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EDGEWOOD ARSENAL TECHNICAL REPORT

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INVESTIGATION INTO THE USE OF SUPPRESSIVE SHIELDING AT RADFORD ARMY AMMUNITION PLANT TNT LINES

by

Bruce W. Jezek
Manufacturing Technology Directorate

October 1975

DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

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This report covers an investigation of the applicability of suppressive shielding to the Radford Army Ammunition Plant. The study specifically addressed the identification of the potential benefits that would have been realized if a suppressive structure had been in place when an accidental detonation occurred at a Radford AAP nitration and purification building. Problems to be resolved included: (1) Could a suppressive structure withstand the loadings imposed by the detonation of large quantities of explosive? (2) Would appreciable damage reduction be achievable by using suppressive shielding? and (3) Could a suppressive structure be built which would be cost effective? Problem 1 could only be addressed theoretically, using

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20. ABSTRACT (continued)

approved scaling laws, since experimental data is not available for large explosive yields in the order of thousands of pounds. Problems 2 and 3 were analyzed in detail.

PREFACE

The work described in this report was tasked by the Project Manager for the Production Base Modernization and Expansion Program under Production Ammunition, Army (PA,A) Project 4932, ARMCOM Project Number 5751264. The work was started in August 1974 and was completed in May 1975.

Acknowledgments

The author is grateful to Mr. P.A. Cox and Mr. Edward Esparaza of Southwest Research Institute, San Antonio, Texas, for their assistance in the design analysis of the alternate suppressive shield configurations.

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I. INTRODUCTION.

The Suppressive Shielding Branch of the Mechanical Process Technology Division, Manufacturing Technology Directorate, Edgewood Arsenal, Aberdeen Proving Ground, Maryland, was tasked by the Project Manager for the Production Base Modernization and Expansion Program* in August 1974 to investigate the applicability of suppressive shielding to the Radford Army Ammunition Plant (AAP). Specifically, the assignment was to identify the potential payoff afforded if a suppressive structure had been in place at a nitration and purification (N&P) building (building 9502) when an accidental detonation took place on 31 May 1974. The site of the explosive accident was the TNT area at Radford AAP (figure 1). A nitration and purification building is a part of each of the three TNT manufacturing lines. (The lines are designated A, B, and C). The detonation took place in the N&P building serving line A. Although the N&P buildings at lines B and C did not detonate, these lines were made inoperative by structural and other damage from the line A explosion.

Problems to be resolved by the investigation included:

1. Could a suppressive structure withstand the loadings imposed by the detonation of large quantities of explosive?

2. Would appreciable damage reduction be achieveable by using suppressive shielding?

3. Could a suppressive structure be built which would be cost effective?

Problem 1 could only be addressed theoretically, using approved scaling laws since experimental data is not available for large explosive yields in the order of thousands of pounds. Problems 2 and 3 were analyzed in detail and are presented in subsequent sections of this report.

The technical approach used in this investigation is described in Section II. A summary of the technical investigation described in Section III includes a theoretical estimate of the damage profile at the Radford AAP and the predictions of the blast and fragment hazards associated with the explosive accident. Section IV, Application of Suppressive Shielding, describes the design guidelines, design alternatives, and suppressive structure cost estimates. Section V lists the conclusions.

II. TECHNICAL APPROACH.

The approach taken to conduct this investigation is outlined as follows:

A. Conduct on-site inspection of the accident scene to acquire blast and fragment damage data.

B. Use the acquired data to conduct analyses to establish explosive yield and to define the fragment hazard of the accidental detonation.

*US Army Armament Command

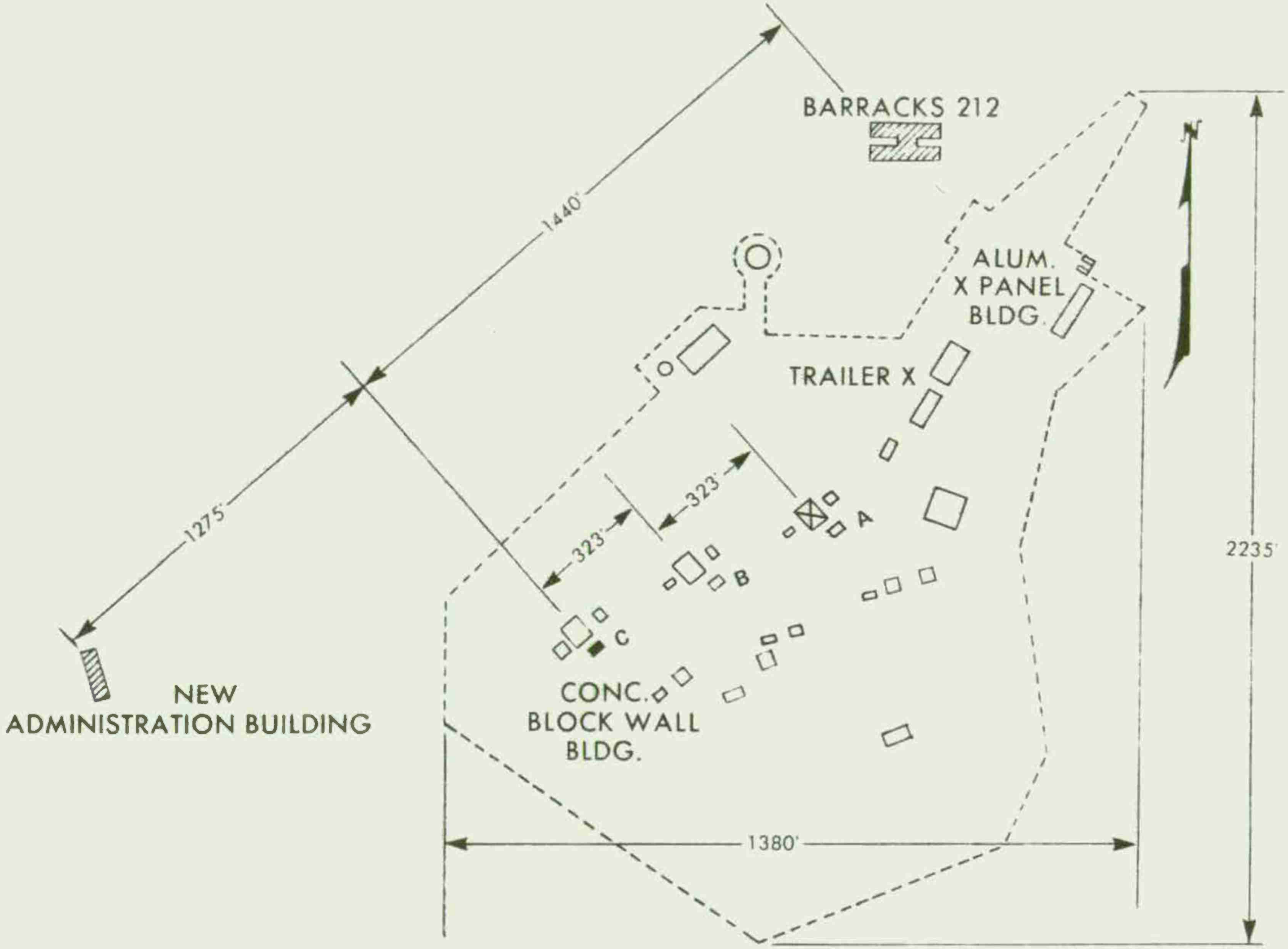

Figure 1. TNT Area Layout at Radford AAP. TNT Manufacturing Lines Are Designated A, B, and C

C. Determine damage cost reduction at Radford AAP by using suppressive shielding.

D. Develop concept design alternatives for suppressive structure to minimize damage.

E. Estimate cost of suppressive structures.

To perform this investigation Edgewood Arsenal obtained assistance from the US Army Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, Maryland, to perform items A, B, and C above, and Southwest Research Institute to perform items D and E. The expertise available at BRL in blast and fragment analyses in numerous previous studies provided a base for good initial estimates of these hazards. Southwest Research Institute has been involved with the design of the category I shield and the development of analytical techniques to design suppressive shields, thus providing immediate application of existing design principles.

To determine the damage cost reduction achieveable by using suppressive shielding at Radford AAP, only the damage to structures and private property were considered. Other savings such as personnel safety, lost production time, and clean-up cost were not included. Additionally, if suppressive structures had been used at Radford on all three nitration and purification buildings, lines B and C would have remained operational. The savings that would have been realized by avoiding the need to produce TNT at other more costly facilities was not considered in this study.

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III. TECHNICAL INVESTIGATION.

A. Damage Profile.

As a result of the accidental detonation in the line A nitration and purification building (building 9502), damage was caused over a large area of the Radford AAP. This damage included buildings, vehicles, property, utilities, equipment and personnel. An attempt has been made to accumulate the cost associated with each of these various items damaged. Only limited cost data has been obtained. The repair cost for line A had not been finalized and was not available in time for incorporation in this investigation. Estimates for line A used in this study were based on cost data available from lines B and C. Cost data for personal property damage and personnel liabilities had not been finalized. The following are total baseline cost estimates of damage available at the time this investigation was conducted.

Location	Cost of damage	Reference source for cost data
Inside TNT Area *	$ 6008K	P-15 Program Document for Project 5765901, Restore TNT Manufacture Facility, Lines B and C
Outside TNT Area	1286K	Report of Proceedings from Board of Investigation, Explosion in TNT Area, Radford AAP, 31 May 1974
Private Property		
	$ 7487K	

For the purposes of this study several assumptions were made specifically concerning the damage cost. All damage to buildings was assumed to be due to blast loading since data was not available to differentiate between fragment and blast damage. The cost of utility lines was not included in the damage analysis due to the difficulty in estimating the pressure level causing damage and the numerous locations of such items. This caused $856,000 to be excluded from the lines B and C damage cost. (A detailed cost breakout is given in BRL IMR373, reference 1).

Other less visible costs factors which have not been considered for this analysis include: (1) the difference in cost to construct a single building to replace several destroyed buildings; (2) the additional cost of new equipment to replace old equipment, and (3) the use of more blast-resistant construction principles and material, i.e., tempered window glass as compared to standard window glass.

B. Determination of Blast and Fragment Hazard.

The Radford AAP was visited on 15-18 October 1974 by members of Edgewood Arsenal's Suppressive Shielding Branch, and by a member of the Ballistic Research Laboratories on 3-4 December 1974. The purpose of these visits was to obtain data on the fragment and blast hazard associated with the accident and data defining the damage which resulted. Little useable fragment data was available for input to this investigation. Fragment impact location and, in most instances, fragment mass were recorded. However, to properly define the fragment hazard, the launch or impact angle and initial fragment velocity are required. Other problems associated with using the fragment data from the accident scene are unknown factors such as fragment perforation of the nitration and purification building structure, the impact with other structures (steam lines, buildings, etc.) and the ricochet of fragments off structures both inside and outside the nitration and purification building. This problem of accurately defining the fragment hazard is the most challenging technological area facing the researcher in the suppressive shielding program. Attempts to calculate unknown fragment variables are presented in appendix A for fragments which were identifiable at the accident site.

During the 3-4 December 1974 visit to Radford, Dr. D.F. Haskell, Ballistic Research Laboratories, measured the deformations of various structures to allow computation of the explosive yield involved in the accident. The TNT area layout (figure 1) indicates the locations of lines A, B, and C and the locations of the damaged structures used by BRL to predict the explosive yield. Figure 1 also provides the basic dimensions of the TNT area and shows the distances between the A, B, and C line nitration and purification buildings, as well as the distance between the C line nitration and purification building and the administrative building

*Does not include cost of nitration and purification building for line A; does include damaged support buildings for line A.

and the barracks. The administrative building and the barracks received extensive window damage; this was not expected based on the use of quantity-distance tables. Sufficient damage was experienced by the additional buildings used in lines A, B, and C to prevent the production of TNT by any of these lines. Other minor structural damage was experienced by the nitration and purification buildings of lines B and C.

The results of the BRL analysis are contained in reference 1. The best estimate of the yield by BRL is 8600 pounds. This value compares favorably with the value obtained by USAEWES* Explosive Excavation Research Laboratory, Corps of Engineers. where window damage was employed to predict the yield. The best estimate by USAEWES was 8000 pounds. The following chart compares the results of these two studies:

Yield	BRL	USAEWES
Lower limit	6200 lb	8000 lb
Upper limit	8600 lb	12000 lb
Best estimate	8600 lb	8000 lb

Calculations were made using the 8600-pound explosive yield to determine the effect of blast pressure attenuation by means of a suppressive shield on the damage to buildings outside the nitration and purification building. By estimating the blast pressure versus distance from small-scale suppressive tests (reference 2) it was possible to predict the distance associated with selected pressure levels to cause (1) window breakage. (2) buckling of corrugated steel or aluminum panels, and (3) shattering of unreinforced concrete or cinder block panels. Figure 2 illustrates the predicted incident blast pressure versus distance from the line A nitration and purification building for an explosive yield of 8600 pounds. The attenuated pressure versus distance curves are included in this figure for several venting ratios. Using this figure to predict the incident pressure for each building within the TNT area, the damage costs were generated for each venting ratio. The curves in figure 3 predict the percent damage savings which could have been achieved if a suppressive shield had been in place at either (1) the nitration and purification building on line A or (2) the nitration and purification buildings of lines A, B, and C.

Since the blast pressure reduction achieved by a suppressive shield is a function of the vent ratio (which can be varied by changing the opening in the suppressive panels), the damage reduction is strongly dependent on the vent ratio. The smaller the vent ratio the lower the blast pressure outside the shield and the less damage – or the greater the "percent damage savings" as plotted in figure 3. The category 1 suppressive shield is currently designed with a two percent vent ratio. Since experimental data is not available for vent ratio less than two percent, suppressive shield designs were not considered for vent ratio less than this value. The costs of several different suppressive shield designs with two percent vent ratio are presented in section IV.C. Cost Comparison of Design Alternatives.

IV. APPLICATION OF SUPPRESSIVE SHIELDING.

A. Design Guidelines.

The development of a structural design to withstand the explosive detonation which occurred in the nitration and purification building requires definition of the blast loadings and

*US Army Explosive Waterways Experimental Station.

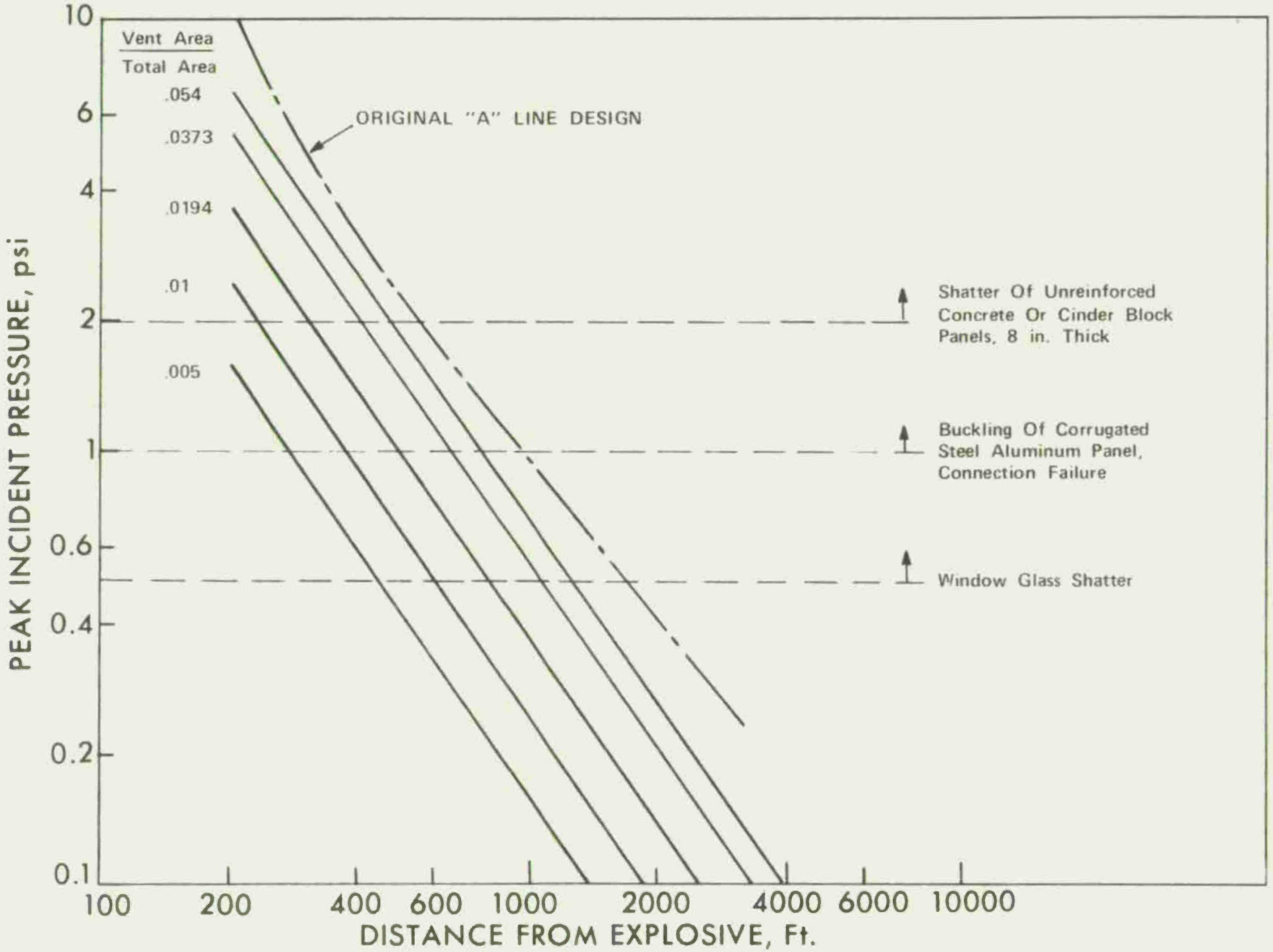


Figure 2. Peak Incident Pressure Versus Distance from Explosive for Detonation of 8600 Pounds of TNT

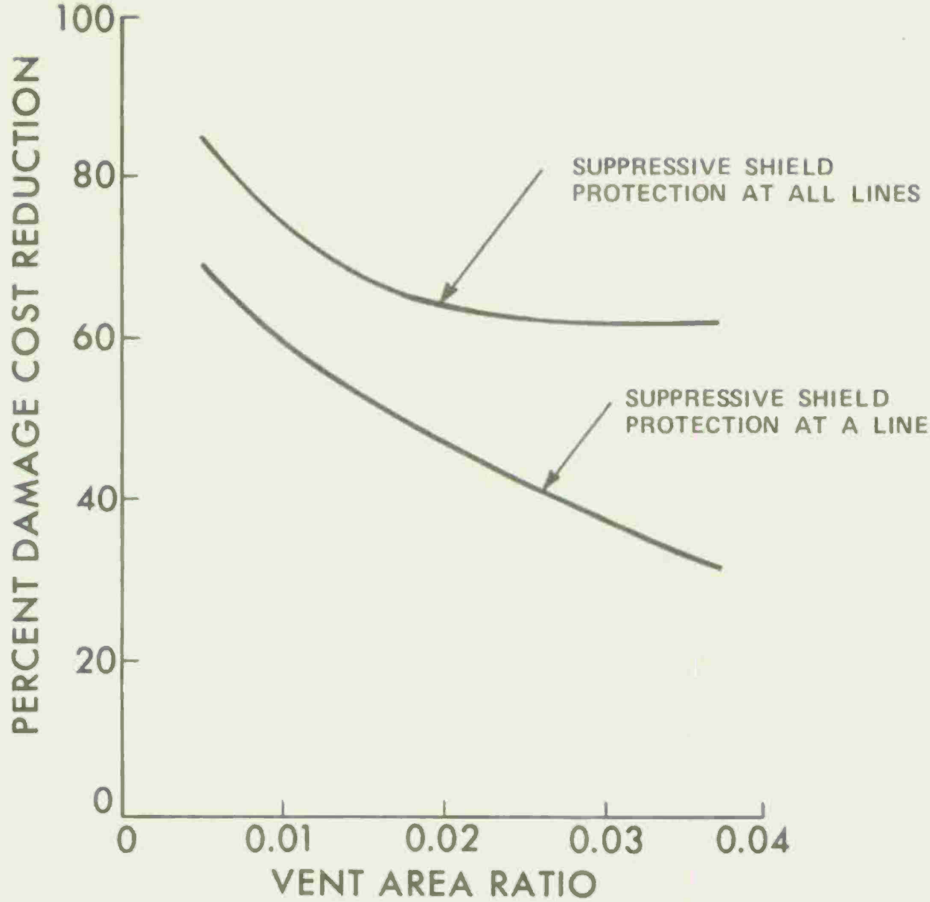


Figure 3. Percent Damage Cost Reduction Versus Vent Area Ratio

fragment hazard. It was determined that the detonation started at nitration vat 3A and propagated to the other nitration vats and separators involved in the process. The nitration vats and separators are located approximately ten feet from the building's side walls (the internal building dimensions are 62 feet by 57 feet). The problem of accurately predicting by analytical methods the blast pressure loading on each wall and the roof of the structure is complicated by the equipment arrangement, the manner in which the propagation occured, the equivalent TNT yield of the material in each nitration vat and separator, and the effect of non-simultaneous detonation of the total yield, to name a few of the factors. Therefore, several assumptions were required to simplify the prediction of the design loads. These assumptions are:

1. Explosive yield spherical in shape.

2. Explosive yield located at geometric center of the building.

3. Total internal volume, including space under the nitration vats assumed for predicting the quasi-static pressure.

The blast loading profile was computed by Southwest Research Institute and is summarized as follows:

	Roof	Side Wall	Category 1 Shield*
Incident pressure (psi)	2,300	548	550
Reflected pressure (psi)	27,200	4,000	4,053
Impulse (psi-sec)	15.1	2.65	2.54
Quasi-static pressure (psi)	290		165

* Shown for comparison purposes.

Previous analyses of hazards associated with explosive containment vessels such as the nitration vats revealed that a potential exists for massive, high-velocity fragment to be a product of an accidental detonation. Therefore, the nitration vat was analyzed by both Ballistic Research Laboratories and Southwest Research Institute. The 3.2-pound peep hole lid from the nitration vat was selected as a potential "worst case" fragment hazard. Calculations indicate velocities in excess of 7500-feet per second will occur. The required material thickness to prevent penetration of this extremely energetic fragment is approximately 5½ inches of mild steel. It was felt that to provide a uniform structural thickness of 5½ inches was too severe a penalty to pay in the design of a suppressive structure; therefore, both extremes for fragment protection were evaluated – one being to design a structure to withstand only the blast loading and the other designed with 5½ inches of material thickness throughout the structure to suppress the "worst case" fragment. Also analyzed was an intermediate level of fragment protection, restricting the fragments within the confines of the TNT area of Radford AAP. By limiting the range of the peep hole lid fragment to 900 feet, ballistic trajectory computations were performed to re-evaluate the structure thickness required. This study showed only a four percent reduction in thickness and this aspect was discarded from further consideration.

Summarizing, the design guidelines are:

1. Assume spherical, centrally-located explosive charge.

2. Allow volume increase to reduce loading on the roof and quasi-static pressure.

3. Analyze these alternatives:

   a. 4000-pound and 8600-pound explosive yields.

   b. Contain "worst case" fragments.

   c. Allow "worst case" fragments to escape, limit range to TNT area.

   d. Design to blast loading only.

4. Evaluate applicability of category 1 shield designs.

The last design guideline was included since extensive analyses and limited scale model testing have been performed in the category 1 shield development program. Application of these study results would reduce the time and cost to complete this design investigation.

B. Design Alternatives.

The design alternatives investigation in this study for application to any one of the three nitration and purification buildings at the Radford AAP are as follows:

1. Hybrid structure consisting of suppressive roof with:

   a. Existing concrete side walls reinforced.

   b. New side walls using construction principles from TM 5-1300.*

2. Complete suppressive structure, side walls and roof.

3. Solid, unvented, dome-type structure.

Initial investigation of the accident site indicated that the simplest approach to repairing the existing nitration and purification buildings of lines B and C was by replacing the frangible roof with a suppressive roof. Unfortunately, the use of a suppressive roof requires reinforcing of the existing earth-barricaded concrete walls to withstand an accidental detonation. The present design for a nitration and purification building is inadequate to survive similar accidental detonations. The nitration and purification building of line A was completely destroyed, and the earth-barricaded concrete walls provided little protection other than to focus the blast and fragment debris upward and out through the roof initially. Large chunks of concrete were found at appreciable distances from the nitration and purification building – i.e., 22-pound chunks at 2,694 feet and 3- by 3- by 6-foot chunks at 400 feet. The addition of a suppressive roof to the remaining nitration and purification buildings would be of minimal benefit since the earth-barricaded concrete walls would be blown away by the blast loading, allowing high pressures to leak out of the buildings. Extensive damage would result to other buildings within the TNT area.

To implement the suppressive roof design alternative, the Huntsville Engineering Division of the Corps of Engineers was requested to investigate the potential feasibility of either (1) reinforcing the remaining nitration and purification building side walls or (2) replacing the remaining structure with laced, reinforced-concrete, blast-resistant walls. Both designs would have a flat suppressive roof as shown in figure 4. The suppressive panels would consist of interlocking I-beams. The results of the Corps of Engineers (Huntsville) investigation are:

1. Rough order-of-magnitude structural cost for a new facility (laced, reinforced-concrete side walls with suppressive roof) is 2.3 million dollars.

2. Rough order-of-magnitude structural cost for modifying the existing facility is 2.7 million dollars.

The Corps of Engineers findings are shown in appendix B. These results are preliminary in nature and should be treated as such; however, the cost estimates do provide an indication of the structural cost involved.

In addition to the preliminary investigation performed by the Huntsville Engineering Division of the Corps of Engineers, Southwest Research Institute was tasked with conducting a preliminary design investigation of curved suppressive roof and complete suppressive structure configurations. The suppressive roof design concepts that were analyzed are summarized in table 1.

The suppressive roof concepts with concrete side and/or end walls are illustrated in figures 5, 6, and 7.

*Department of the Army Technical Manual TM 5-1300, Structures to Resist the Effects of Accidental Explosions, June 1969.

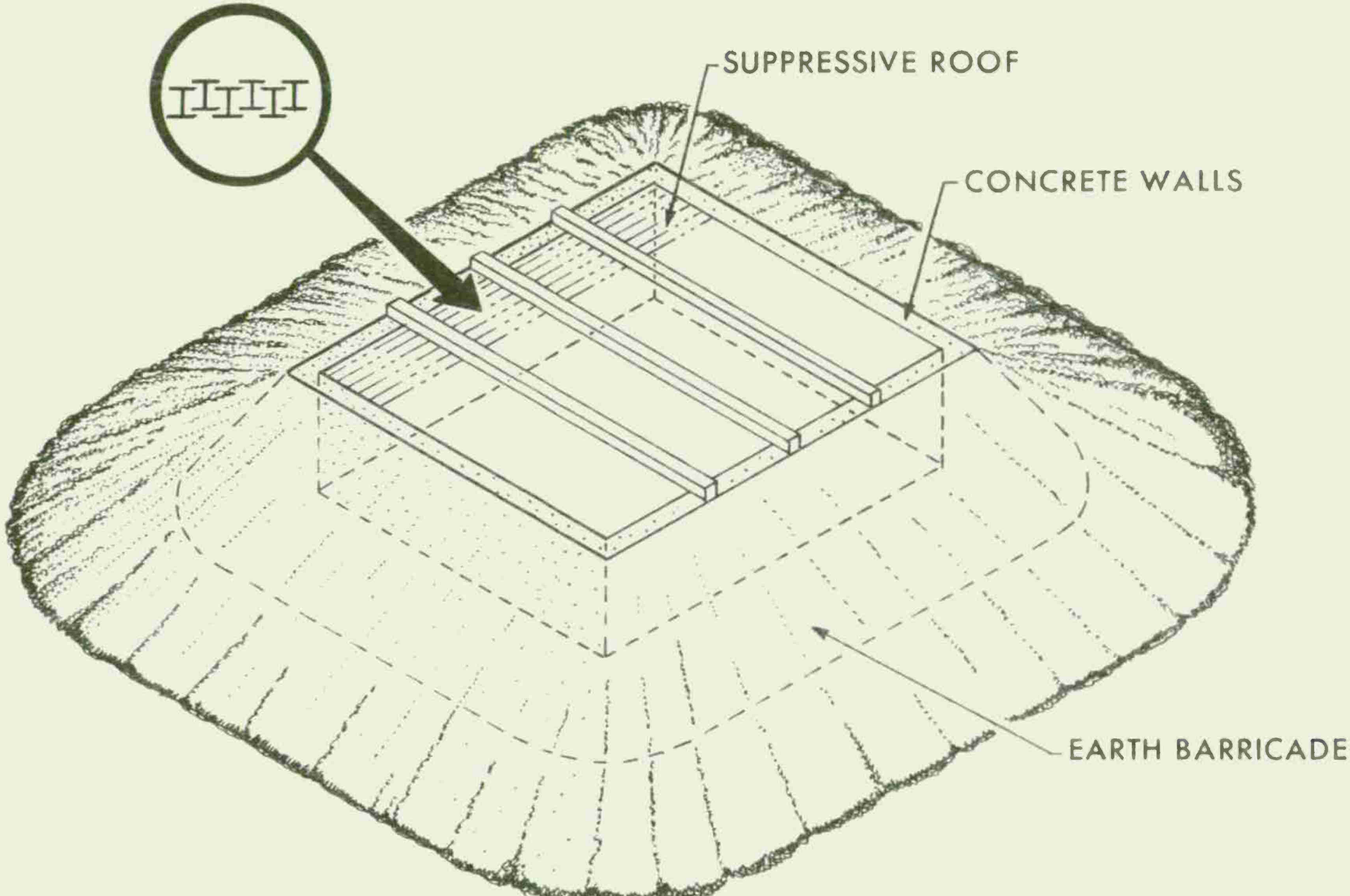


Figure 4. Flat-Type Suppressive Roof with Concrete Walls

Table 1. Suppressive Roof Concepts

Concept	Type	Explosive yield	Fragment containment	Description
		lb		
A	Suppressive roof	4000 8600	5½-in. thickness 5½-in. thickness	Hemi-cylinder with side and end walls same as existing structure but constructed of laced reinforced-concrete
B	Suppressive roof	4000 8600	5½-in. thickness 5½-in. thickness	Arch that is equidistant from the charge with same walls as A
C	Suppressive roof	4000 8600	5½-in. thickness 5½-in. thickness	Hemi-cylinder sitting at ground level with semi-circular, laced reinforced-concrete end walls

Configurations S-1 and S-2 (figures 8 and 9) were scaled-up category 1 shield designs using vertical interlocking I-beams to form a cylinder for the side walls, with hoop stress bands around the circumference and a solid dome for the roof. Venting would occur only through the side walls of this structure. By scaling-up the category 1 shield in volume (configuration S-1) a structure results that is smaller in floor space than required and much higher than is necessary (figure 8).

Configuration S-2, (figure 9) is similar to the category 1 shield; however, the dimensions have been modified to be compatible with the present building dimensions for the nitration and purification building. Reviewing the cost of this configuration indicated a large saving if the side walls were eliminated. This resulted in the unvented, solid-dome configuration S-3, illustrated in figure 10.

The domes for configurations S-1, S-2, and S-3 are of sandwich construction consisting of an inner steel dome one inch thick, four feet of sand, and an outer steel dome 1- to 1¼-inches thick. This design will provide the equivalent fragment suppressive capability as 5½ inches of mild steel to stop the "worst case" fragment.

Consideration was given to the design of a blast-suppressive structure only, without concern for the penetration of a "worst case" fragment. A single-thickness steel dome (1¼ inches thick) would withstand the blast loadings from the detonation of 8600 pounds of TNT and stop such fragments as large motors, piping valves, and other similar fragments weighing up to 20 pounds and traveling at velocities of 700-1000 feet per second. (These types of fragments were found at Radford AAP during accident site investigation).

The reduction of damage and the cost of suppressive structures for the nitration and purification building were determined for a range of explosive yields. This analysis was performed because (1) the results predicted by Ballistic Research Laboratories indicated that the damage was strongly dependent on the explosive yield and (2) consideration is being given to using dynamic separators in the TNT manufacturing process which would reduce the explosive yield. The use of these separators effectively reduces the equivalent quantity of TNT contained

CHARGE WEIGHT	INTERNAL SUPPORT RINGS	CAGE BEAMS	BAND AREA	STEEL WEIGHT
4000 LB	W 14 x 246	W 14 x 246	240 in^2	1052 TONS
8600 LB	W 14 x 246	W 14 x 246	360 in^2	1087 TONS

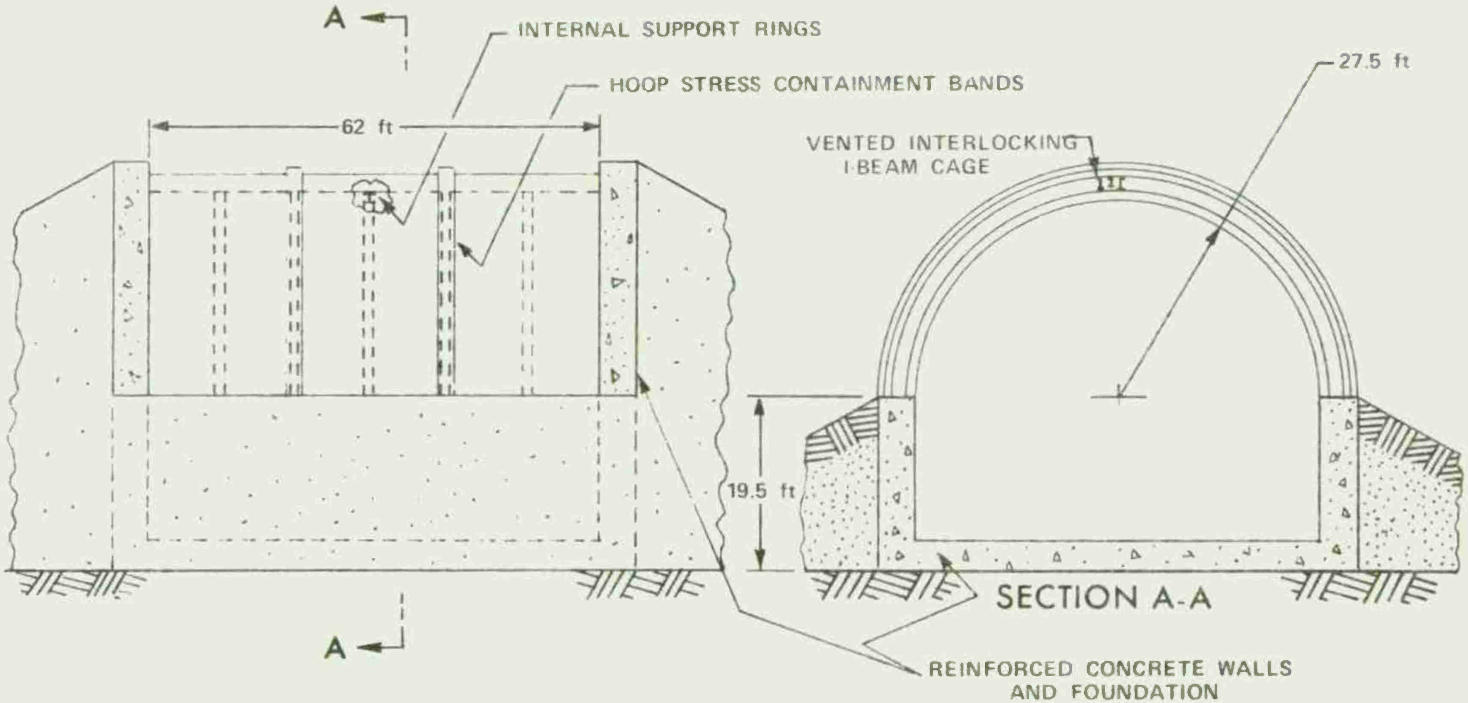


Figure 5. Hemi-Cylinder Suppressive Roof – Concept A

CHARGE WEIGHT	INTERNAL SUPPORT RINGS	CAGE BEAMS	BAND AREA	STEEL WEIGHT
4000 LB	W 14 x 246	W 14 x 246	336 in^2	876 TONS
8600 LB	W 14 x 246	W 14 x 246	504 in^2	911 TONS

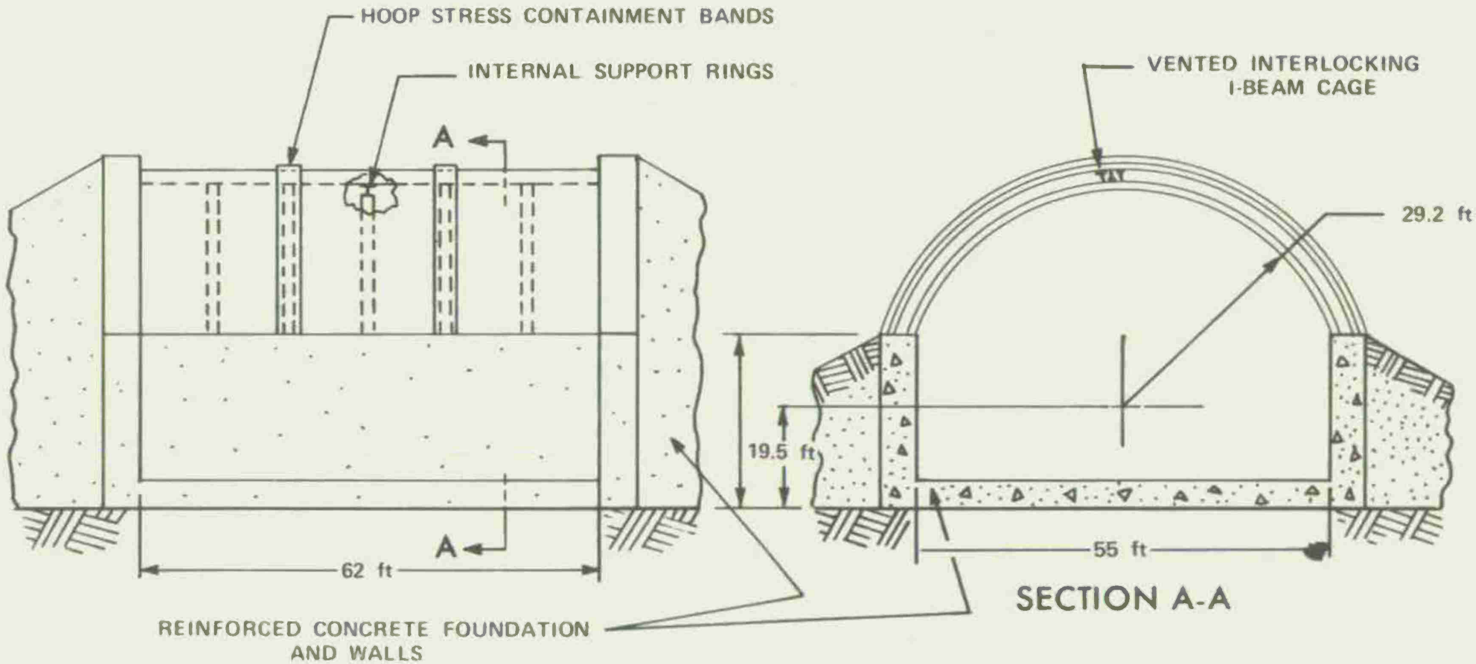


Figure 6. Arch-Type Suppressive Roof – Concept B

CHARGE WEIGHT	INTERNAL SUPPORT RINGS	CAGE BEAMS	BAND AREA	STEEL WEIGHT
4000 LB	W 14 x 246	W 14 x 246	336 in^2	1190 TONS
8600 LB	W 14 x 246	W 14 x 246	504 in^2	1243 TONS

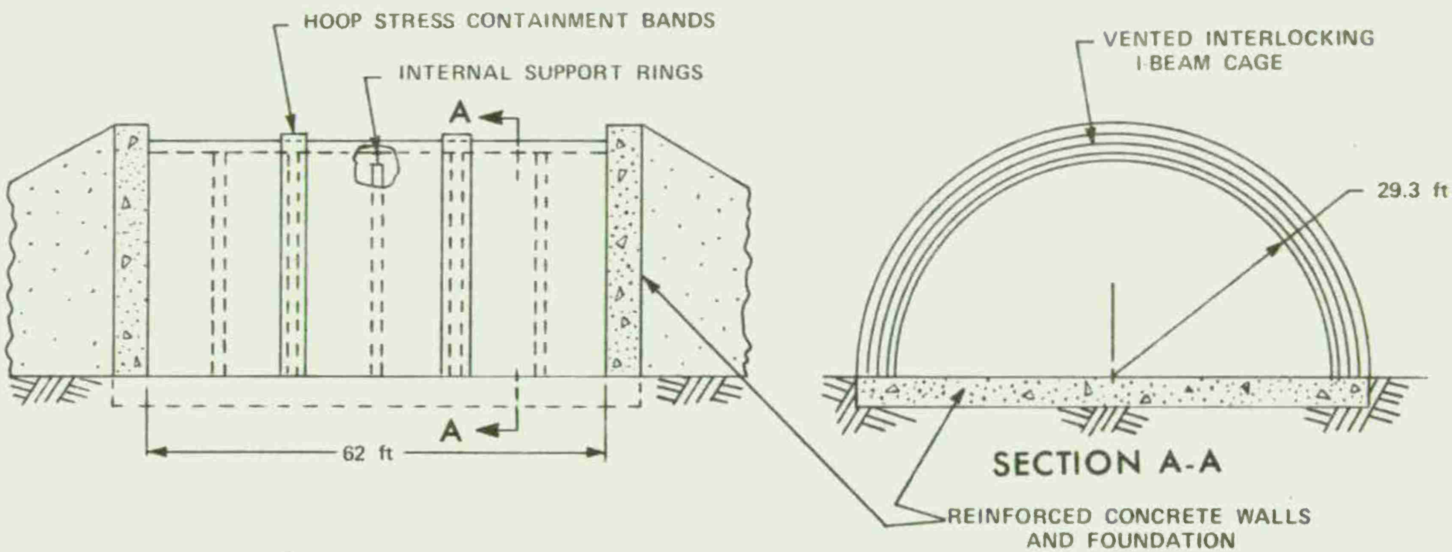


Figure 7. Hemi-Cylinder Suppressive Roof Without Sidewalls – Concept C

CHARGE WEIGHT	CAGE BEAMS	BAND AREA	OUTER DOME THICKNESS	INNER DOME THICKNESS
4000 LB	W14 X 246	330 in^2	5/8 IN	1 IN
8600 LB	W14 X 246	510 in^2	1 IN	1 IN

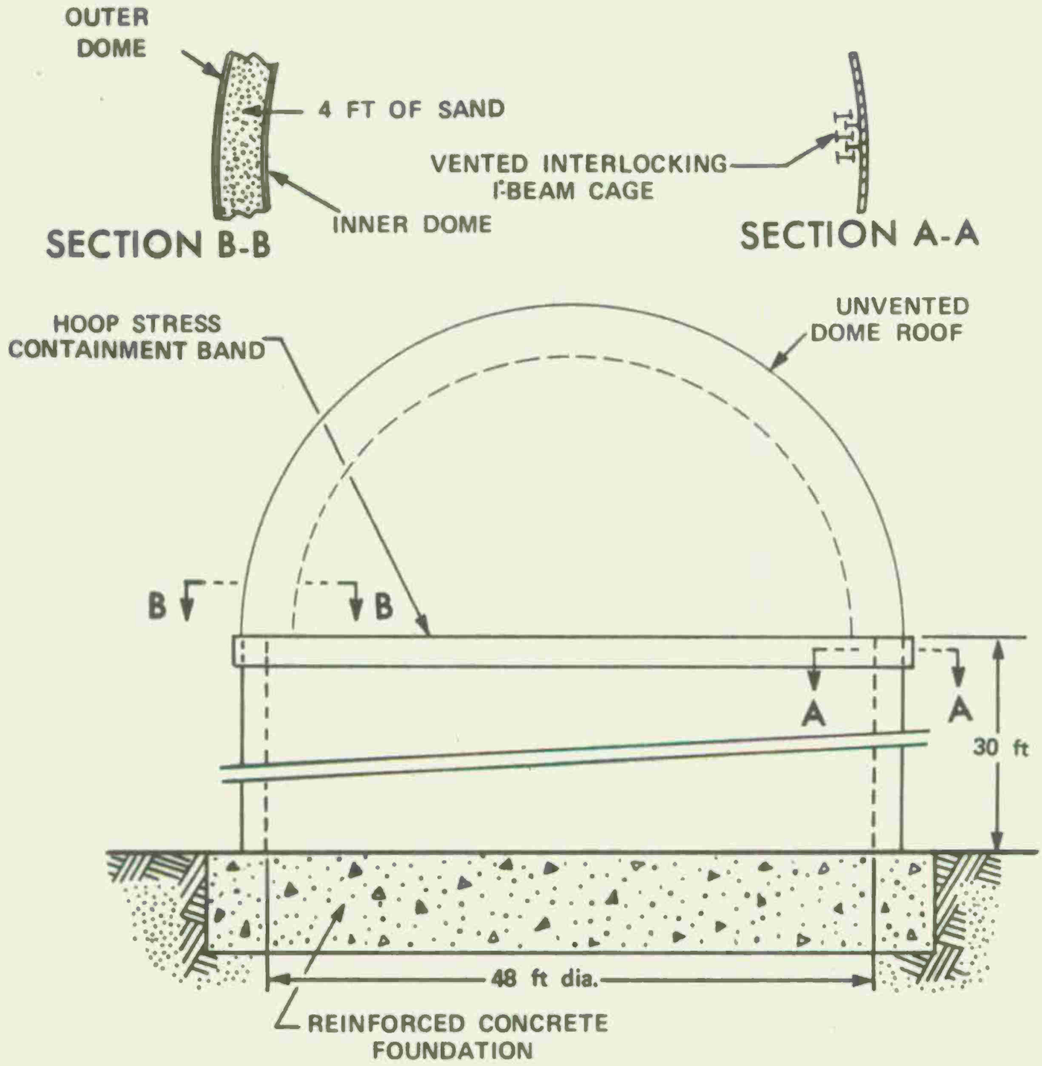


Figure 8. Scaled-Up Category 1 Shield, Same Volume as the Nitration and Purification Building – Configuration S-1

CHARGE WEIGHT	BAND AREA	FRAGMENT REQUIREMENT	CAGE BEAMS	OUTER DOME	SAND	INNER DOME	STEEL WEIGHT
8600 LB	260 in^2	PRIMARY	W14 X 246	1-1/8 in Thick	4FT	1 IN	759 TONS
		NONE	W 8 X 40	1-3/8 in Thick	NONE	NONE	414 TONS

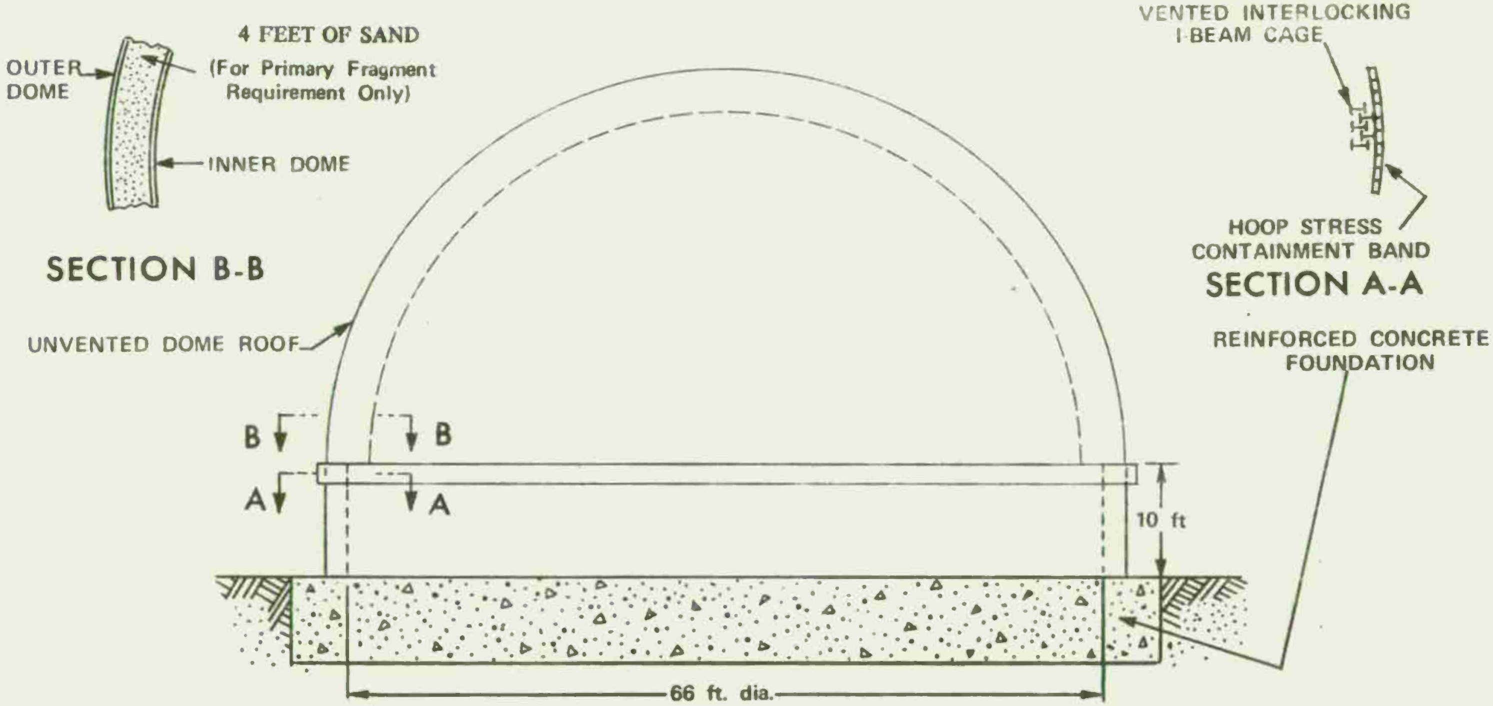


Figure 9. Scaled-Up Category 1 Shield, Same Floor Space as the Nitration and Purification Building – Configuration S-2

CHARGE WEIGHT	FRAGMENT REQUIREMENT	OUTER DOME	DOME DIAMETER	SAND	INNER DOME	TOTAL STEEL WEIGHT
8600 LB	PRIMARY	1-3/8 IN	74 FT	4 FT	1 IN	380 TONS
	NONE	1-1/4 IN	66 FT	NONE	NONE	174 TONS

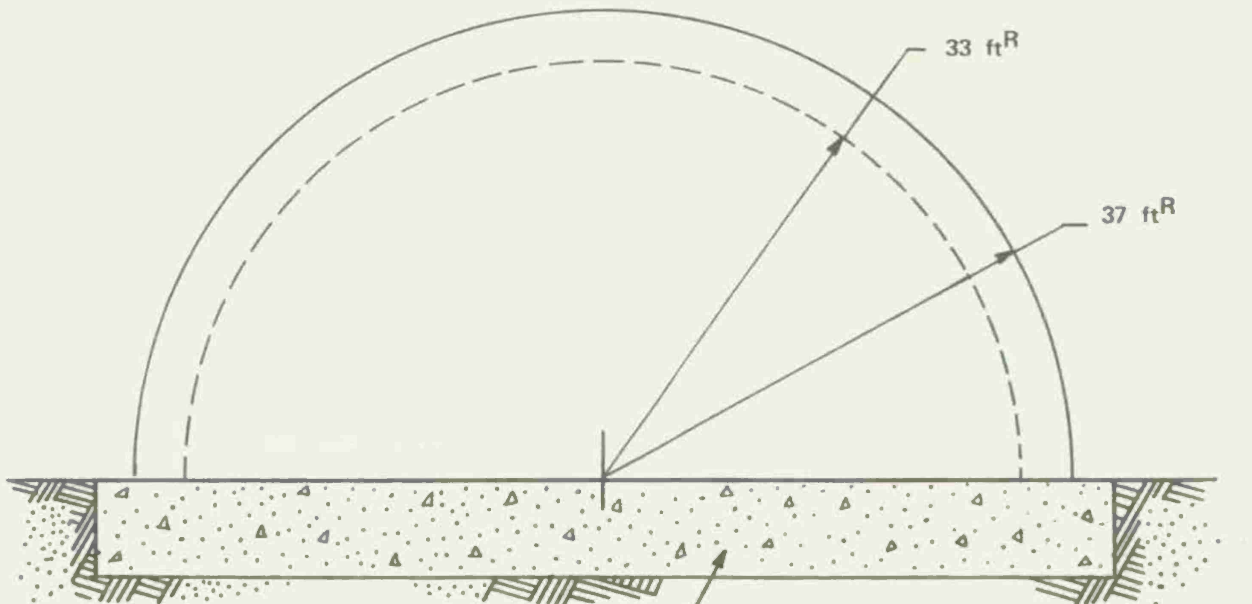


Figure 10. Unvented Dome Structure – Configuration S-3

in the nitration and purification building. A presentation by Dr. W. T. Bolleter, Radford AAP, to the Radford Accident Ad Hoc Committee on 3 December 1974* revealed that the explosive quantity would be reduced from 16,900- to 8800 pounds. The Ballistic Research Laboratories' best estimate of the explosive yield was 8600 pounds, or approximately one-half of the total quantity of explosive contained in the nitration and purification building. To evaluate the effect of reducing the yield, it was assumed that the use of dynamic separators would reduce the yield for an accidental detonation to 4000 pounds. Consequently, design calculations were made for the lower explosive yield of 4000 pounds as well as the best estimate of the explosive yield, 8600 pounds.

C. Cost Comparison of Design Alternatives.

An extensive engineering development effort has been under way at Edgewood Arsenal to design the category 1 suppressive shield. The primary application for this structure is the continuous-process melt/pour facilities which utilize the porcupine melter. The explosive quantity involved is 3125 pounds when the 25% safety factor is incorporated. The Corps of Engineers, Huntsville Division, has been extensively involved in the category 1 shield development. Engineering drawings have been submitted to Huntsville Division for cost estimates on the category 1 structure. These cost data have been used to estimate the cost of candidate suppressive structures for application to Radford AAP. The following cost factors were derived for the various structural components and include materials, labor and overhead:

WF beams (used in vented roof and side walls)	$ 1192/ton
Formed rings (used to contain hoop stress in vented structure)	1064/ton
Domes	2000/ton
Laced reinforced-concrete blast walls and foundations	300/cubic yard

Using the above cost factors, the design alternatives previously discussed were costed for the following conditions:

1. A structure that would suppress all fragments.

2. A structure that would withstand the blast loading (and not prevent penetration of the "worst case" fragment).

3. Explosive yields of 4000 pounds and 8600 pounds. Comparison of cost for each design alternative and selective comparison for conditions 1 and 2 above are summarized in table 2.

All of the above designs, with the exception of the unvented dome, provide the same degree of protection, provided one compares items in the "blast only" column or items in the "blast and fragment" column. The damage cost reduction indicated in figure 3 applies to all designs except the unvented dome. The solid dome does not allow the venting of any blast pressure (except at localized fragment holes in the "blast only" configuration) and hence provides for a 100% damage reduction; no blast damage would result.

*At Headquarters, US Army Armament Command, Rock Island, IL.

Table 2. Cost Comparison of Design Alternatives (8600 Pound Yield)

Design alternatives	Cost ($ millions)	
	Blast only	Blast and fragment suppression
Suppressive roof concepts		
Flat roof with reinforced side walls		2.6
Flat roof with TM5-1300 blast walls		2.3
A - Hemi-cylinder		1.8
B - Arch		1.6
C - Hemi-cylinder (no side walls)	1.5	1.9
Total suppressive shield		
(S-1) - Scaled-up Category 1 in volume		1.6
(S-2) - Scaled-up Category 1 - same floor space	1.0	1.4
Solid unvented dome - configuration S-3	0.7	1.1

These results indicate a cost savings of $300,000 and $400,000 if the "worst case" fragment is not prevented from penetrating the shield.

Comparison of the total suppressive designs for the 4000-pound and 8600-pound explosive yield is described in table 3.

Table 3. Cost Comparison of Design Alternatives for 4000-Pound and 8600-Pound Explosive Yields

Design alternatives	Explosive yield	
	4000 lb	8600 lb
Configuration S-2 Scaled-up Category 1		
Blast only	$ 686K	$ 957K
Blast and fragments	1220K	1427K
Configuration S-3 Unvented Dome		
Blast only	449K	667K
Blast and fragments	673K	1079K

Cost savings possible by reducing the explosive yield are $300,000 to $500,000, depending on the design. This savings must be compared to the cost of the new equipment required to reduce the explosive yield and the benefits provided by using the dynamic separator versus the old gravity separator. No attempt has been made in this study to conduct this economic analysis.

V. CONCLUSIONS.

A. Explosive yield involved in the accident ranged between 6200 and 8600 pounds, with the most realistic value being 8600 pounds.

B. Use of suppressive shields will appreciably reduce damage such as that experienced at Radford AAP. The degree of venting establishes the damage reduction level. The curves shown in figure 3 define the damage reduction and illustrate that an unvented structure which can survive the blast loading would completely eliminate the blast damage experienced.

C. An unvented structure is the most desirable for Radford AAP due to the close proximity of buildings to the nitration and purification building.

D. An unvented dome designed to contain the "worst case" fragment and withstand an 8600-pound detonation would cost $1,100,000 (preliminary rough order-of-magnitude cost).

E. Allowing the "worst case" fragment to penetrate the structure and designing a suppressive shield to withstand the explosive blast loading will result in a $200,000-$500,000 cost savings.

F. Use of dynamic separators would reduce the equivalent explosive yield within the nitration and purification building and would reduce the suppressive structure cost by $200,000-$400,000.

SELECTED REFERENCES

1. Haskell, D. F. BRL Interim Memorandum Report No. 373. Estimates of Radford AAP Explosive Yield and Potential to Avoid Damage by Use of Suppressive Structures. April 1975.

2. Schumacher, R., and Ewing, W. BRL Interim Memorandum Report No. 376. Blast Attenuation Outside Enclosures Made Up of Selected Suppressive Structure Panel Configurations. April 1975.

APPENDIX A

Fragment Data Accumulated at Radford AAP Accident Site and Analysis of Fragment Characteristics

Table A-1. Blast Fragments – Building 9502, Radford AAP

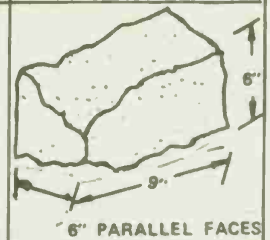
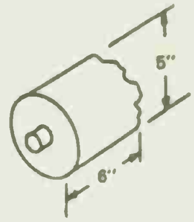
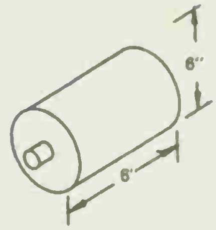
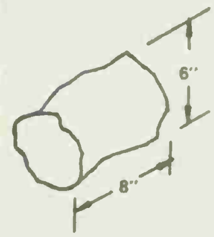
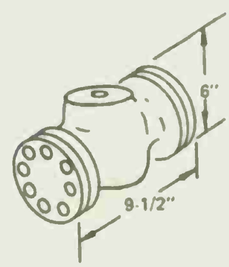
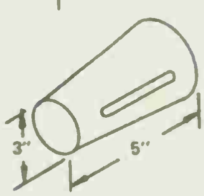
Fragment No.	Description	Material	Weight	Range	Angle of fall		Size	Shape
					Degrees	Comment		
			(lb)	(ft)				
3-45	Concrete chunk	Concrete (Non-reinforced)	22	2694	7	Minimum to clear trees	9" long X 6" wide X 6" parallel faces	
3-47	Hydraulic motor	Steel	19	2675	7	Minimum to clear trees	5" diameter X 6" long	
3-57	Electric motor	Steel/copper interior, stainless steel case	25	2495	69	Entered roof, chipped concrete wall	6" diameter X 9" long	
3-59	Electric motor	Steel/copper interior, stainless steel case	22	2162	14	Minimum to clear steam pipes	6" diameter X 8" long	
3-67	Plug cock	Stainless steel	38	2595	6	Minimum to clear terrain	6" diameter X 9½" long	
3-70	Valve plug	Stainless steel	9	2440	6	Minimum to clear terrain	3" diameter X 5" long	

Table A-2. Fragment Velocity Versus Launch Angle

Fragment	Fragment number	Range**	Launch angle	Launch velocity	Angle of fall
		ft	degrees	ft/sec	degrees
Concrete chunk (22 lb)	3-45	2694	10	1150	
			20	1050	
			30	937 minimum*	
			40	1000	
			50	1200	
Hydraulic motor (19-lb)	3-47	2675	10	770	
			20	570	
			30	510	
			35	499 minimum*	
			40	510	
			50	540	
			60	670	
Electric motor (25-lb)	3-57	2495	10	700	19
			20	540	36
			30	475	49
			40	456 minimum*	60
			50 (measured angle of fall)	490 (probable)	69*
			60	600	78
			75	1100	87
Electric motor (22-lb)	3-59	2162	10	650	
			20	500	
			30	425	
			40	405 minimum*	
			50	450	
Plug cock (38-lb)	3-67	2595	10	700	
			20	525	
			30	500	
			40	451 minimum*	
			50	480	
			60	580	
Valve plug (9-lb)	3-70	2440	10	710	
			20	520	
			30	460	
			40	444 minimum*	
			50	485	
			60	590	

*Minimum velocities are accurate to 1-2%; other velocities are accurate to 5%.
**Roll distance after impact was ignored.

APPENDIX B

Excerpt, Letter, Corps of Engineers, Huntsville Division, Subject: Recommendations for a Feasibility Study to Modify Existing Nitration and Purification Buildings with TM Blast Walls and S/S Panels or Constructing New Nitration and Purification Buildings Using TM Blast Walls and S/S Panels (12 February 1975)

1. After preliminary investigation of the various alternatives, Huntsville Division, HNDED-CS, recommends that a feasibility study be made for the design of a new facility to replace the existing Nitration and Purification Building.

2. A rough order of magnitude (ROM) (structural) cost for the new facility would be 2.3 million dollars. ROM (structural) cost for modifying the existing facility is 2.7 million dollars.

3. A new facility is more economical than a modified facility for various reasons, such as:

a. Construction of a new facility will not require closing of the Operating TNT Line. However, modification of the existing facility will cause shut down of the operation for the entire time of construction.

b. The overall dimensions of a modified existing facility would be larger than for a new facility. This would require greater quantities of concrete and steel which indicates a higher cost (figure B-1 and B-2).

c. Tight working conditions (required for modification of existing facility) would also increase unit labor costs. The placing of laced reinforcement would be extremely difficult.

4. HNDED-CS also suggests that the design of a new facility not be limited by the requirement that the roof be composed of suppressive shields. In our investigation, it was determined that vent holes placed in concrete walls would furnish the same degree of venting. Also, placing the vent holes at an angle would prevent missile problems. If the vent holes in concrete are an allowable solution, a substantial dollar savings would be realized.

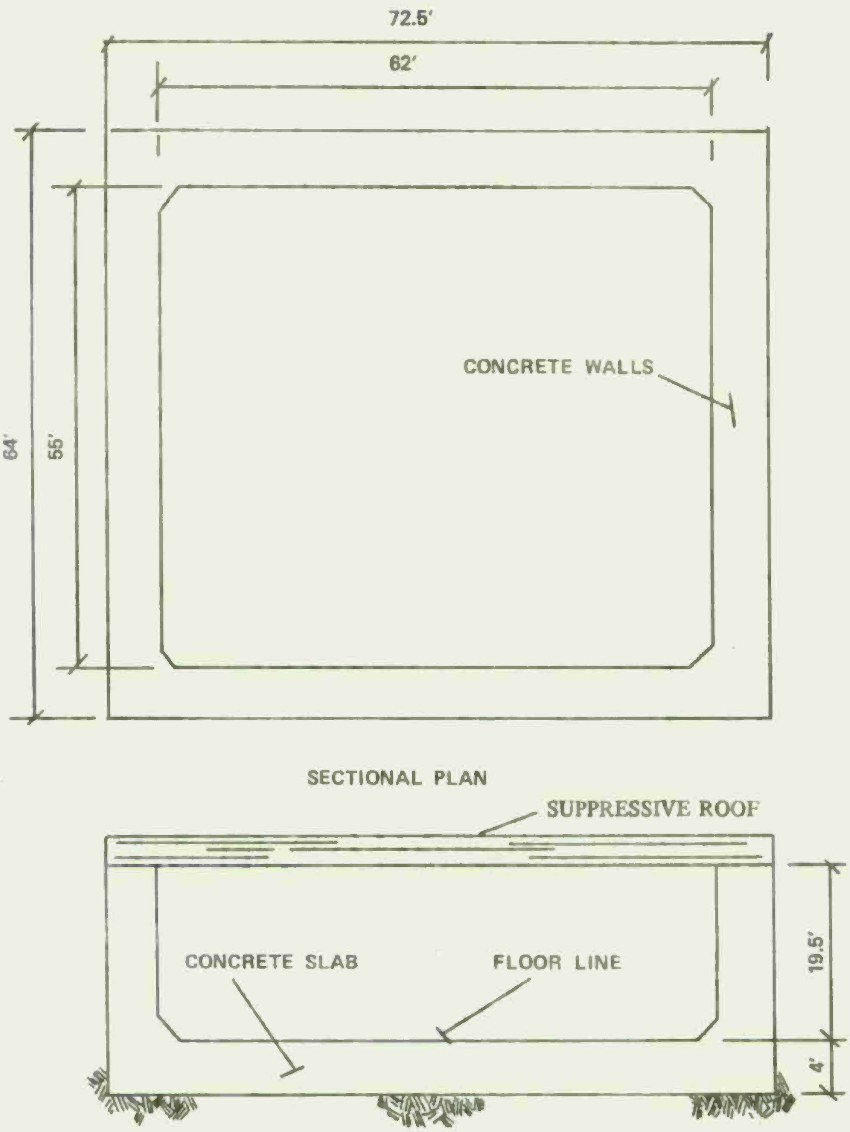


Figure B-1. New Nitration and Purification Building for TNT Line

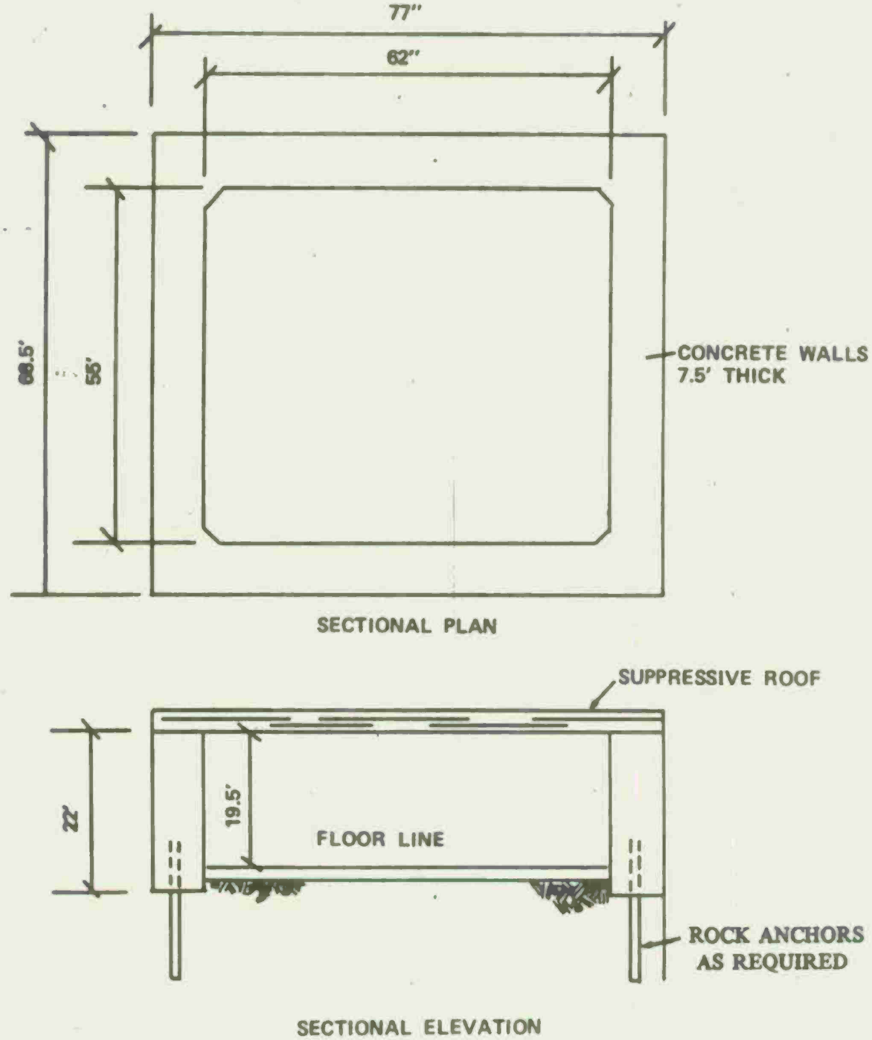


Figure B-2. Hardening of Existing Nitration and Purification Building

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