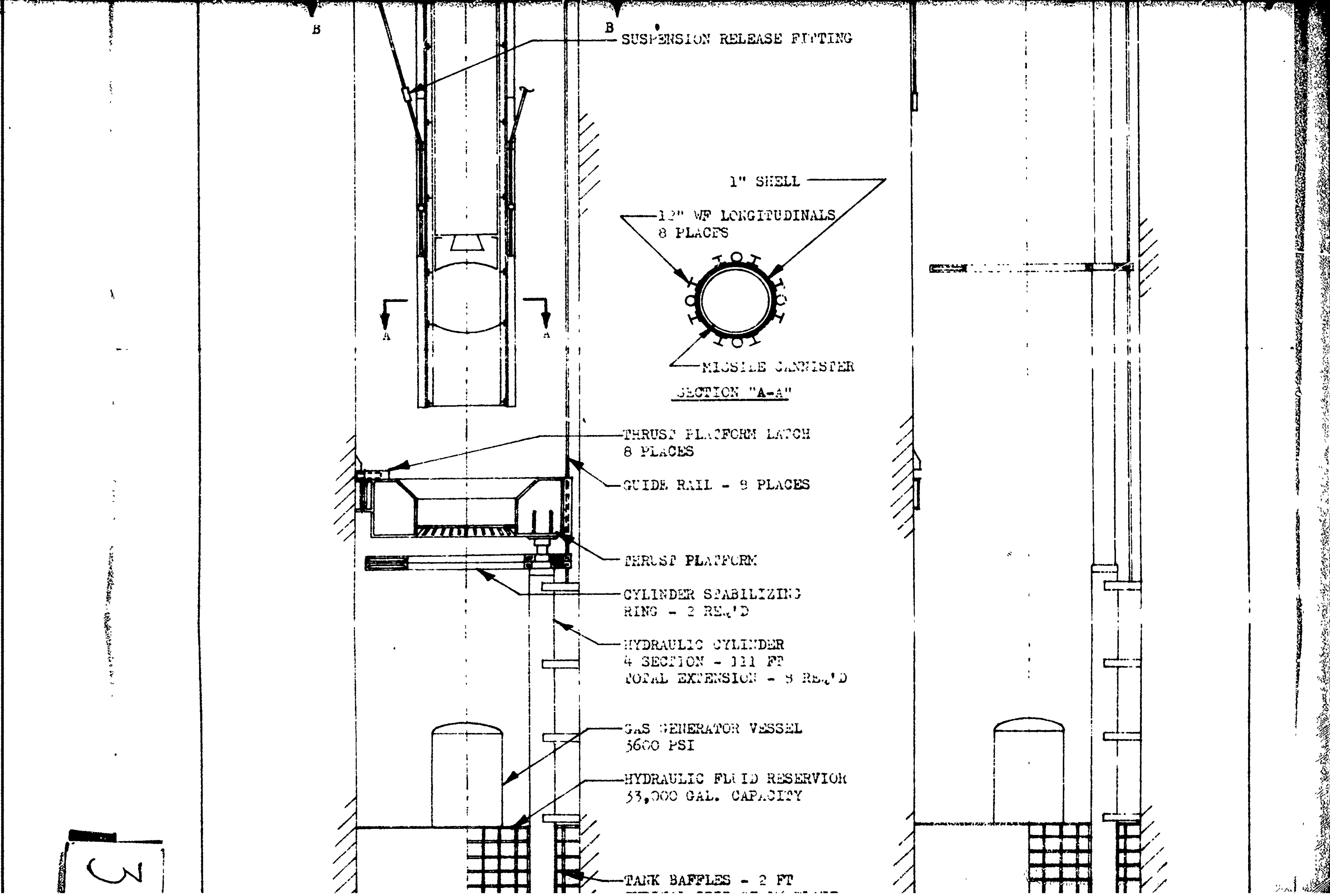
This configuration is illustrated in Fig. 5.3-1. In order to use the smallest diameter silo opening, the thrust structure is made to fit closely around the missile canister (a cold launch system is the most compatible with this silo concept), and this entire assembly is suspended within the silo to provide the necessary dynamic clearance envelope. The push-out assembly is configured in 3 sections which are separated by the required clearance for shock survival. The first section consists of the silo closure and the debris penetrator upper structure. The second section is the canister and thrust structure assembly. The third section at the bottom of the silo, is the thrust ring and hydraulic actuator assembly.



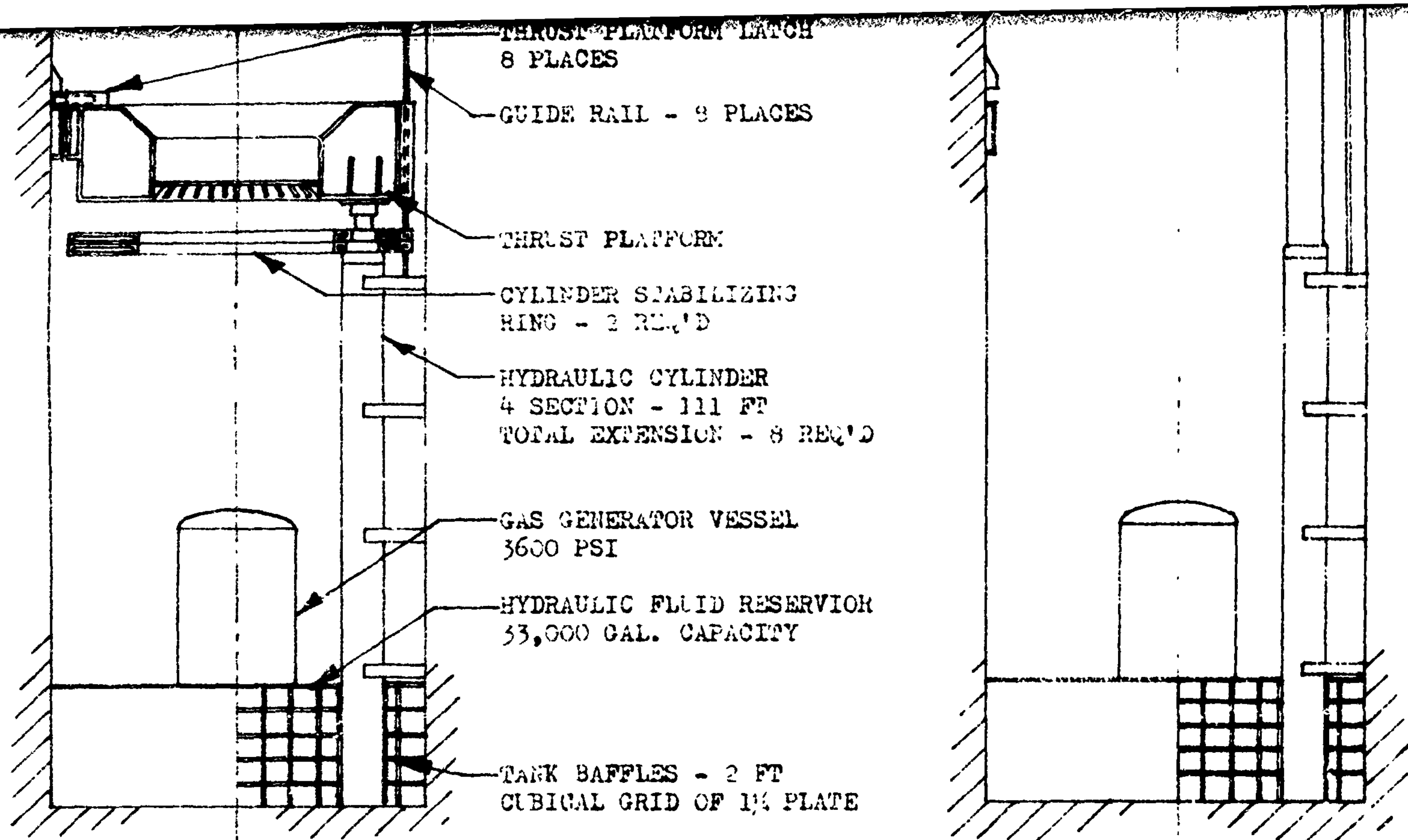
SUSPENSION CABLE
THRUST STRUCTURE
C
C
GUIDE RAIL
SECTION "B-B"
11' DIA. FLYOUT ENVELOPE
CLAMSHELL CLOSURE OPEN
NOMINAL DEBRIS LEVEL
36'
SURFACE PROTECTION FILL
MATERIAL - GRAVEL
GROUND SURFACE


GROUND SURFACE
CLAMSHELL CLOSURE
SEE FIGURE 5.5 -
FOR FURTHER DETAILS
CLOSURE LATCH
UPPER SECTION
UPPER SECTION LATCH
MISSILE CANNISTER WITHIN
THRUST STRUCTURE
THRUST STRUCTURE
SUSPENSION CABLE
AFTER RELEASE
8 POINT CABLE SUSPENSION
SPRING UNITS MOUNTED
ON THRUST STRUCTURE
B
B
SUSPENSION RELEASE FITTING

2



B
B
SUSPENSION RELEASE FITTING
1" SHELL
12" WF LONGITUDINALS
8 PLACES
MISSILE CANNISTER
SECTION "A-A"
A
A
THRUST PLATFORM LATCH
8 PLACES
GUIDE RAIL - 8 PLACES
THRUST PLATFORM
CYLINDER STABILIZING
RING - 2 REQ'D
HYDRAULIC CYLINDER
4 SECTION - 111 FT
TOTAL EXTENSION - 8 REQ'D
GAS GENERATOR VESSEL
3600 PSI
HYDRAULIC FLUID RESERVIOR
53,000 GAL. CAPACITY
TANK BAFFLES - 2 FT
3



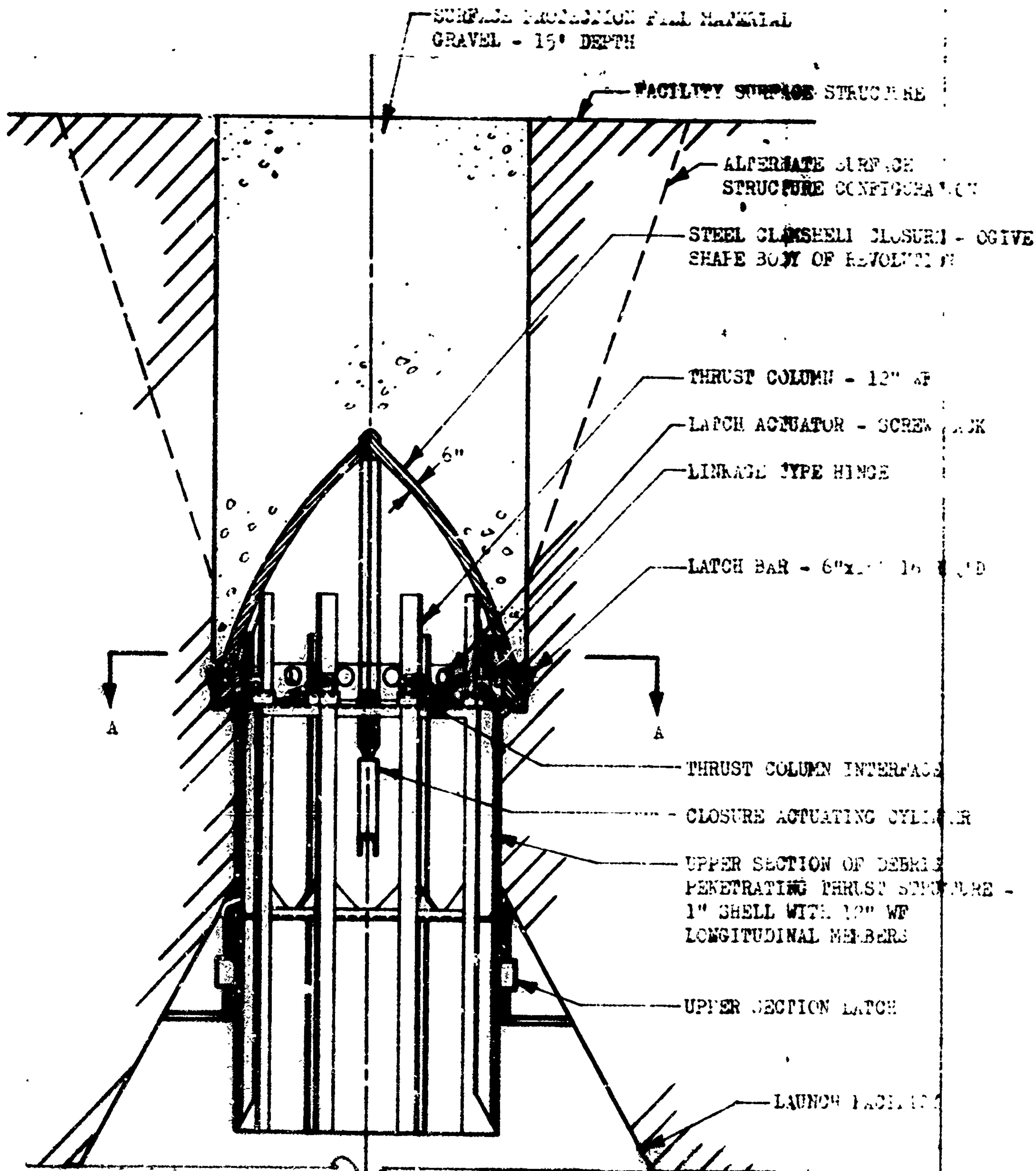
FACILITY IN SURVIVAL CONFIGURATION "C-C"

FACILITY IN LAUNCH CONFIGURATION

FIGURE 5.3 - 1

DEBRIS PENETRATING LAUNCHER II

(REF. DWG. 2-5167-C-219)



CLAMSHELL CLOSURE

UCTURE

RFACE
NFIGURATION

CLOSURE - OGIVE
EVOLUTION

12" WF

SCREW JACK

NGE

16" 16 WF

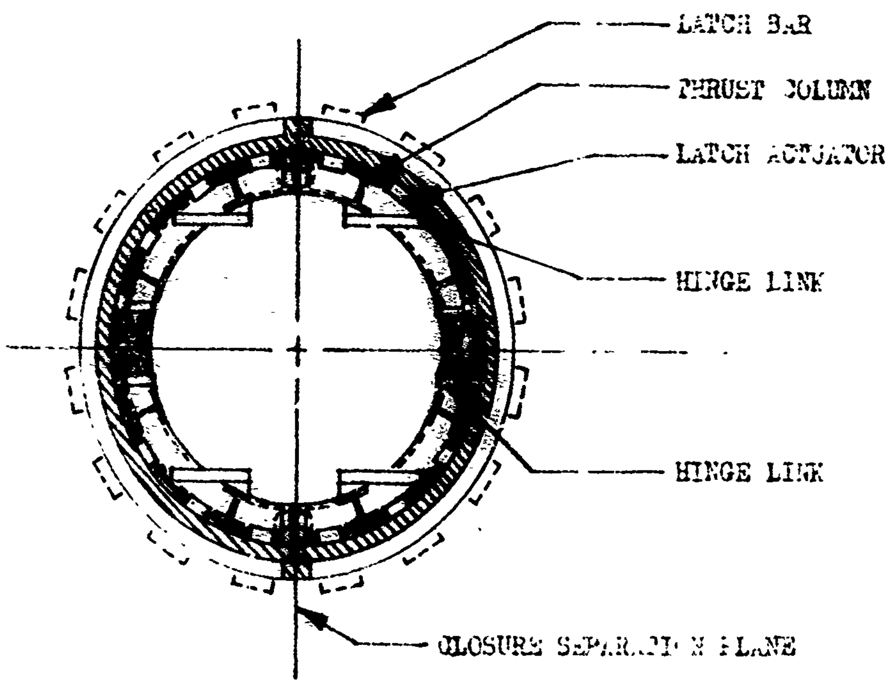
NTERFACE

NG CYLINDER

DEBRIS
ST STRUCTURE -
2" WF
BERS

TCH

ACILIT



SECTION "A - A"

FIGURE 5.3 - 2

CLAMSHELL CLOSURE

5.3 (Continued)

In the launch sequence, the thrust platform raises approximately 15 feet to engage the lower end of the thrust structure. This combined assembly continues to raise, removing the load from the suspension springs. When the springs bottom out, the cables are separated from the assembly by a release fitting and fall to the side of the silo. The assembly continues to rise and the thrust structure engages the upper section of the penetrator with an overlap of approximately 10 feet. At this point, the closure is unlatched and the assembly is pushed through the debris to a fixed height and is latched in place. The clamshell closure is opened and the missile is ready for launch. The environmental cover is to be carried out with the missile and separate by an unbalanced dynamic pressure or a small thrust device soon after launch.

UPPER SECTION

The upper section consists of the silo closure and debris penetrator upper structure. The components are individually secured against dynamic loads but of necessity have functional interfaces in the hinges, thrust structure, and actuator linkages.

The silo closure is configured as an ogive shaped body of revolution 6 inches thick, with a minimum slope of 40° to insure debris fall off after penetration. The closure is split vertically for opening and is actuated by a linear actuator which may be hydraulically or gas actuated. The closure halves are to be keyed together and latched in the closed position. The circumferential reinforcing ring at the base of the closure carries the closure latching devices and is keyed into a receiving groove in the facility. The latching devices are the compression bar type with screw jack actuators. Sixteen latches having a 6-inch x 16-inch cross section are provided.

The debris penetrator upper structure consists of an outer shell and eight wide flange beam stiffeners with rings at the top and center to maintain shape and provide interface structure. The lower half of the cylinder is designed to overlap the upper few feet of the mating thrust structure to make a bayonet type point for pushout. The nominal 12 inch depth will allow space for lid actuators, locking devices, etc.

The upper structure is provided with a separate latch system designed to support the structure under dynamic conditions. The interfaces between the closure and this structure must have sufficient play to accommodate the relative motion between the components.

THRUST STRUCTURE

The second section of the assembly is a structural container for the missile canister which is suspended within the silo to provide shock isolation for the missile. The structure is similar to the upper structure, consisting of a shell and wide flange stiffeners nominally 12 inches deep. The shell, however, is on the inner diameter to provide the mating half of the "bayonet" joint and to allow suspension attachment. The inner diameter is approximately 6 inches greater than the missile canister outside diameter, with a two

5.3 (Continued)

location interface, so that deflection of the structure during push-out will not strain the missile canister.

The suspension system, as shown, is assumed to be an eight point cable suspension symmetrical about the C.G. of the assembly as described in Section 5.0. The spring units are secured to the structural cage, for this concept, with ring stiffeners and cable guides at the desired support locations.

To provide release of the suspension during push-out of the assembly, a release fitting is defined which will actuate when the pneumatic spring is retracted to the lower limit. The cable is released and falls to the side of the silo.

THRUST ASSEMBLY

The thrust assembly is located at the bottom of the silo and consists of the hydraulic actuators, a large rail guided thrust platform, and the hydraulic power supply.

The thrust platform is an assembly approximately 25 feet O.D. by 13 feet I.D. and 8 feet deep fabricated of welded 1 inch plate. A ledge within the I.D. interfaces with the lower end of the suspended thrust structure when the platform is raised for push-out. The platform is actuated by eight four-section hydraulic cylinders approximately 45 feet long having a maximum stroke of approximately 111 feet to accomplish debris penetration. The cylinders are approximately 30 inch maximum piston diameter and operate at approximately 3,600 psi to provide a total push-out thrust of 20 million pounds.

The platform is guided during push-out by eight guide rails which run the full length of the silo. The guide rails are designed to be loaded in tension to minimize any jamming tendency should the cylinder thrust become unbalanced.

The thrust platform is latched at eight locations to accommodate dynamic loads, the latches being designed to restrain the upward movement of the hydraulic cylinders in addition to the thrust platform. Downward reactions of the hydraulic cylinders are taken by bottoming. At each latch location, a bearing block is provided to restrain the thrust platform radially and prevent the guide rail bearings from being loaded dynamically.

The hydraulic power supply consists of an integral baffeled fluid reservoir which is directly pressurized by a solid propellant gas generator. Hydraulic actuation is provided to insure control during push-out and a gas generator is utilized as the only available power source which will produce the high horsepower required for penetration and launch in a short time period.

Approximately 33,000 gallons of fluid and 8,000 pounds of propellant are estimated to be required.

5.3 (Continued)

The tank baffling consists of approximately 1-1/4 inch thick plates in a 2-foot cubical grid. The gas generator is configured as an integrally mounted pressure vessel similar to the foregoing concepts.

5.4 DEBRIS PIT WITH SLIDING CLOSURE

This debris pit concept presents the least complex closure developed during the study. The sliding closure requires no survivable actuating system or power supply except a small gas generator to operate the latch devices and the single section debris shield.

The closure system as shown in Fig. 5.4-1, consists of a primary blast closure to withstand the peak overpressure, a secondary closure which can withstand the impact of the loose debris as it is deflected into the debris pit and a single section debris shield which prevents loose debris from falling onto the exposed missile after the facility and canister are open for launch.

The closure consists of a dome section of 4 inch thick steel and enclosed with a 2 inch thick cover, a 1-1/2 inch thick bottom and 2 inch thick sides. It is intended to withstand the blast overpressure, but on command the latches can be released so the closure will slide down the ways into the debris pit by gravity.

The debris shield is a steel ring stiffened with structural I Sections. It is actuated by three gas operated cylinders.

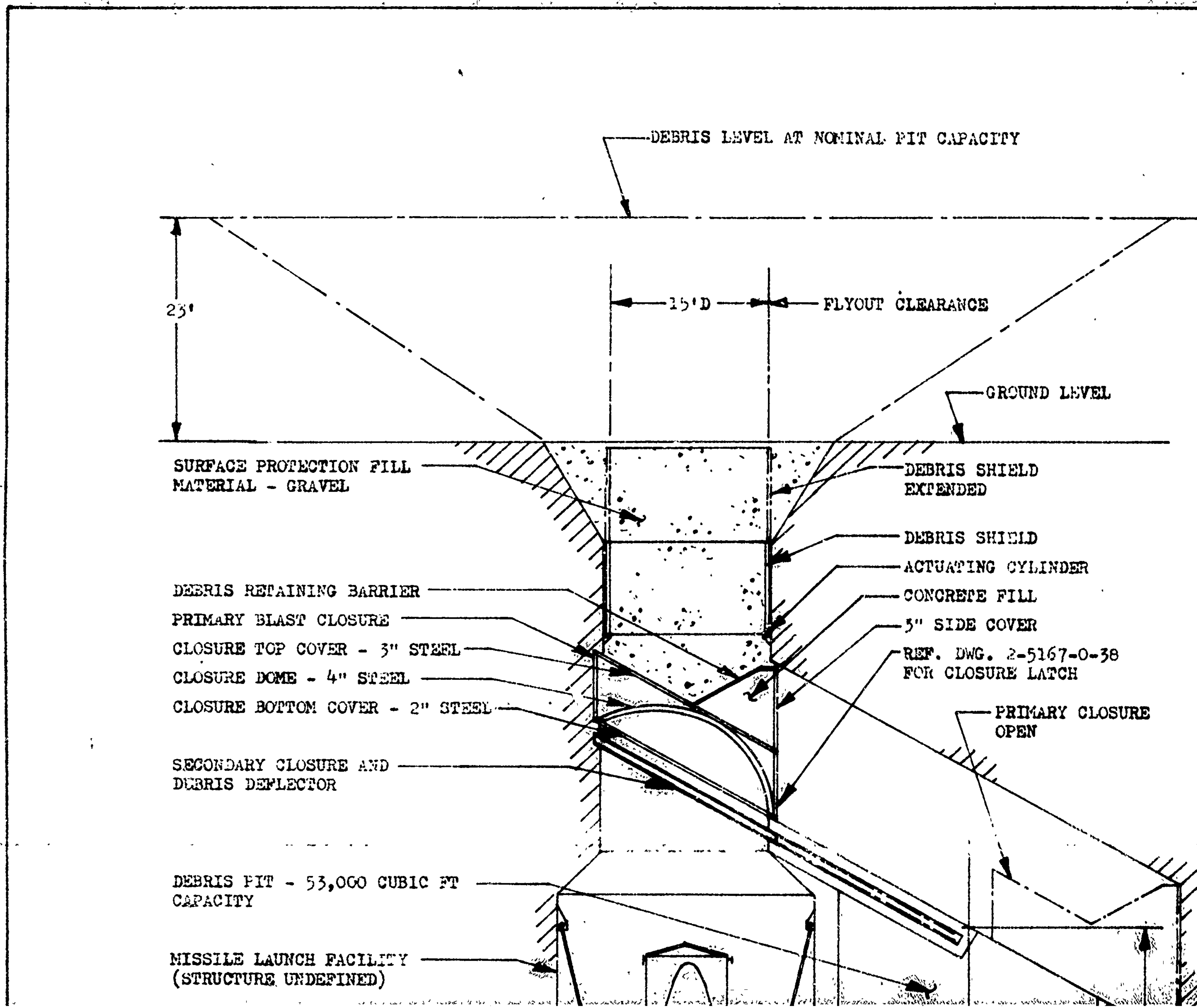
The secondary closure keeps the silo closed while the debris is discharged into the debris pit. It is then unlatched and slides down the ways into the debris pit by gravity.

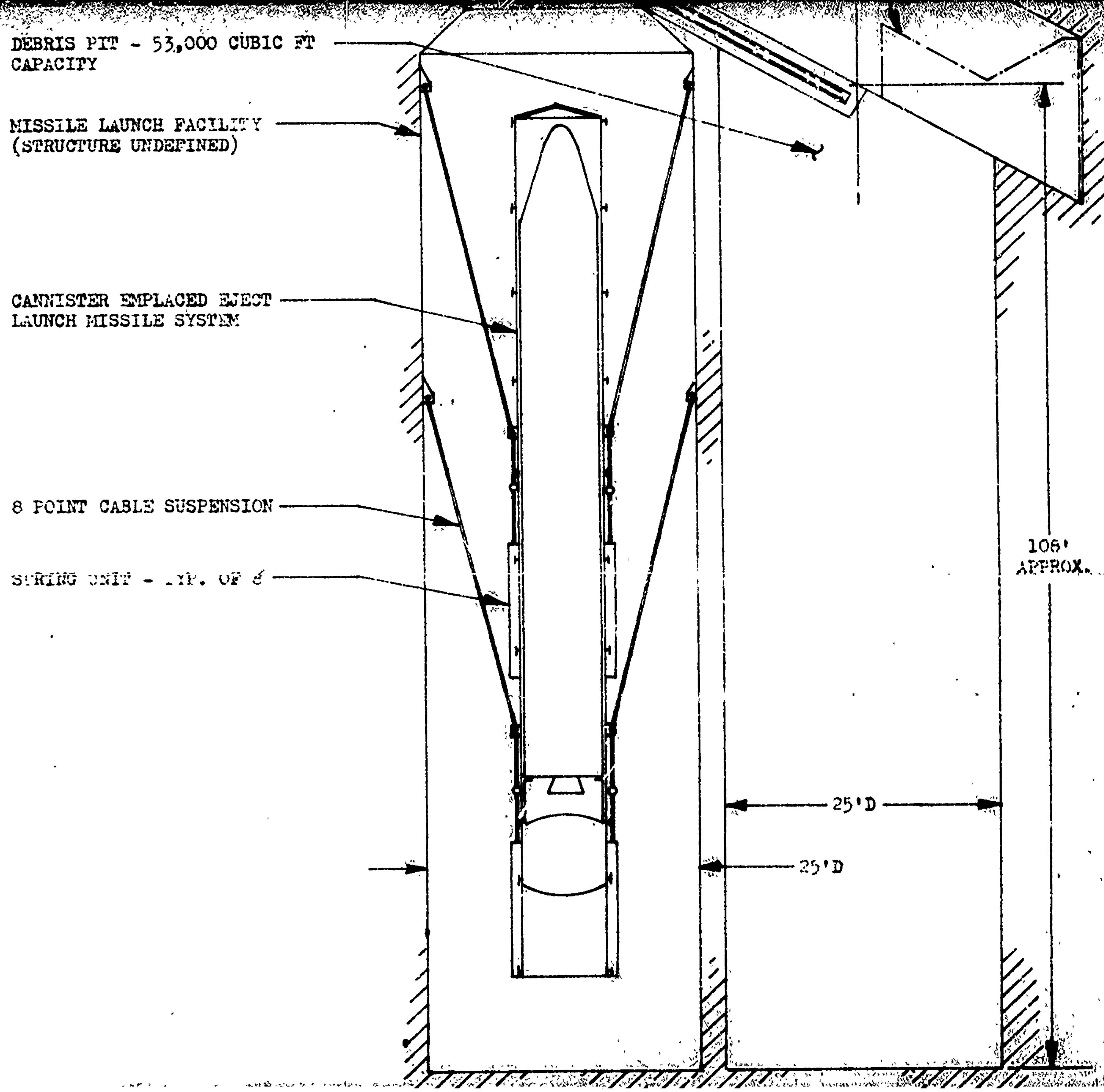
After installation of the missile, the deflector is pulled into place by a cable from an external power source and latched in place. Then the closure is pulled into place by the same power source and latched.

In the dormant or stand by status, the closure and deflector are closed and latched, the debris shield is retracted and the cavity above the closure is filled with a granular material such as coarse sand or small gravel.

To open the silo, the sand is removed, a cable from an external power source is attached to the closure, and an external source of gas at sufficient pressure is connected to the latch cylinder control valve. Sufficient strain is then put on the cables to remove the load from the latch. The latch is then released. The closure is allowed to slide down the ways to the full open position and locked. The cable is then removed. The secondary closure is opened by the same procedure.

To open the silo for launching the missile, the closure latch is released. This is done by high pressure gas from a generator acting on the latch control cylinders. The closure then slides down the ways to the end of the debris pit. The sand and rubble above the silo opening then flows down over the deflector and into the debris pit.


DEBRIS LEVEL AT NOMINAL PIT CAPACITY
23'
15'D
FLYOUT CLEARANCE
GROUND LEVEL
SURFACE PROTECTION FILL MATERIAL - GRAVEL
DEBRIS SHIELD EXTENDED
DEBRIS SHIELD
ACTUATING CYLINDER
CONCRETE FILL
DEBRIS RETAINING BARRIER
PRIMARY BLAST CLOSURE
CLOSURE TOP COVER - 3" STEEL
CLOSURE DOME - 4" STEEL
CLOSURE BOTTOM COVER - 2" STEEL
3" SIDE COVER
REF. DWG. 2-5167-0-38 FOR CLOSURE LATCH
PRIMARY CLOSURE OPEN
SECONDARY CLOSURE AND DEBRIS DEFLECTOR
DEBRIS PIT - 53,000 CUBIC FT CAPACITY
MISSILE LAUNCH FACILITY (STRUCTURE UNDEFINED)


DEBRIS PIT - 53,000 CUBIC FT CAPACITY
MISSILE LAUNCH FACILITY (STRUCTURE UNDEFINED)
CANNISTER EMPLACED EJECT LAUNCH MISSILE SYSTEM
8 POINT CABLE SUSPENSION
25'D
25'D
108' APPROX.

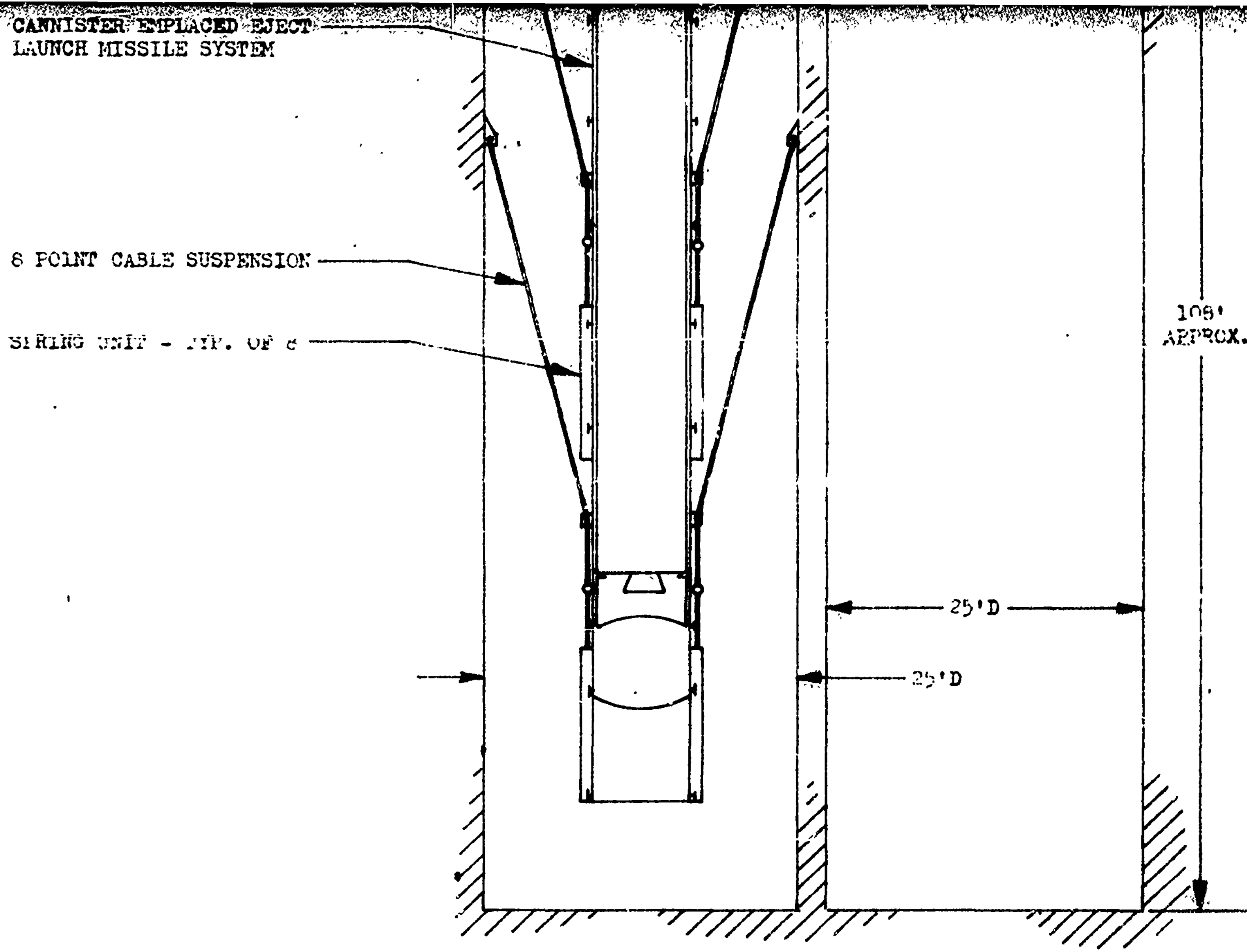


FIGURE 5.4 - 1

DEBRIS PIT WITH SLIDING CLOSURE

(REF. DWG. 2-5167-0-157)

REV LTR A

3

5.4 (Continued)

The debris shield is then extended by the hot gas operated cylinders to prevent loose rubble from rolling down into the silo. The secondary closure is then released and slides down into the debris pit prior to launch.

5.5 DEBRIS PIT WITH HINGED CLOSURE

This closure is a second version of the basic debris pit concept proposed for the study. The concept as shown in Figure 5.5-1 consists of a primary blast closure which is hinged to swing inward, a secondary closure to deflect the falling debris into the debris pit, and a single section debris shield to prevent additional loose debris from falling on the exposed missile after the facility is open for launch.

The debris shield is a steel ring with an inside diameter 15 feet. The shield is stiffened by rings and longitudinal members. It is elevated by three cylinders operated by gas from a hot gas generator.

The closure is an orthogonal grid structure covered top and bottom and on the edge by steel plate. It is hinged to the silo structure so it will swing down to open the silo. It is controlled and closed by a strut and trolley moving along guides mounted on each side of the silo. The trolley is driven by a gas turbine through a gear train and roller chain. The door is held closed by latches engaging the silo wall.

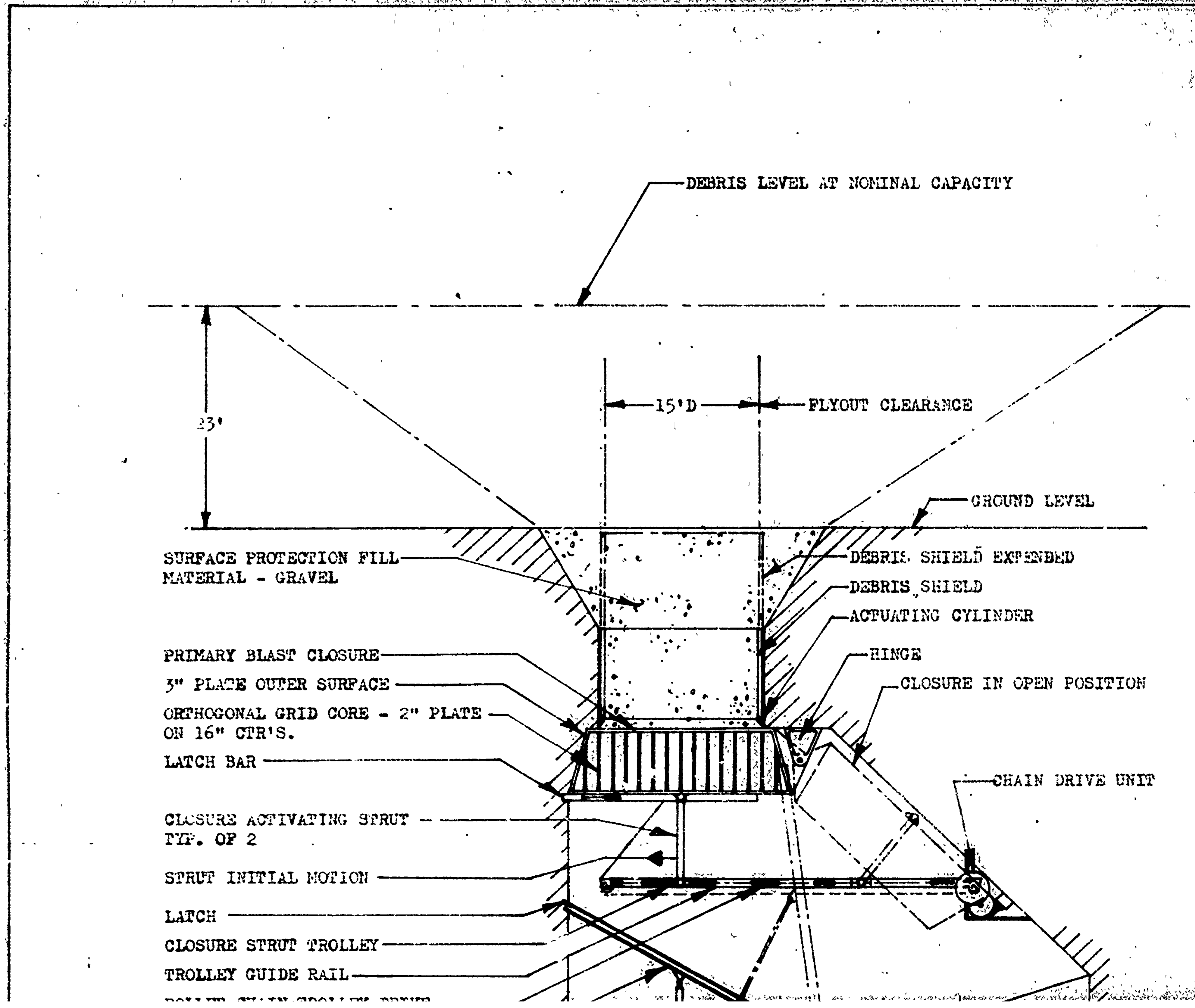
The secondary closure deflects the debris into the debris pit after the closure is opened. It is hinged at the lower end so it can be raised up to clear the silo by two cylinders operated by a gas generator or by an external power source. After the missile is installed, the secondary closure is closed and latched in place. The main closure is closed by gas supplied to the turbine from an external source.

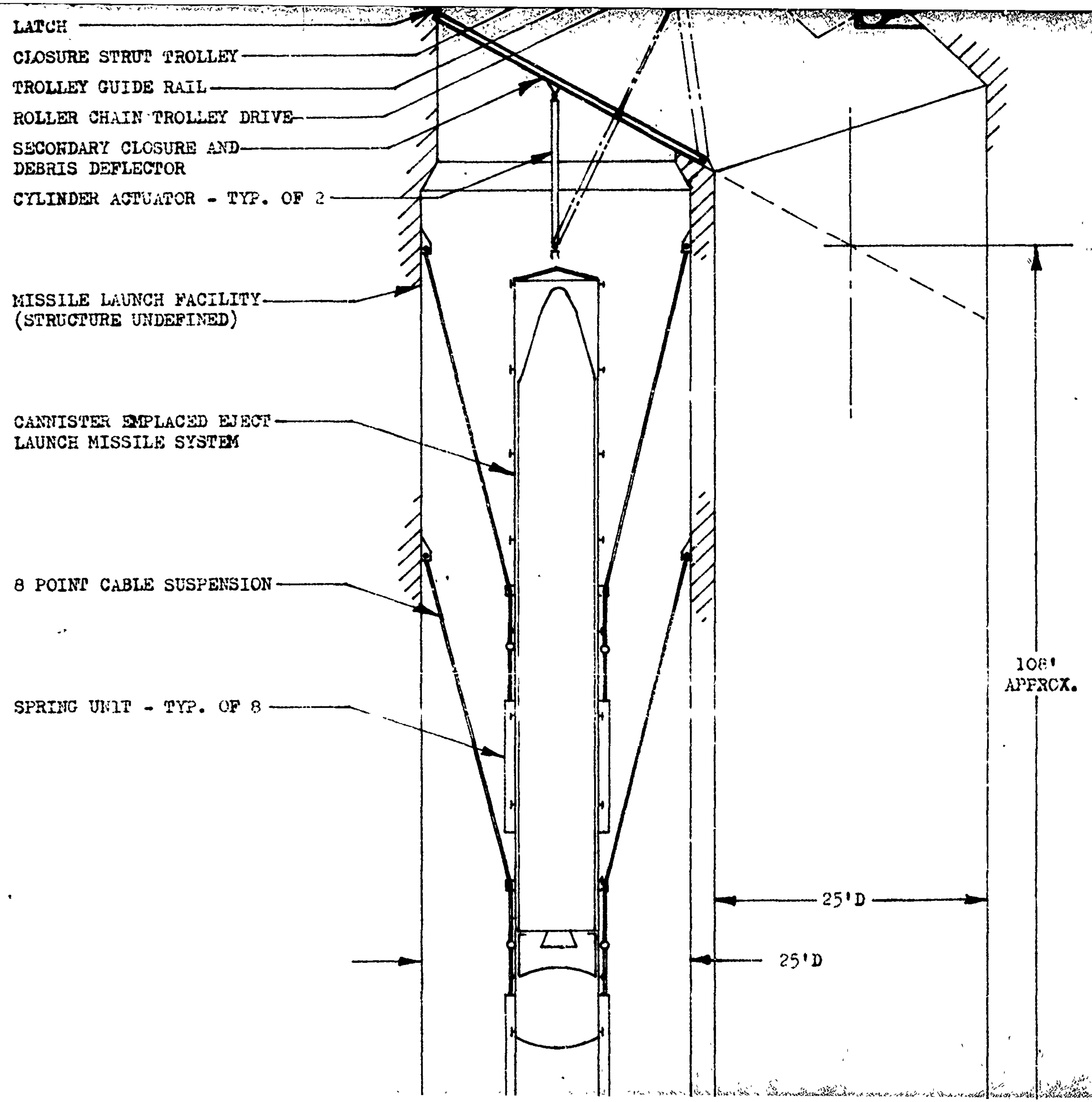
The closure is then locked in place by the latches which engage the silo wall and the space above filled flush with the ground with a granular material such as coarse sand or small gravel.

For maintenance the sand is first removed. This can be done by pumping or by a clamshell bucket and crane. The closure is opened by moving the trolley towards the driving motor. The closure can then be opened wide enough so the secondary closure will clear the silo opening.

To open the silo for launching the missile, the latches are first released. The trolley is then moved away from the motor allowing the door to swing down. It is then pushed to the full open position. This allows the debris, up to 15-foot diameter boulders, to slide down the secondary closure into the debris pit. The debris shield is then raised preventing any more debris from rolling into the silo.

The secondary closure is then opened so the missile can be launched.


DEBRIS LEVEL AT NOMINAL CAPACITY
23'
15'D
FLYOUT CLEARANCE
GROUND LEVEL
SURFACE PROTECTION FILL MATERIAL - GRAVEL
DEBRIS SHIELD EXTENDED
DEBRIS SHIELD
ACTUATING CYLINDER
HINGE
CLOSURE IN OPEN POSITION
PRIMARY BLAST CLOSURE
3" PLATE OUTER SURFACE
ORTHOGONAL GRID CORE - 2" PLATE ON 16" CTR'S.
LATCH BAR
CHAIN DRIVE UNIT
CLOSURE ACTIVATING STRUT TYP. OF 2
STRUT INITIAL MOTION
LATCH
CLOSURE STRUT TROLLEY
TROLLEY GUIDE RAIL


LATCH
CLOSURE STRUT TROLLEY
TROLLEY GUIDE RAIL
ROLLER CHAIN TROLLEY DRIVE
SECONDARY CLOSURE AND DEBRIS DEFLECTOR
CYLINDER ACTUATOR - TYP. OF 2
MISSILE LAUNCH FACILITY (STRUCTURE UNDEFINED)
CANNISTER EMPLACED EJECT LAUNCH MISSILE SYSTEM
8 POINT CABLE SUSPENSION
SPRING UNIT - TYP. OF 8
108' APPROX.
25'D
25'D

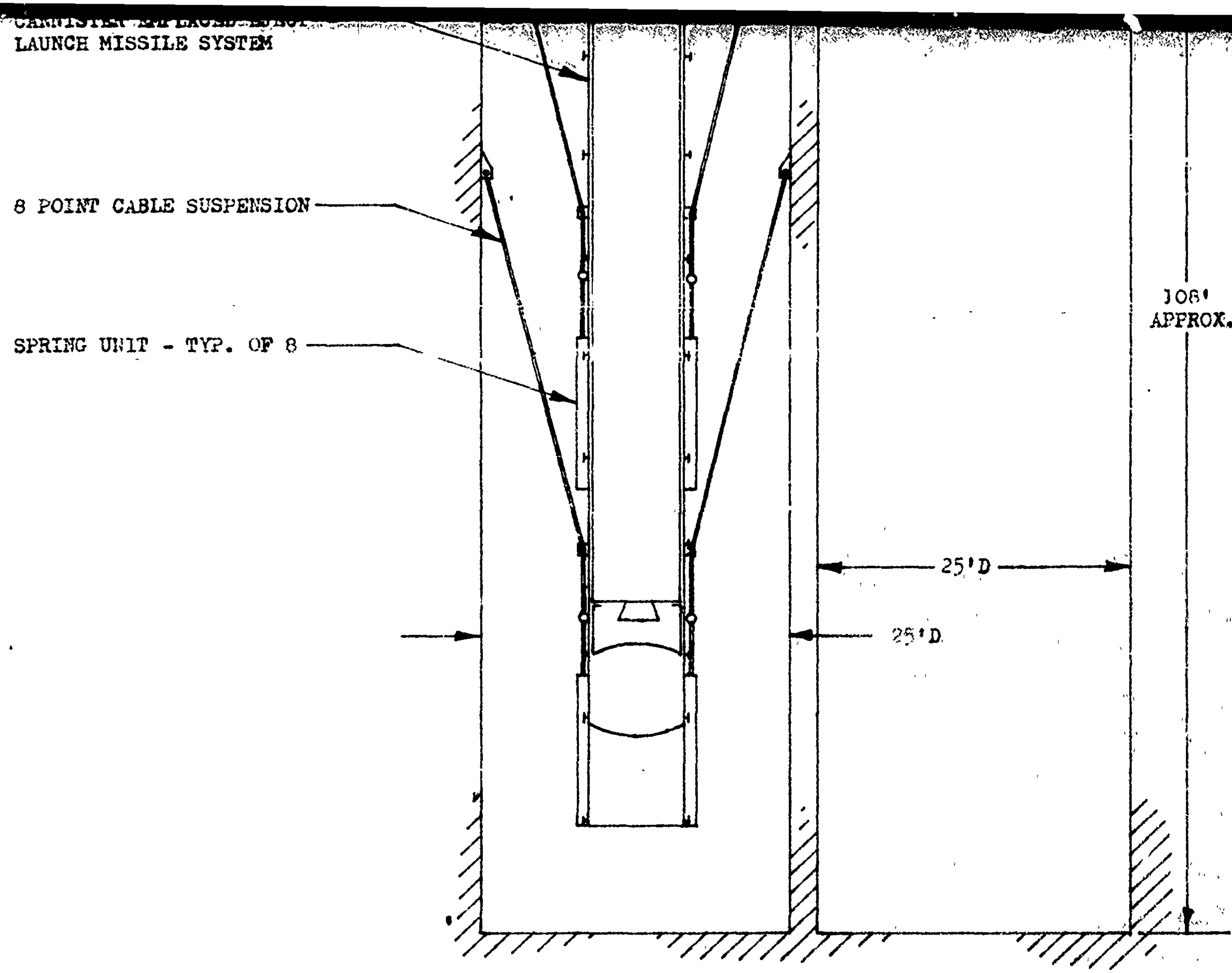


FIGURE 5.5 - 1

DEBRIS PIT WITH HINGED CLOSURE

(REF. DWG. 2-5167-0-158)

6.0 COST COMPARISON

The concepts developed during the study have been evaluated for cost on a preliminary basis. The costing basis has been limited to material quantities and unit costs to correspond to the level of detail in the configurations.

The resulting values are presented only to illustrate the order of magnitude of the costs associated with systems designed for the environment near the limits of survivability as interpreted for the study. A secondary purpose is served by exposing the high cost components and systems, which will aid in defining future design concepts and study objectives.

The cost values have been devloped on the basis of material quantities for the major components which are required for the closure system. The evaluation is limited to closure associated items and it is to be noted that the resulting figures are for the closure systems only and not the entire facility. Also, no attempt has been made to evaluate other requirements such as maintenance equipment, emplacement difficulty, or other launch facility requirements such as access and security. These factors would affect the system design but would have little effect on the major functional components of the closure system.

The three penetrating closure concepts have been evaluated by estimating steel quantities for four categories of fabrication difficulty, and include costs for excavation, fluids, and the solid propellant power source.

The debris pit concepts have been evaluated similarly except that the nature of the debris pit does not allow a straightforward assignment of a cost figure. The basic debris pit structure is as undefinable as the facility structure and a construction cost cannot be realistically assigned. Accordingly, the debris pit has been evaluated for three possible configurations to illustrate the variability of the system cost as it depends on the structure required for survival.

The cost figures for the study concepts are summarized in Table 6.0-1 with a first level breakdown of material categories. It may be noted that the debris handling functions are the source of high cost components with the basic closures being a relatively small fraction of the total cost in most cases.

It must be particularly noted that the penetrating closures cannot be directly compared with the debris pit concepts because of the limitations assumed to define the debris pit size. The debris pit concepts are limited to a nominal blast overpressure level substantially below the study design criteria, and cannot be defined for conditions equivalent to the criteria.

USE FOR TYPEWRITTEN MATERIAL ONLY

Table 6.0-1; PRELIMINARY CLOSURE SYSTEM COSTS * DOLLARS

	LINER*	CLOSURE	MACHINED** FABRICATION	WELDED** FABRICATION	EXCAVATION COST	OTHER COSTS	TOTAL CLOSURE SYSTEM COST
DEBRIS PENETRATING CLOSURE		567,000	2,046,700	995,000	259,000	97,500	3,965,200
DEBRIS PENETRATING LAUNCHER I		570,000	2,139,700	701,800	280,000	97,500	3,789,000
DEBRIS PENETRATING LAUNCHER II		118,000	1,604,000	535,600	294,000	56,500	2,608,200
DEBRIS PIT SLIDING CLOSURE	1	405,000	162,400	8,200	336,000	23,380	934,980
	2	405,000	162,400	358,200	336,000	23,380	1,261,000
	3	405,000	162,400	1,408,200	336,000	23,380	2,311,600
DEBRIS PIT HINGED CLOSURE	1	207,500	142,000	8,200	336,000	23,380	717,080
	2	207,500	142,000	358,200	336,000	23,380	1,043,700
	3	207,500	142,000	1,408,200	336,000	23,380	2,093,700

*LINER 1 = ROCK BOLTS AND WIRE MESH
LINER 2 = 1" STEEL SPALL LINER
LINER 3 = 4" STEEL STRUCTURAL LINER

** SEE APPENDIX IV

7.0 CONCLUSIONS

7.1 At least one of the closure designs developed will survive all the weapons effects postulated for this study. The "Debris Penetrating Launcher - II" (Section 5.3) can survive elastically, and its minimal size will place the least load requirements on the basic launcher, aiding that structure's survivability. The other penetrating closure concepts, while feasible, have more limitations, and greater degrees of complexity.

7.2 The debris pit concept has a lower survivability due to the debris model used. It has good potential for lesser debris environments and where unlined or lightly lined cavities can survive as debris pits.

7.3 The designs reflect clearly that the basic problem for closures at the limit of survival is not structural survivability, but debris management. The indicated high costs are associated with this function.

7.4 The greatest structural problem is "latching" the closure to the basic structure in the high acceleration environment.

7.5 While several feasible designs have been evolved, and at least one can be considered promising for further development, it is concluded that further design should not be pursued without additional work in the following areas:

7.5.1 More definitive work needs to be done in the "structure-media interaction" field, particularly with tespect to acceleration effects. The basic problems of the survival of a cavity or launcher structure without the effects of loading from a closure, must first be solved. Tests for resolving some of these problems are now in the planning and preliminary implementation stages. It is hoped that sound answers to the major questions will be made available soon.

7.5.2 Verification of debris environment is badly needed, since this is a controlling parameter to which all design concepts are sensitive.

7.5.3 The severe impact effects shown for a modest size debris particle at a minimum velocity indicate that considerable work must be done, both in defining the impact criteria and in establishing the design requirements to withstand the impact.

7.5.4 Push out forces required are so large, that the proposed actuation systems are inefficient and at state-of-the-art limits. Actuation systems and power sources must be developed to perform this function economically before further closure design refinements are pursued.

USE FOR TYPEWRITTEN MATERIAL ONLY

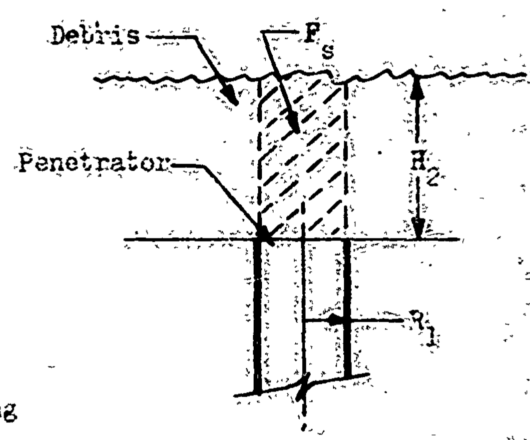
APPENDIX I - WEAPONS EFFECTS CALCULATIONS

A) Debris Penetration Forces

The maximum force required during penetration of a debris layer is calculated by obtaining a theoretical sand penetration value and applying an experimentally determined factor for larger particle sizes. (Reference 6)

This is represented by a three factor formula as

$F_{max} = F_s N_1 N_2$



F_s = Overburden weight

N_1 = A non dimensional number relating the ideal (dry sand) lifting force to the overburden weight. This is shown in Figure I-A-1.

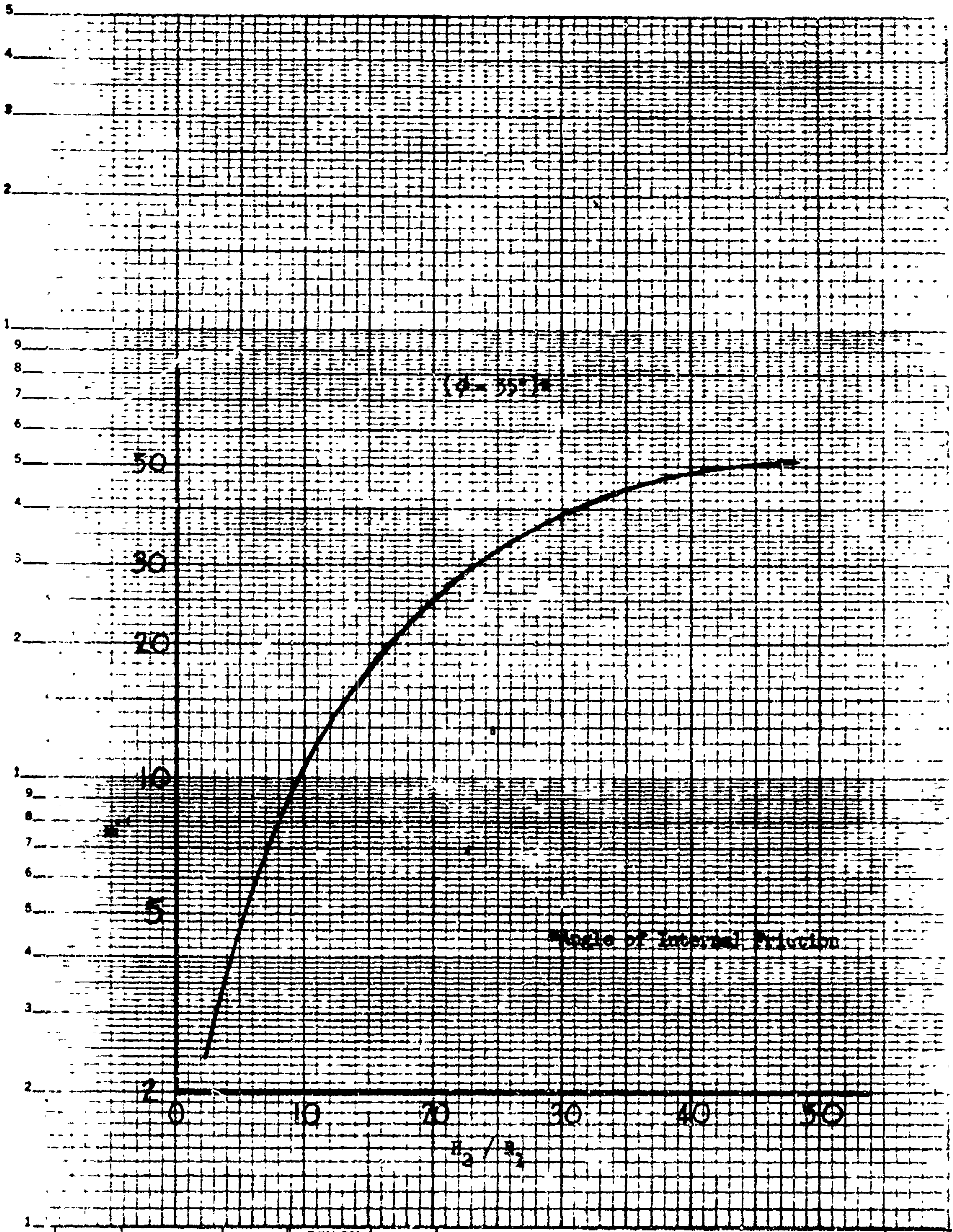
N_2 = A non dimensional number relating the actual peak lifting force for large particle debris to the ideal lifting force. This is shown in Figure I-A-2 for a probability penetration of greater than 97%.

For the two cases under consideration, the values are as follows:

	R_1 Penetrator Radius	H_2 Debris Depth	F_s* Overburden Weight - lb.	N_1 From Fig. I-A-1	N_2	Fmax
Case I	≈15'	36'	3,050,000	2.4	5.7	41,000,000
Case II	7.5'	36'	762,000	4.4	5.7	19,000,000

The value of N_2 is dependent on the debris particle size and a nominal value of S/R_1 of 2 has been used.

* γ = 120 lb/ft^3



	INITIALS	DATE	REV BY INITIALS	DATE	TITLE	MODEL
CALC					FACTOR N_1 VS BURIAL DEPTH	
CHECK					FIGURE I-A-1	
APPD						
APPD						

REV LTR A

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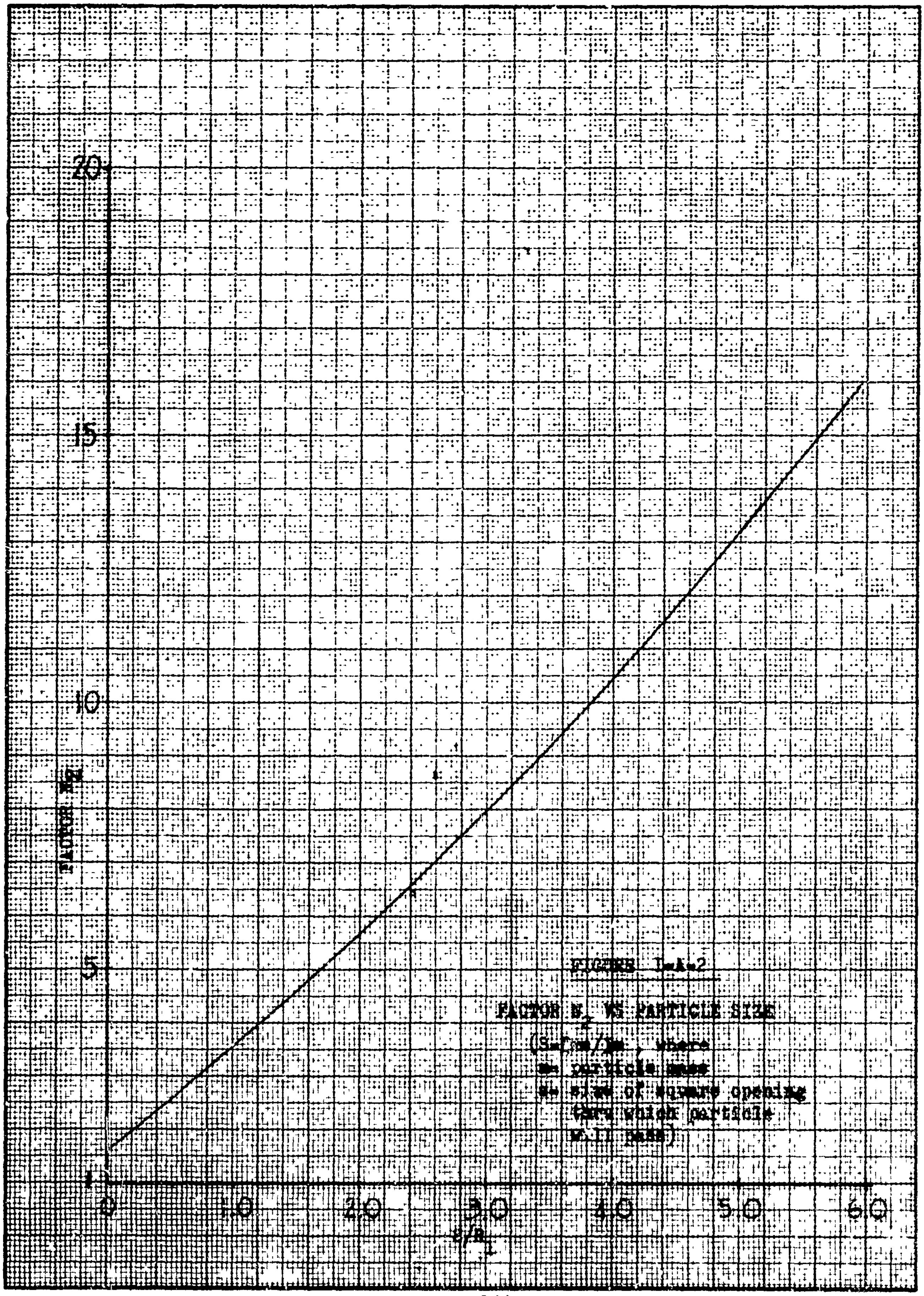


FIGURE I-A-2

FACTOR N_2 VS PARTICLE SIZE
(S=∛m/Dm , where
m= particle mass
w= size of square opening
thru which particle
will pass)

B) Debris Impact

The effect of a large debris particle impacting on a launch facility has been estimated on an impulse basis as suggested in the referenced paper. (Ref. 1)

The particle is assumed to arrive with a vertical velocity component and is assumed to be stopped within a short distance depending on the deformation of the particle and the displacement of the impacted object.

The event is evaluated by equating a pressure pulse to the rate of change of impulse:

$$p(t) = dI/dt \tag{1}$$

where $p(t)$ = pressure/time function and

I = impulse = $m\Delta V$.

m = particle mass per unit area

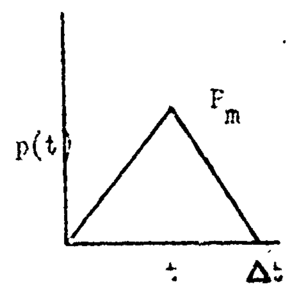
ΔV = change in velocity

Equation (1) may be rewritten

$$I = \int dI = \int p(t)dt = m\Delta V \tag{2}$$

If $p(t)$ is assumed a triangular pulse as shown

$$\int p(t)dt = \frac{P_m}{2}\cdot\Delta t \tag{3}$$

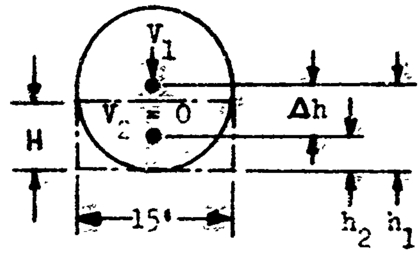


Combining equation (3) and (2),

$$m\Delta V = \frac{P_m}{2}\cdot\Delta t \qquad \text{or,} \quad P_m = 2m\frac{\Delta V}{\Delta t} \tag{4}$$

This is the equation used to evaluate a equivalent peak pressure pulse from the impact event.

For the present problem as a first estimate, a spherical particle is assumed to impact on a rigid surface and deform into a flat configuration of equal diameter as shown.



Assumed conditions are as follows:

Particle dia. $D = 15'$

Weight density $\gamma = 170\ lb/ft^3$

Vertical velocity component $V_1 = 300$ fps

The value of Δt is evaluated by assuming an average velocity of $\Delta V/2$ over the total distance of deformation, Δh. (Compression of the impacted surface is neglected)

Thus, $\Delta t = \dfrac{2\Delta h}{\Delta V}$

To evaluate Δh, a cylindrical volume is set equal to the spherical volume and difference in centroid heights is used.

Spherical volume;

$V = 4/3\ \pi R^3$

$V = (4/3)\ (\pi)\ (7.5)^3 = 1610\ ft^3$

also $W = (1610)\ (170) = 275{,}000$ lb.

Cylindrical Volume;

$V = \dfrac{\pi}{4} D^2 H = AH;\ A = 176\ ft^2$

$H = \dfrac{V}{A} = \dfrac{1610}{176} = 9$ ft

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Thus

$h_1 = 15/2 = 7.5$ ft.

$h_2 = 9/2 = 4.5$

$\Delta h = h_1 - h_2 = 3.0$ ft

$$\Delta t = \frac{2\,\Delta h}{\Delta V} = \frac{(2)\ (3.0)}{(300 - 0)} = .020 \text{ sec.}$$

Rewriting equation (4) using

$$m = \frac{W}{gA};$$

$$P_m = \frac{2W\,\Delta V}{gA\,\Delta t}.$$

Evaluating

$$Pm = \frac{(2)\ (275000)\ (300)}{(32.2)\ (176)\ (.020)} = 1{,}455{,}000 \text{ lb/ft}^2$$

$$Pm = \frac{1455000}{144} = 10100 \text{ psi equivalent}$$

APPENDIX I WEAPONS EFFECTS

C. Debris Pit Capacity

The nominal capacity is the volume of debris which can be accommodated in a receiver of the same diameter and maximum depth as the launch facility. This is V1 on the Figure.

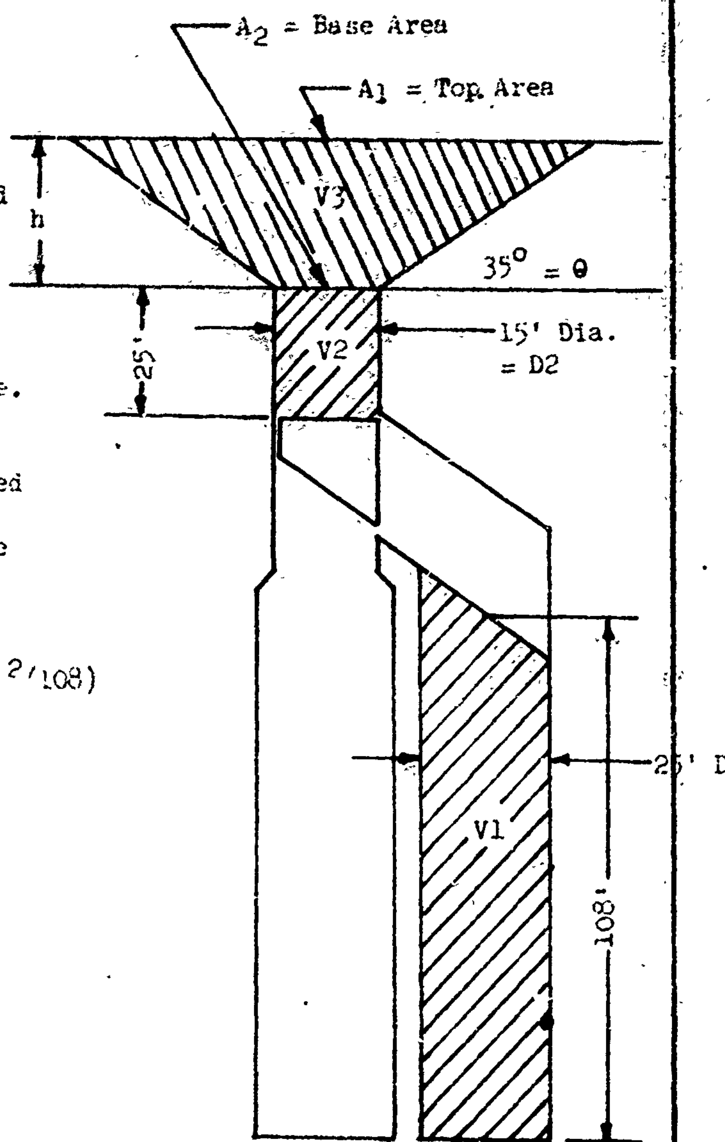


Figure I-C-1
DEBRIS PIT CAPACITY

The nominal capacity must be reduced by the overburden above the closure to obtain the net debris capacity.

V_1 = Nominal capacity = $\frac{\pi}{4}(25)^2(108)$

V_1 = 53,000 cubic feet

V_2 = Overburden = $\frac{\pi}{4}(15)^2(25)$

V_2 = **4,400** cubic feet

V_3 = Debris volume = $V_1 - V_2$

V_3 = **48,000** cubic feet

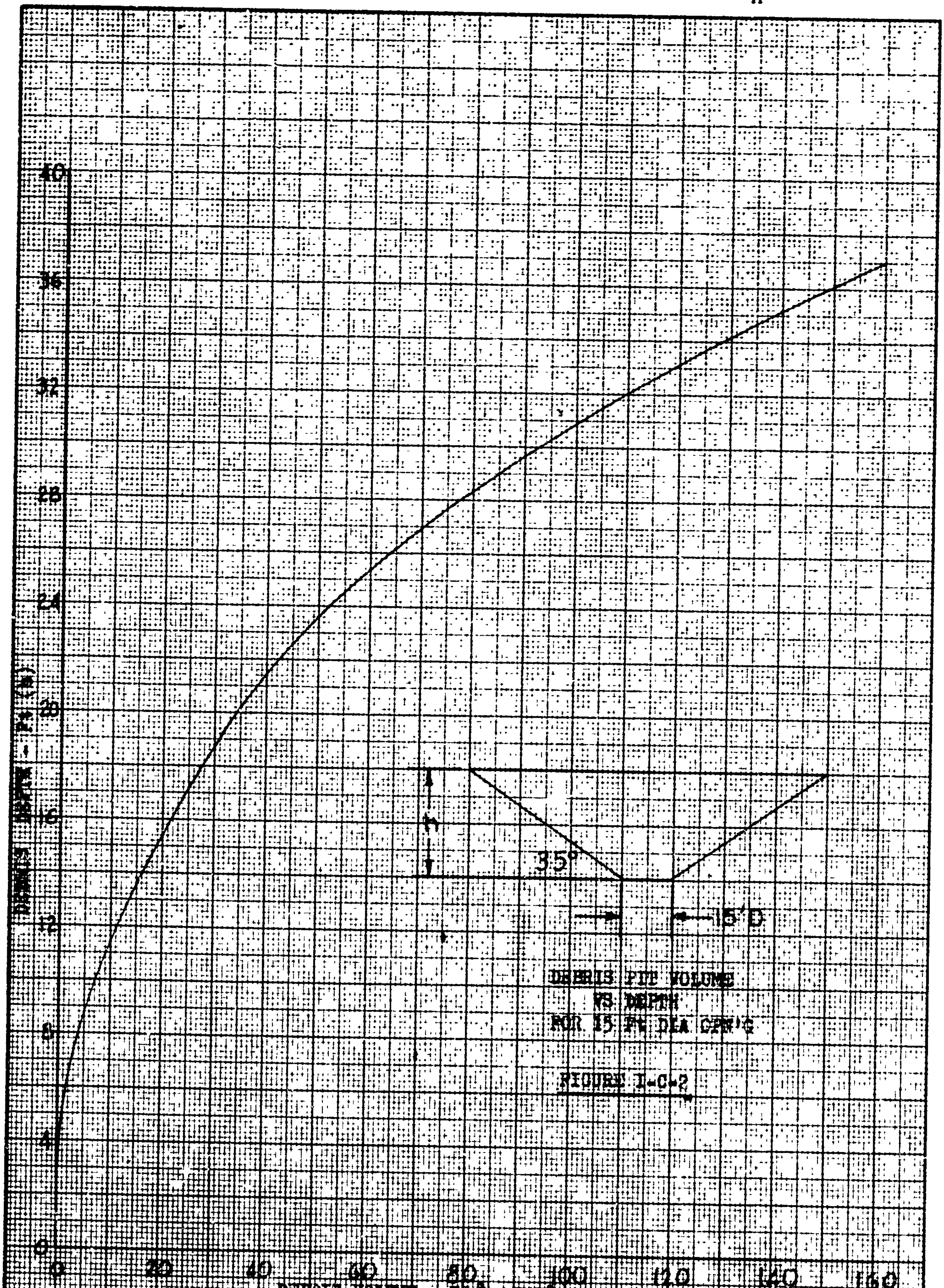
Also

$$V_3 = \frac{1}{3} h (A_1 + A_2 + \sqrt{A_1 A_2})$$

$$A_2 = \frac{\pi}{4}(15)^2 = 177 \text{ FT}^2$$

$$A_1 = \frac{\pi}{4}(D_1)^2 = \frac{\pi}{4}\left(D_2 + 2\frac{h}{\tan\theta}\right)^2$$

A plot of h vs. volume is shown on Figure **I-C-2.** This indicates the pit assumed will accommodate 23 feet of debris.



DEBRIS PIT VOLUME
VS DEPTH
FOR 15 FT DIA OPN'G

FIGURE I-C-2

APPENDIX II HYDRAULIC SYSTEM

A. Operating Pressure

The total force requirement is 40×10^6 pounds maximum, to be provided by eight cylinders.

Load per cylinder, $W = \frac{40 \times 10^6}{8} = 5 \times 10^6$ pounds.

Using a 30 inch maximum stage diameter, the required pressure will be,

$$P = \frac{W}{A};\ A = \frac{\pi}{4} d^2 = 707 \text{ in}^2$$

$$P = \frac{5 \times 10^6}{707} = 7100 \text{ psi}$$

B. Reservoir Volume

Hydraulic Systems have 8 cylinders with 4 sections as shown.

Volume of one cylinder

$$V = \sum A_i L_i = 4L \sum A_i$$

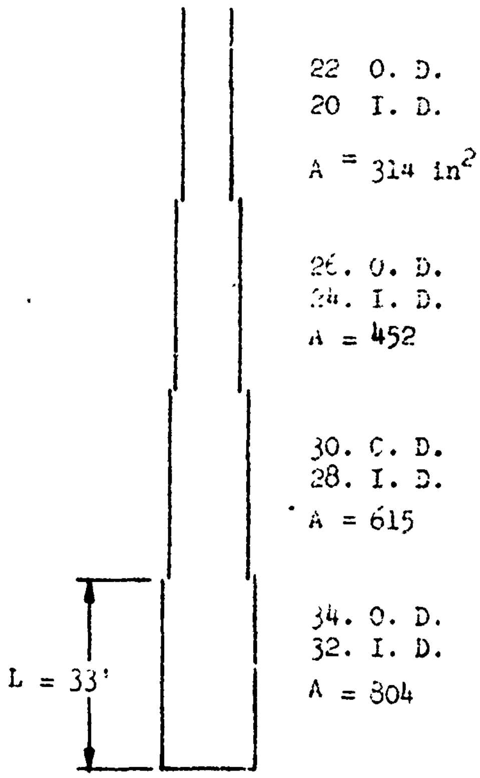
$$\sum A_i = 314 + 452 + 615 + 804$$

$$= 2185 \text{ in}^2$$

For 33' stroke (396 in.)

$$V = \frac{(396)(2185)}{(232)} = 3750 \text{ gal.}$$

8 cylinders require	30,000 gal.
Add 10%	3,000
Tank size required	33,000 gal.



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APPENDIX II (Cont'd)

C. Propellant Requirement

Propellant weight is estimated by assuming a final pressure, temperature, and average molecular weight of the combustion products, and calculating on the basis of the final volume.

Volume required, V = 4500 cubic feet

Final pressure, P = 1000 psi

Final Temperature, T = 300°F = 760°R

Molecular Weight, M = 30

From the gas laws

$PV = NMRT$

N = Number of mols.

R = Gas constant

$MR = 1545 \frac{\text{Ft Pounds}}{°R}$ (Universal gas constant)

Solving for N

$$N = \frac{PV}{MRT} = \frac{(1000)(144)(4500)}{(1545)(760)} = 550 \text{ Mol.}$$

$(550)(30) = 16{,}500$ lb.

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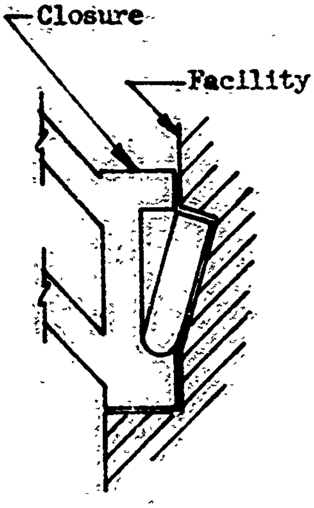
APPENDIX III - CLOSURE LATCH LOADS

A) Large Closure Latch (large debris penetrating closures)



Latch Bar Configuration

Assume latch bar acts in direct compression to react load at 1000 g.

Closure Weight; W = 570,000 lbs.

Total Vertical Reaction

$$F_T = (570,000)(1000) = 5.7 \times 10^8 \text{ lb.}$$

Using 24 latch bars the nominal load per latch is

$$F_V = \frac{5.7 \times 10^8}{24} = 2.38 \times 10^7 \text{ lb. vertical}$$

Latch Normal Load at 15° Inclination

$$F_N = \frac{2.38 \times 10^7}{\cos 15°} = 2.46 \times 10^7 \text{ lb.}$$

Latch Bar Area (8" x 30")

$$A = 8 \times 30 = 240 \text{ in}^2$$

Compressive Stress

$$S = \frac{F_N}{A} = \frac{2.46 \times 10^7}{240 \text{ in}^2} = 102,000 \text{ psi}$$

B) Small Closure Latch (small debris penetrating closure)

Assume latch bar acts in direct compression to react load at 1000 g.

Closure Weight $W = 118{,}000$ lb.

Total Vertical Reaction

$$F_T = (118{,}000)(1000) = 1.18\times10^8 \text{ lb.}$$

Using 16 latch bars the nominal load per latch is

$$F_V = \frac{1.18\times10^8}{16} = 7.4 \times 10^6 \text{ lb.}$$

Latch Normal Load at ≈ 20° inclination

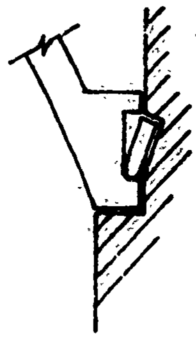
$$F_N = \frac{7.4 \times 10^6}{\cos 20°} = 7.9 \times 10^6 \text{ lb.}$$

Latch Bar Area (6" x 16")

$$A = 6 \times 16 = 96 \text{ in.}^2$$

Compressive Stress

$$S = \frac{F_N}{A} = \frac{7.9 \times 10^6}{96 \text{ in.}^2} = 82{,}300 \text{ psi}$$



Latch Bar Configuration

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APPENDIX IV - COSTING BASIS

The following sheets summarize the first level cost estimates made for the study.

The cost estimates are based on material weight and unit costs. Closure system components only are considered to a level of detail comparable to the developed designs.

The majority of the fabrication is of steel and the system components have been categorized for four unit prices as follows:

Category I - Precision Machined critical items
$4.00/Lb.

Category II - Items generally machined but non-critical fit or finish
$1.50/Lb.

Category III - Primarily welded fabrications with some non-precision machining (closures)
$1.00/Lb.

Category IV - Welded fabrications of high strength steel requiring little or no machining.
$0.75/Lb.

The debris pit concepts have been estimated for three liner possibilities to illustrate the relative effects of the required structure for survival.

APPENDIX IV (Cont'd)

A) Debris Penetrating Closure

Component	Total Weight Pounds	Category Or Unit Cost	Cost Dollars
Closure	567,000	III	567,000
Welded Fabrications			
Gas Generator	120,800	IV	
Fluid Tank Baffles	335,000	IV	
Debris Shields	570,000	IV	
Shield Support	57,500	IV	995,000
Reinforcing Ring	10,900	IV	
Platform	80,400	IV	
Brackets	152,000	IV	
Machined Fabrications			
Latch Actuators	20,800	I	83,200
Latches - Thrust Ring	78,000	II	117,000
Debris Shield Rails	168,000	II	252,000
Debris Shield Latches	103,000	II	154,500
Hydraulic Cylinders	360,000	I	1,440,000
Excavation - 3700 Cubic Yards		$70/CY	259,000
Gas Generator Propellant	16,000	$ 5/Lb.	80,000
Hydraulic Fluid - 33,000 Gallons		$.50/Gal	17,500
			3,965,200

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APPENDIX IV (Cont'd)

B) Debris Penetrating Launcher - I

Component	Total Weight Pounds	Category Or Unit Cost	Cost Dollars
Closure	570,000	III	570,000
Welded Fabrications			
Gas Generator	120,800	IV	
Fluid Tank Baffles	335,000	IV	701,800
Cylindrical Structure	400,000	IV	
Thrust Ring	80,000	IV	
Machined Fabrications			
Latch Actuators	20,800	I	83,200
Thrust Ring Latches	78,000	II	117,000
Cylindrical Str. Latches	68,000	II	102,000
Guide Rails	169,000	II	253,500
Hydraulic Cylinders	396,000	I	1,584,000
Excavation - 4000 Cubic Yards		$70/CY	280,000
Gas Generator Propellant	16,000	$ 5/Lb.	80,000
Hydraulic Fluid - 33,000 Gallons		$.50/Gal	17,500
			3,789,000

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APPENDIX IV (Cont'd)

c) Debris Penetrating Launcher - II

Component	Total Weight Pounds	Category Or Unit Cost	Cost Dollars
Closure	118,000	III	118,000
Welded Fabrications			
Gas Generator	60,400	IV	
Fluid Tank Baffles	335,000	IV	
Upper Structure	44,700	IV	535,600
Thrust Ring	126,300	IV	
Thrust Cage	135,000	IV	
Latch Brackets	12,800	IV	
Machined Fabrications			
Guide Rails	114,000	II	171,000
Latches	57,800	II	86,700
Hydraulic Cylinders	330,000	I	1,320,000
Closure Actuators	6,400	I	26,400
Excavation - 4200 Cubic Yards		$70/CY	294,000
Gas Generator Propellant	8,000	$ 5/Lb.	40,000
Hydraulic Fluid - 33,000 Gallons		$.50/Gal.	16,500
			2,608,200

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APPENDIX IV (Cont'd)

D) Debris Pit with Sliding Closure

Components	Total Weight Pounds	Category Or Unit Cost	Cost Dollars
Closure	117,500	III	177,500
Secondary Closure	30,000	III	30,000
Guide Rails	71,000	II	106,000
Debris Shield	11,000	IV	8,200
Latch Assembly	9,000	I	36,000
Excavation - 4800 Cubic Yards		\$70/CY	336,000
Debris Pit Liner Alternates - 11,690 Ft^2			
1) Rock Bolts and Wire Mesh		\$2.00/Ft^2	23,380
2) 1 In. Str't'l Liner	468,000	IV	350,000
3) 4 In. Str't'l Liner	1,870,000	IV	1,400,000

Total Cost-Liner 1)	\$ 717,080
Total Cost-Liner 2)	1,043,700
Total Cost-Liner 3)	2,093,700

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APPENDIX IV (Cont'd)

E) Debris Pit with Hinged Closure

Component	Total Weight Pounds	Category or Unit Cost	Cost Dollars
Closure	375,000	III	375,000
Secondary Closure	30,000	III	30,000
Hinge Assembly	24,000	II	36,000
Actuator System	11,600	I	46,400
Debris Shield	11,000	IV	8,200
Latches	44,800	II	67,200
Latch Actuators	3,200	I	12,800
Excavation - 4800 Cubic Yards		$70/CY	336,000
Debris Pit Liner Alternates - 11,690 Ft^2			
1). Rock Bolts and Wire Mesh		$2.00/$Ft^2$	23,380
2) 1 In. St'r'l Liner	468,000	IV	350,000
3) 4 In. St'r'l Liner	1,870,000	IV	1,400,000
Total Cost-Liner 1)		$ 934,980	
Total Cost-Liner 2)		$1,261,600	
Total Cost-Liner 3)		$2,311,600	

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LIMITATIONS

Document to be distributed to the Defense Documentation Center (DDC).

Each transmittal of this document outside the agencies of the United States Government must have the prior approval of The Boeing Company.

This document is controlled by Development Design Organization 2-5166

All revisions to this document shall be approved by the above noted organization prior to release.

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REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
A	Document revised to add Part II (1968 Results) Added Sheets 99 through 164. Sheets 1 through 88 and 98 reidentified to Revision Letter A to make a complete revision. Deleted sheets 89, 90, 91, 92, 93, 94, 95, 96 and 97.		Prepared by: Checked by: Approved by: Approved by: